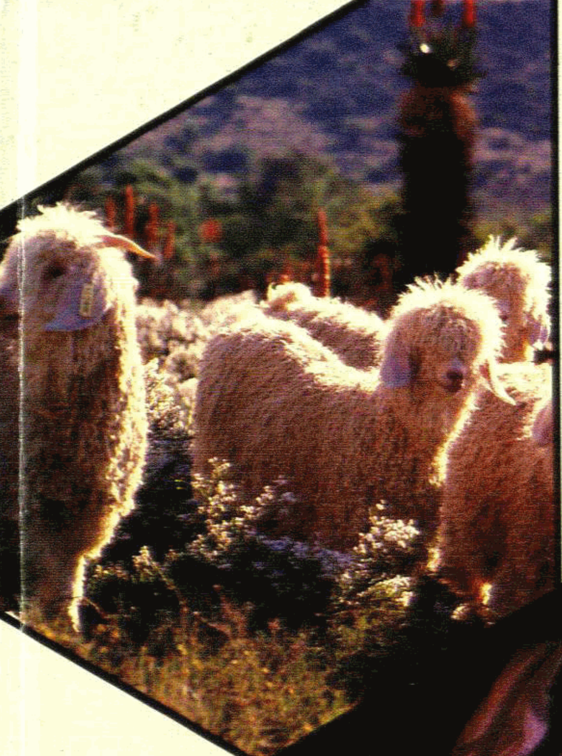

Mohair:

A review of its properties, processing and applications

CTM

by L Hunter

MOHAIR: A REVIEW OF ITS PROPERTIES, PROCESSING AND APPLICATIONS

by

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10 Blackfriars Street
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ISBN 0 7988 3717 9

Jointly published by:

CSIR Division of Textile Technology
International Mohair Association
The Textile Institute

Printed and bound in South Africa by
NMB Printers (Pty) Ltd, Port Elizabeth

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CHAPTER 1

INTRODUCTION

1.1 Preamble

Mohair remains one of the most important speciality animal fibres, finding application in a wide range of textile end-uses, notably apparel and household textiles. Although a great deal of published information exists on mohair, much of the specialised know-how required to convert the fibre into the superb quality and highly desirable products so characteristic of mohair, remains unpublished and a closely guarded secret.

This review covers work published over roughly the past half a century and mainly aims at providing a comprehensive source of textile related information, data and references.

1.2 General Background Characteristics and Properties*

For centuries mohair, the lustrous fleece of the Angora goat, has been regarded as one of the most luxurious and best quality fibres available to man. It is generally a straight (uncrimped but often wavy), smooth and naturally lustrous fibre which can be dyed to deep, brilliant and fast colours, but can also produce high fashion muted tones with equal distinction[553]. The predominant natural colour of mohair is white although there are also occasionally brown, black and pink (red) varieties[547], the coloured fibres containing pigment (mainly melanin) in the cortex[728]. The Angora goat has developed a single coat of long lustrous fibres, having lost the tendency to moult[550], with good quality mohair virtually free of medullation[376] and kemp. The average mohair fibre diameter ranges from below $24\mu m$ for Superfine Kids to over $40\mu m$ for Coarse Adults[1046].

Mohair is considered the main speciality (or rare) animal fibre[426] (see Fig. 1[202]) and has the highest production (see Table 1)[840] of speciality animal fibres, although it represents less than 0.05% of the total world fibre production[1046,1077].

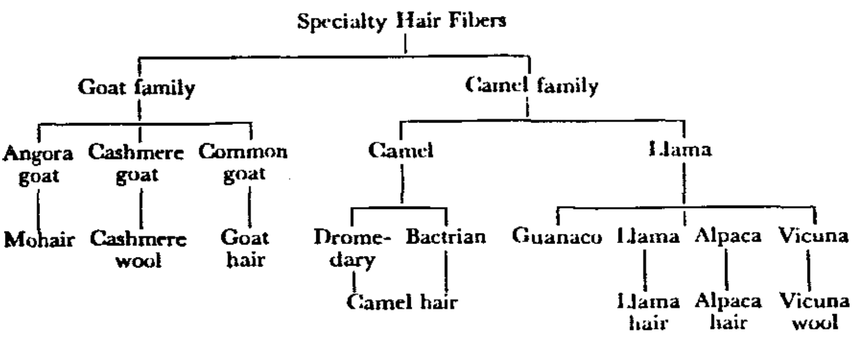

Fig. 1 Speciality Hair Fibres[202].

*See other sections for more detailed Information

TABLE 1[840,858,978]
THE WORLD PRODUCTION OF RARE FIBRES (1987)

Fibre	Source animal	Diameter (um) *	Fibre Length (mm)	Price range (£1/kg) **	Producing Regions	Approximate world production (tons)	production trend
Angora	Angora rabbit	11–15	25–50	20–30	China South America France	8500	Growing
Vicuna guanaco	South America Auchenides family	10–20	30–50	150–200	Peru/Chile	50	May be partially processed at source
Cashmere	Cashmere goat	15–19	25–90	35–70	China Mongolia Iran Afghanistan	5000	Some processed at source
					Russia	Unknown	Processed at source
					Australia New Zealand	200	Growing
Super geelong and fine wool (for comparison)	Sheep	17–22	50–60	6–10	Australia New Zealand South Africa	100 000	Static
Yak hair	Bovine family	19–21	30–50	15	Tibet China/Mongolia	Small	Static
Cashgora	Angora goat/ feral crossbred	19–22	50–60	8–20	New Zealand Australia	200	Growing?
Camel hair	Camel Camelides Family	18–26	29–120	10–12	China Mongolia	2000	Static
Alpaca and llama	South America Auchenides family	22–25	75	12–15	Peru/Chile	4000	Growing
Mohair	Angora goat	24–40	75–100	6–18	South Africa Texas Turkey Australia Argentina	22 000	Growing

* Projection microscope ** These prices vary due to international currency movements

With acknowledgement to the Textile Outlook International for some information given in this table

Today mohair is largely produced in South Africa, United States of America (Texas) and Turkey, but also in Argentina, Lesotho, Australia and New Zealand[460], with Table 2 showing the annual production of mohair worldwide.

Mohair has low flammability, felting and pilling and good durability, elasticity, resilience (almost non-crushable), lustre, resistance to soiling, soil shedding (it brushes clean easily), setting, strength, abrasion resistance, draping, shaping, moisture (and perspiration) absorption (and release), insulation and comfort. Its good insulation, makes mohair fabrics lightweight and warm in winter, comfortably cool in summer[556] (this also being a function of the fabric and garment construction). It blends well with other fibres [553]. More than 50 years ago[1,14] it was reported that because of the relatively smooth character of mohair fibre, mohair soiled less easily and could be cleaned more easily than other fibres.

Mohair's good lustre, smoothness, low friction, low soiling, good soil shedding and low felting are all related to its surface scale structure (faint pattern of scales), the scales generally being thin (unpronounced or flat) and relatively long.

TABLE 2**
WORLD MOHAIR PRODUCTION BY MAIN PRODUCING COUNTRIES (m kgs)

YEAR	SOUTH AFRICA	USA	TURKEY	ARGENTINA	LESOTHO	AUSTRALIA	NEW ZEALAND	MISC. PRODUCTION	TOTAL
1970	4.1	7.8	4.1	1.1	0.9	-	-	-	18.0
1971	4.3	6.8	4.5	1.0	0.9	-	-	-	17.5
1972	3.7	4.6	4.1	1.0	0.8	-	-	-	14.2
1973	3.4	4.5	4.1	1.0	0.6	-	-	-	13.6
1974	3.7	3.8	4.1	1.0	0.6	-	-	-	13.2
1975	3.8	3.9	3.9	1.0	0.6	-	-	-	13.2
1976	4.1	3.6	4.0	1.0	0.6	-	-	-	13.3
1977	4.5	3.6	4.1	1.0	0.4	-	-	-	13.6
1978	4.9	3.7	4.5	1.0	0.5	-	-	-	14.6
1979	5.4	4.2	4.5	1.0	0.5	-	-	-	15.6
1980	6.1	4.0	4.5	1.0	0.5	-	-	-	16.1
1981	6.9	4.5	4.5	1.0	0.5	-	-	-	17.4
1982	7.6	4.5	4.5	1.0	0.5	-	-	-	18.1
1983	7.5	4.8	4.5	1.3	0.67	-	-	-	18.77
1984	8.1	5.1	3.5	1.0	0.75	0.5	0.05	0.05	19.05
1985	9.1	5.4	3.5	1.1	0.8	0.5	0.07	0.06	20.53
1986	11.0	5.6	3.5	1.25	0.8	0.6	0.14	0.07	22.26
1987	12.0	6.8	3.5	1.5	0.8	0.8	0.25	0.08	25.73
1988	12.5	7.0	3.0	1.5	0.6	1.0	0.35	0.1	25.95
1989	11.6	6.8	2.0	1.2	0.6	1.0	0.5	0.2	23.9
1990	10.8	6.8	1.8	1.0	0.5	1.0	0.5	0.2	22.6
1991	7.5	6.8	1.2	0.6	0.5	0.6	0.3	-	17.5
1992*	7.0	6.8	1.0	0.8	0.45	0.5	0.3	-	16.85

*Projection.
**Provided by the International Mohair Association (IMA).

Because of its coarseness relative to other types of apparel fibres, mohair has some limitations in certain apparel applications, but has proved extremely popular in many apparel applications and has proved to be virtually unsurpassed in many non-apparel applications, such as furnishings, blankets and upholstery. Mohair's excellent properties, such as resilience and durability, make it particularly suitable for house-hold textiles, such as upholstery fabrics, curtains and carpets[1046].

Phan *et al*[895] compared the diameters (in μm) they obtained over a number of years at DWI with those given by ASTM (see Fig. 2).

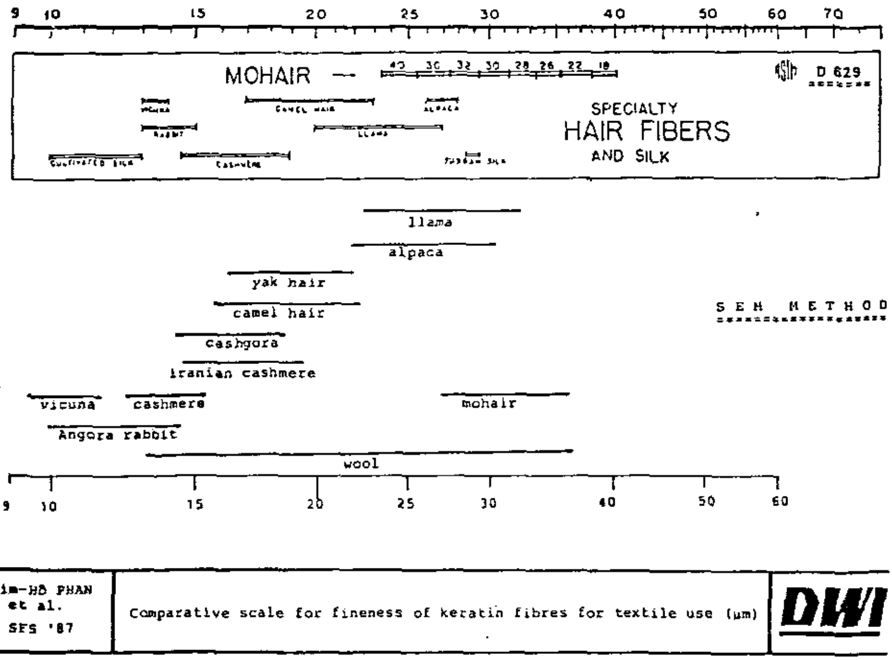

Fig. 2 Comparative Scale for Fineness of Keratin Fibres for Textile Use(μm)[978].

Kettle and Wright[718] gave the following comparative figure (Fig. 3) for the diameter ranges of various goat fibres:

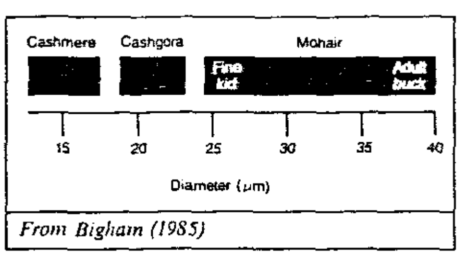

Fig. 3 Diameter Ranges of Goat Fibres[718].

Woodward[1006] listed the following as the main distinguishing characteristics of mohair, which is among the most versatile of natural fibres[1006]:

Non-Flammability:

Mohair is almost non-flammable. When exposed to a naked flame, it burns at a low temperature and tends to shrink. The flame produces a bead-like ash, but the fibre will stop burning almost as soon as it is taken away from the flame.

Durability:

Because mohair's structure is pliable rather than solid, it can be bent and twisted without damage to the fibre. Helped by its pliability, mohair is claimed to be the world's most durable animal fibre.

Elasticity:

Mohair is extremely elastic. An average mohair fibre can be stretched to 30% of its normal length and will still spring back in shape. Because of the fibre's resilience, mohair garments resist wrinkling, stretching, and sagging during wear.

Moisture Retention:

All animal fibres can absorb moisture from the atmosphere readily. Because mohair dries slowly, the danger of getting a chill is reduced.

Setting:

Mohair may be set to retain extension or deformation more readily than other animal fibres. The fibre's setting ability is capitalised on in the manufacture of curled-pile rugs and imitation Astrakhan rugs.

Lustre:

Mohair's famous lustre is caused by its closed scale formation. Lustre is improved by careful processing and dyeing.

Dyeing:

Mohair, more than any other animal textile fibre, has the ability to be dyed brilliant colours that resist time, the elements, and hard wear. From its dyeability has come the name **The Diamond Fibre.**

Soiling Resistance:

Because dust does not rest on mohair's slippery fibres, their use in furnishing fabrics and hangings is advocated. Dust which adheres at the intersections of woven fabrics can be easily removed by shaking or brushing.

Non-Felting:

Scarcely any felting shrinkage shows up in mohair woven fabrics while knitted mohair fabrics shrink much less than those of untreated wool.

Light-Weight:

Although mohair is a fairly heavy fibre on its own, it blends well with wool. The resulting smooth yarns make up into fabrics which are noted for coolness, such as lightweight summer fabrics. The material is unsurpassed in tropical suitings. Because in combined coolness with durability, the material is also effective when made into linings.

Length:

Prized as a textile fibre because of its length, mohair fibre averages about

300mm for a full year's growth (ie 25mm per month), and 150mm when the animals are shorn bi-annually. Mohair up to 900mm long can be produced over three years from animals as they do not shed the fibre easily, provided special attention is paid to tying up the fleece. Such exceptionally long fibres are used to make women's switches, doll's hair and theatrical wigs.

In 1967 the following mohair emblem was adopted internationally[452].

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International Mohair Emblem

Various articles[91,99,179,304,309,430,452,546,567,767,797,806,807,809,853,871,872,883,937,951,953,977,1002] provide general background information on mohair, its production, properties, marketing and related applications.

1.3 Historical Background

Mohair, one of the most ancient fibres known to man[233] and referred to in biblical times[25,546,553,580,883], is the fibre (ie the coat) from the Angora goat. The word mohair is derived from the Arabic word "Mukhayar" (also spelt Makhayar[964], and Mukhaya[883]) stated to mean, "best of selected fleece"[1027], select choice[553], "silky goat-skin cloth"[309], cloth of bright goat hair[883] or hair cloth[233].

The Angora goat (Capra hircus aegagrus)[1032] is of the same species, Capra hircus, as the European milch breeds and all other breeds of domesticated (common) goat, and also a near relative of the Cashmere Goat of Asia[376] and certain types of Himalayan goats[36]. (**Richterich**[851], quoting Cronwright Schreiner, stated that the Angora goat descended from the genus Capra falconeri, which is thought to have had its origins in Tibet and Kashmir and is believed to be closely related to the Cashmere goat, whereas the domestic goat Capra hircus is descended from the genus Capra aegagrus). The Angora goat tends to thrive in areas of low rainfall and humidity[36].

The exact origins of the Angora Goat are unknown[883]. The animals are believed to have originated in the Asian Himalayas (Asia Minor)[25] (Highlands of Tibet[553,883]) but later migrated to Ankara (known in Ancient times[851] as Ancyra, the province of Phrygia in Asia Minor[851], in Turkey from whence the name Angora was derived[376], the angora goat emerging in Turkey after the Middle Ages[964] (at least the 13th or 14th century)[376]. Records of the Angora goat dating back to the 11th, 12th and even 14th centuries BC have been uncovered[883]. In the Bible, 1500 years BC, the book of Exodus relates that the sons of Israel left Egypt "carrying with them goats whose fleece (pure white goats wool)[25] was used to make fabric to dress the altar"[883], their fleeces being woven into altar cloths and curtains for the Tabernacle[25,546,580].

The Angora goat is regarded as being unique amongst goats, in growing fibres not widely different in diameter from the primary and secondary follicles([1045], with some primaries producing coarser medullated fibres. The Angora goat, unlike other goats, can therefore for all practical purposes be regarded as a single-coated animal[823,1045], and unlike cashmere goats, the Angora's fibres grow continuously throughout the year[1045], and the fibres are not shed annually.

In Ankara the birth of the mohair industry took place (Turkey being the first country to supply mohair as a raw material[25]) after the animals had trekked thousands of kilometres on a journey from Turkestan, the journey beginning during the 13th century[883]. In 1550 a Dutchman found the Angora goat in Angora (Turkey) and recognised the exceptional qualities of the fleece[546], a pair of goats being sent to the Holy Roman Emperor Charles V in 1554[546,580]. Ryder[1002] stated that the first European record of the Angora was made by Belon and Tournefort (1654) in his Levant Voyage wrote that the finest goats in the world were bred in Angora[1002]. Tournefort, a French botanist, reported in 1653, that "the Angora goats dazzled with their whiteness and had hair as fine as silk". The spinning of mohair in Ankara (or Ancyra, as it was known) was done by women for their families but later a closely guarded mohair industry developed in Turkey[546], with the export of unprocessed mohair being forbidden by the Sultan[546,567]. In 1838, under pressure from England, the ban was lifted and to meet the demand, the Angora goat was crossed with the Kurdish goat with a decline in quality[546] and a few bales were shipped to Europe. Holland used a fair amount of "Turex Gaaren" (Turkish Yarn), combining a *mohair weft with a silk warp*[546]*. In 1820 there occurs the first authentic record* of the export of a few bales of mohair fibre from Asia Minor to Europe[425]. In 1853 mohair spinning was started in England.

When mohair first reached Europe, wigmakers appreciated its qualities[376,964,1002]. The first raw mohair reached Europe in 1820. Mohair goods were first manufactured in England in the 19th century[233], a cloth containing a mohair weft across a cotton warp being much in demand in 1883[233].

The first Angora goats to leave Turkey went to South Africa in 1838[425,546], (during the journey, involving a cargo of 12 buck and one doe, the latter gave birth to a male kid) [546]. Only in 1865 did mohair exports from the Cape to the United Kingdom reach any magnitude[5]. Angora goats (7 does and two buck)[553] arrived in the USA around 1849[25,376,546,553,567,964]. Angoras were introduced into Australia during the 1850's and 1860's[550] (1832 has also been mentioned[376]), but received little interest, a new "mohair industry" being established in about 1970[550]. Angora goats were introduced to Britain in 1881[550].

CHAPTER 2

MOHAIR FIBRE GROWTH AND PRODUCTION

2.1 General

Mohair grows about 25 mm per month[383,470,956] and Angora goats are generally shorn twice per year in South Africa and the USA and once in Turkey and Lesotho, although high levels of nutrition could necessitate more frequent shearing[728, 1027] (annual shearing can lead to cotting in the middle of the staple[984]). Young and Adult goats produce about 2 to 2.5kg of greasy mohair per 6 months, while rams generally produce considerably more[383,470]. Angora rams normally produce more and coarser hair than ewes[728], the average mass of the fleece of an adult Angora ewe being about 2 to 2.5kg at each shearing[165]. In the case of Kids, the fleece barely weighs 1 kg at the first shearing and is generally less than 2 kg at the age of one year[456]. In one study it was found[957] that, on average, Kids produced about 1.1kg of greasy mohair per 6 month growth while Young Goats and Adults produced about 2.1kg per six months. The overall averages for all the goats in the study was found to be about 3.7kg per 12 month growth[957].

It appears that the Angora goat is very efficient in converting feed into fibre[279] and more affective than woolled sheep[535,728], whereas sheep are more effective in converting feed into body mass. **Shelton and Basset**[535] discussed the biology and efficiency of animal fibre production for Angora goats and sheep, and reported that the Angora goat produced more fibre in relation to its size than Rambouillet sheep, also producing it more efficiently[326, 886]. Owing to the metabolic priority for mohair production, mohair does not develop a break in the fibre during severe under-nutrition to the same extent as wool[728]. Nevertheless, under-nutrition does reduce body growth, mohair production rate and fibre diameter so that a finer lighter fleece is produced[728]. Although there appears to be a seasonal effect on mohair production this is overshadowed by the more significant effects of age, nutrition and reproduction, mohair production being mainly dependent upon the nutritive value of feed[728].

Fleece mass in Angora goats increase with age, up to about 4 years (see later), mainly due to the fibres becoming coarser [1002]. Greasy fleece mass has a hereditability of 0.4 (ie 40% is controlled genetically, the rest being due to factors such as feed), with staple length having a hereditability factor of 0.8[531,1002]. Fibre diameter has a hereditability of 0.2[531], It being very sensitive to changes in nutrition and to the age of the animal.

Müftüogli[97] found that fibre length and fineness were positively influenced by feeding and age, particularly before the goat reached adulthood. Fibre diameter can increase with age from about 24μm for the first shearing (ie Kids) to about 46μm for strong Adults[684,728,1027]. Staple length shows very little change with age, being about 20 to 25 mm per month[728,1027]. Mohair production reaches an economic peak at approximately 18 to 24 months of age[728].

Tucker *et al*[691] gave the following comparative table for the factors which affect fibre growth (Table 3).

Delport[776,777] and **Erasmus**[799] reported a negative correlation between lustre and fibre diameter and between wave frequency and fibre diameter. Follicle density was also negatively correlated with fibre diameter, with the latter being positively correlated with fleece mass.

TABLE 3 [691]
THE MAJOR PARAMETERS AFFECTING FIBRE GROWTH

Parameter	Goats: Cashmere	Goats: Angora	Sheep: Fine Merino	Sheep: Scottish Blackface
S/P ratio	7 - 9	7 - 9	15 - 25	3
Follicles/mm^2	20	20	50 - 85	7 - 9
Fibre diameter (µm)				
- primary	50 - 150	30 - 40	15 - 23	70 - 95
- secondary	10 - 20	30 - 40	15 - 20	22 - 35
Medullation				
- primary	+	+,-		+
- secondary	-	-		?
Fibre length (mm)				
- primary	50 - 150	25 mm/mth.		
- secondary	20 - 80	25 mm/mth.		

Mohair is not considered to have crimp in the true sense of the word but is rather considered to exhibit a "waviness". The following values for the crimpiness (curvature or waviness) has been given for mohair and other animal fibres [93,447] it being reported that the para-cortex shrinks more upon drying than the ortho-cortex, this leading to crimp or curvature in the case of a bilateral (para/ortho-cortex) structure such as found in merino wool.

TABLE 4[93]
CURVATURE AND DIAMETER VALUES OF SEVERAL DIFFERENT WOOL FIBRES (BROWN AND ONIONS)

Fiber	Mean Curvature (cm^{-1}) Wet	Mean Curvature (cm^{-1}) Dry	Mean Diameter (Microns)
White Alpaca	2.0	8.4	30.2
Fawn Alpaca	1.2	6.0	40.0
Lincoln	2.4	5.0	36.0
Mohair	1.2	1.4	43.6
Cashmere	6.8	12.7	13.8
Southdown	18.8	32.0	23.8
Corriedale	10.0	16.4	29.7

Lupton *et al*[888] found that heavy, short-term lice infestation had a negligible effect on objectively measurable mohair characteristics.

Details of Angora goat farming, husbandry etc can be found in various sources[34,533,728,977].

2.2 Effect of Angora Goat Age

According to **Van Der Westhuysen** *et al*[392,533,728], the age of the goat is probably the most important factor determining the quantity and quality of mohair produced. Kids have a birth coat of fibres mainly grown from the primary follicles, those being the follicles which produce kemp and medullated fibres[684]. From about three to six months the goats shed their birth coat, as the fibres increasingly grow from the secondary follicles[684]. Fibre production increases from birth and Angora goats appear to reach their maximum fibre production (fleece mass) at an age of between approximately 3 and 4 years[669,683,728,1027], while they attain their maximum fibre diameter at an age of some 5 years or older[669,683,728]. **Jones** *et al*[13] found that the maximum diameter of mohair was reached at 8 years of age while **Davis** and **Bassett**[118] mentioned that an increase in fibre diameter was found at each shearing[163]. Good mohair can be obtained from goats up to eight years old[279,1027]. **Duerden and Spencer**[6] and **Venter**[72] found the mohair fibres were finer towards the tips, due to the fact that mohair fibres become coarser as the goat ages (up to the age of about eight years)[13,669,728].

Kids normally produce mohair with a diameter of 28μm or finer (7 or 8 Bradford count) at their first shearing, approximately 29 to 30μm (6's count) at the age of one year (second shearing), and 31 to 34μm (5's count) for Young Goats at 18 months of age (third shearing), while Adult Goats produce mohair varying in fibre diameter from 36 to over 46μm (4's, 3's and 2's counts) with increasing age[728].

Goats are classed as Young Goats up to the age of 3 years in Turkey but only up to 18 months in South Africa[165].

According to **Van Wyk and associates**[64] (quoted by **Von Bergen**[202]) mohair diameter varies as follows with the age of the goat.

TABLE 5[64]
CHANGES IN FIBRE DIAMETER WITH AGE OF GOAT

Age of animal[a] (years)	Grades	Jansenville fiber (μ)	Somerset East fiber (μ)	Cradock fiber (μ)
1/2	SK	26.2	27.9	26.9
1	WK	30.8	32.2	31.2
1 1/2	YG	32.8	35.0	31.8
2	SF	35.3	38.9	41.1
2 1/2	WH	35.8	39.1	39.5

[a] At shearing time.

Van der Westhuysen *et al*[533,728] gave the following figure (Fig. 4) illustrating the effect of goat age.

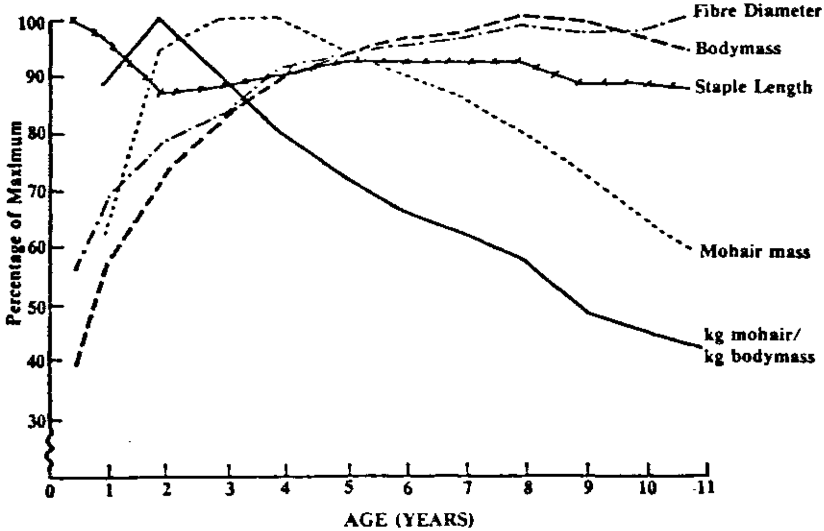

Fig. 4 The Effect of Age on Fleece and Fibre Characteristics in the Angora Goat[728].

Barnard[669] gave the following graphs (Figs 5 and 6) showing the effect of Angora goat age on fibre production and fibre diameter.

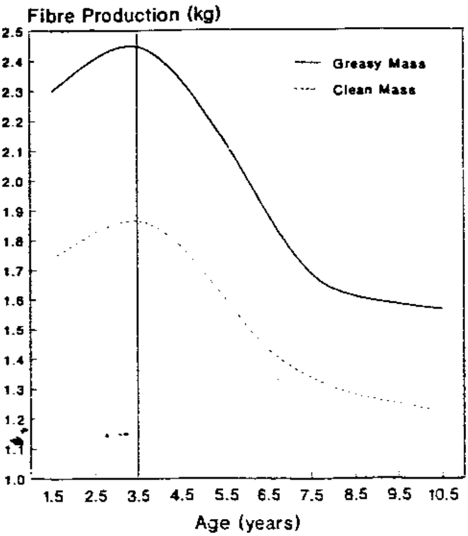

Fig. 5 The Influence of Angora Goat Age on Fibre Production[669].

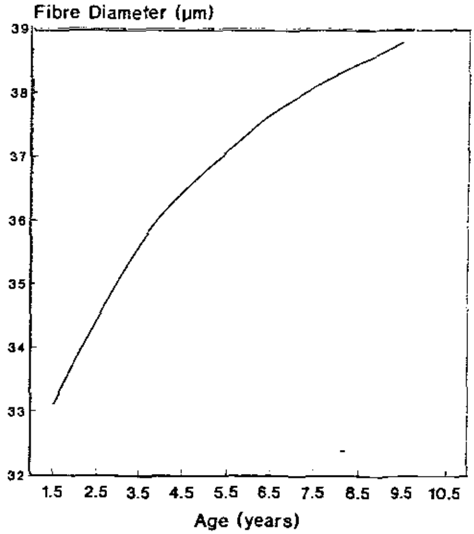

Fig. 6 The Influence of Angora Goat (Doe) Age on Fibre Diameter[669].

2.3 Effect of Nutrition and Season

Mohair growth shows a seasonal effect, probably as a result of changes in the day length, even when the goats are kept on a constant diet[785]. More fibre is grown in summer than in winter, this being a seasonal cycle controlled by day-length, nutrition affecting the seasonal growth cycle but it cannot eliminate it entirely. Angora goats can grow up to 1.7 times more mohair in Summer than in Winter[222,984,1002], fibre production tending to increase with increasing temperature and length of day[535], with lactation and low nutrition having the opposite effect. In South Africa as well as Texas, the winter mohair tends to be shorter, finer and less kempy[785]. Reproduction generally suppresses the rate of mohair growth, with the demands of lactation more pronounced than those of pregnancy[728], body mass, mohair production and fibre diameter generally decreasing during lactation. Adult body mass is correlated with mohair production and fibre diameter[728].

Some spontaneous loss of hair (shedding) can occur, mainly towards the end of winter, possibly aggravated by shearing during the wrong time of the year but this is a rarity in well-bred Angora goats[728]. In late winter, it can sometimes occur that up to 25% of the hair follicles become inactive, while in old animals more of the hair follicles can become inactive[785], hairs in inactive follicles being shed as the growth of the replacement hair commences in spring. This can cause fleece cotting (felting)[785], the shedding of fibres, which intermingle with others which do not shed, results in a matted zone which is known as cotting[6]. Hair loss owing to nutritional conditions may also occur possibly as a result of certain mineral deficiencies or imbalances (high calcium and low zinc may be a cause).

Grobbelaar and Landman[475] studied the effect of supplementary nutritional energy levels on mohair fibre diameter and length, showing that higher levels increase fibre diameter and length. The high nutrition group sometimes had a fibre diameter as high as 5.8μm coarser than the control group at the third shearing. Differences of as much as 4μm or even more, between the fibre root and tip were observed[475] for the third shearing. Stocking rate can have a large effect on fibre diameter[784], differences of up to 4μm being observed for 4 year old goats grazed at 7.5 compared to 12.5 goats/ha. An investigation by **Hurton** *et al* [887] indicated that "fine" and "coarse" goats responded similarly to changes in range-land environment. It has also been reported that improved pasture can increase fibre diameter from 26 to 38μm (**McGregor quoted by Ryder**[785]). **Calhoun** *et al*[886] showed fibre diameter to be positively correlated with body mass and actual digestible energy intake. **Bassett** *et al*[549] and **Shelton** *et al*[158] (quoted by **Calhoun** *et al*[886]) reported that mohair growth responds dramatically to additional dietary protein or supplementation with a rumen-protected form of the amino-acid menthionine. **Stewart** *et al*[278] reported that fibre diameter increased with an increase in protein content in the feed but without any apparent effect on staple length.

Badenhorst and Diedericks[1064] investigated the effects of nutrition on certain mohair quality traits, finding a difference of 9μm or 30% (30.7 vs 39.7μm) between the low nutritional and the high nutritional level groups. The mass of the mohair produced by the high level nutritional group was almost 80% greater than that produced by the low level nutritional groups with the former also producing more kemp and a higher fibre density. There appeared to be no significant effect of nutrition on mohair style and character, although it was stated that style and character were affected differently by nutrition. It was concluded that style and character cannot be regarded as one combined quality but must rather be judged as two separate qualities.

Recently, **Badenhorst** *et al*[1058] found that nutrition affected all mohair quality characteristics, with the exception of style and evenness of fleece, improved nutrition increasing kemp, fibre diameter (31 to 40μm), fleece mass (2.1 to 3.7kg), "fleece density" and character, style and character being influenced differently by nutrition.

2.4 Secondary and Primary Follicles

The amount and type of hair produced by an Angora goat depends upon the number of follicles present in the skin, namely primary (P) and secondary[977] (S), and their ratio (S/P ratio), the Angora having a skin follicle structure almost indentical to sheep (with an S/P ratio of between 7 and 12)[828].

It is generally thought that all primary follicles are producing fibre when the kid is born; the fibres that make up the birth coat are extremely coarse, although the primaries do subsequently produce less coarse fibres[977]. ("Mother" hair is the name given to the hairy birth coat grown from the primary follicles, this coat normally falling out before the Kid is four months old and then the primary follicles produce normal mohair)[977]. The secondary follicles show little sign of development in the first week of the kid's life, but during the next two weeks follicle maturity is very rapid. By the time a well fed kid is six to eight weeks old, 75 to 80% of its ultimate number of follicles may be producing fibres. Research results have emphasised the important relationship between nutrition and follicle numbers and hence the effect of nutrition on fibre production. Since there are many times more of the finer secondary follicles than primaries, it follows that the plane of nutrition of the doe late in pregnancy (ie when the secondary follicles are developing in the foetus) and of the kid during its first ten months of life (ie when the secondary follicles are maturing and coming into production) are critical. If insufficient food is provided at these stages, the lifetime fibre production will be affected[977].

Tiffany-Castiglioni[765] reviewed the follicle and fibre development for kemp and mohair. The primary follicles are those that appear first and begin producing fibres early in foetal development, the secondary follicles occurring at a later stage of foetal development and may not begin producing fibres until after birth[765]. The two types of follicles occur in bundles called follicle groups, each group typically containing a variable number of secondary follicles and a triad of primary follicles (a central and two laterals) [531,533,984], although occasionally two, four or five primary follicles are present. In well bred Angora goats, the limited numbers of kemp and heterotype fibres present are produced by the primary follicles and the mohair by the secondary follicles[337]. In less well-bred flocks, gare (a heterotype medullated fibre) can also be produced by the secondary follicles[388]. According to **Margolena**[144], Angora goats usually produce no medullated fibres from lateral primary follicles and sometimes produce incomplete medullated fibres from central primary follicles. The kemp content of the coat tends to reflect the S/P ratio. A high S/P ratio has been bred into Angora goats for increased growth of the "undercoat", it having a moderately high hereditary coefficient of 0.52 (**Yalcin and co-workers** quoted by **Tiffany-Castiglioni**[765]). It has been stated that in the Angora goat the secondary fibre population has been developed to such an extent that it virtually masks the primary fibres. The Angora goat has about 10 to 15 follicles per mm^2 and an S/P follicle ratio ranging between about 6 and 10. The Angora goat is a "one coat" animal[550], with the diameter of fibres from primary and secondary follicles not so very different[625], although **Yalcin** *et al* (quoted in Ref. [765]) reported a high negative correlation between S/P ratio and mean fibre diameter, the latter decreasing as the former increased. At birth, the ratio of secondary to primary (S/P) fibre producing follicles is reported to be about 2.3:1 for South African Angora goats[163] and about 2.6:1 for Texas Angora goats[285]. This ratio increases for about three to four months until the final S/P ratio of 6.5:1 to 8.3:1 is reached for Texas animals[144] and 9.1:1 (8.6:1 after three months) for South African goats[163]. Some follicles become non-functional with age[535].

The S/P follicle ratio of Turkish Angora goats is around 8 to 10[291], while **Shelton**[531] (quoted by **Ryder**[984]) and others[291], reported that for South African Angora goats, the S/P follicle ratio is 7 at birth and increases to about 9 at 13 weeks, indicating that not all the follicles have fibres at birth, since, as stated above, the S/P *fibre ratio* increases from about 2 at birth to about 10 at 4 months[533], at this stage the primary follicles producing the coarse "guard type" hairs and the secondary follicles producing the fine and shorter "undercoat or down" type fibres[531]. According to **Harmsworth and Day**[977], the S/P ratio for Angora goats is about 8.5. **Yalcin**[291] (quoted by **Ryder**[374]) found that the S/P ratio for Angora goats ranged from 7.91 To 10.30 with a mean of 9.16.

Clake and Smith[376] gave the following table (Table 6) of comparative data for mohair from different countries:

TABLE 6[376]
MEAN FIBRE CHARACTERISTICS (≈SE) DERIVED FROM SKIN SAMPLINGS OF ADULT ANGORAS IN AUSTRALIA, USA AND SOUTH AFRICA

Group	No. and sex of animals	S/P ratio	$\bar{d}$ (μm)	Medullation (%)
Australian	32 ♂	8.8 ± 0.3	36.0 ± 1.0	7.9 ± 1.5
	7 ♀	7.5 ± 0.6	32.0 ± 1.0	3.0 ± 0.6
Texan^A	7 ♀	7.7 ± 0.3	30.4 ± 1.6	1.5 to 3.5
South African^A	6 ♀	7.5 ± 0.3	32.7 ± 2.9	1.5 to 3.5
South African^B	5 ♀	8.6 ± 0.3	37.9 ± 1.8	5.4 ± 0.8
South African^B	5 ♂	9.5 ± 0.6	38.3 ± 0.9	8.0 ± 1.8

Koratkar[466] *investigated the follicle density and secondary to primary* (S/P) follicle ratios from 10 bucks and 10 does at 21 months of age and from 4 male and 8 female kids at the age of 9 to 10 months.

Shelton and Bassett[535] gave the following table:

TABLE 7[535]
SECONDARY TO PRIMARY FOLLICLE (S/P) RATIOS OF VARIOUS BREEDS OR SPECIES

Scottish Blackface Sheep	3-5
Cheviot Sheep	4-6
Suffolk Sheep	5-7
Hampshire Sheep	5-6
Shropshire Sheep	5-9
Corriedale Sheep	9-11
Romney Sheep	5-6
Polwarth Sheep	12-15
Angora Goat	7-9
Merino Sheep	20-25

From Ryder (1957), Schinckel and Short (1961) and Margolena (1966)

2.5 Weathering

Similar to wool, the tips of the mohair fibres covering the back of the animal are damaged by sunlight or weathering, especially during the summer months[202]. This damage (ie sunlight[34] and other) has an influence on the dyeing property of the affected fibre part[202]. *Mohair, by virtue of its open* fleece structure, is more generally exposed to weathering than wool and its grease is therefore more oxidised than that of wool[115].

Louw and Van Wyk[57] studied the reaction of the root, middle and tip portions of various types of mohair towards dyeing with acid milling dyestuff and towards a buffered solution of ninhydrin. *A linear relationship between* fibre diameter and dye absorption as well as the colour developed with ninhydrin was found, the extent of deviations from this straight line being a measure of the extent of weathering. Changes in the cystine and cysteine content of the fibre from root to tip run parallel to the changes in behaviour of the fibre towards dye absorption and ninhydrin. Most Adult mohair samples showed more weathering in the middle and especially the tip portions of the staple than Kid mohair, although the latter weathered further down the staple. A single linear relationship between fibre diameter and optical density of the "ninhydrin colour" for undamaged wool and mohair was found(57) for the diameter range of 18 to 40μm. Higher degrees of weathering were generally associated with lower cystine (ie loss of disulphide) and higher cysteine (ie increase in sulphydryl content) levels(57). The weathered tips adsorbed more dye and at a higher rate than the roots, as had been found for wool. In the case of the ninhydrin test, however, the weathered mohair tips developed more colour than the roots, the reverse having been the case for wool(57). Weathering damage tended to extend deep down the fibre, especially in the case of Kid mohair.

Veldsman(73) studied the influence of weathering on the tryptophane content of wool and mohair. He used the ninhydrin test for weathering. He found that coarse wool or mohair tended to have a lower tryptophane content than fine wool or mohair, with natural weathering decreasing the tryptophane contents of wool and mohair. **Swanepoel**(95) investigated the supercontraction of sound and weathered mohair in lithium bromide, the weathered tips were found to exhibit lower levels of supercontraction than the unweathered roots, the two-stage contraction being much more pronounced for the latter.

CHAPTER 3

MOHAIR PRODUCTION IN VARIOUS COUNTRIES

3.1 South Africa

3.1.1 Introduction

The mohair grown in South Africa is generally known as Cape Mohair and is widely regarded as one of the best, finest and highest yielding[456,554] in the world. The excellent quality of Cape Mohair makes it ideally suited to high quality application[958], eg high quality menswear and ladieswear[958], fineness and length being important in both cases. Cape Mohair is the only clip that is prepared in the true sense of the word[958]. In South Africa, mohair with more than 1% kemp is considered[933] to be crossbred fibre. **Van der Westhuysen** *et al*[533] published a book on the Angora goats and mohair in South Africa, covering the production of mohair and its classing, while **Uys**[872] described the history of mohair in South Africa from 1838 to 1988. He mentioned that the first mohair tops were produced in 1963 at Gubb & Inggs[872].

The South African Mohair Growers Association was formed on 16 August 1941 and the Mohair Advisory Board in 1951. Cape Mohair is sold through a one channel marketing scheme, which was introduced by proclamation on 24 December 1971 [1009], with 1972 the first year of its operation[947,1009]. Some 97% of the South African mohair is exported[932], the marketing being the responsibility of the Mohair Board, brought into being on October 1965 by moh ir producers[1009], it being entrusted with the administration of the one-channel marketing scheme. Its responsibility extends from when the mohair is "weighed in" up to and including the completion of the marketing action, which includes shipping and promotion [936]. It used to employ BKB to carry out mohair preparation, but now carries it out itself in the Board's own warehouses and uses the South African Wool Board's (now Wolex) computer department to process its data and the IMA to carry out promotion. The Board has no involvement with field services, production sales, crop pre-payment etc, but initiates and co-ordinates research and promotion[834]. In South Africa, no person or firm is entitled to trade with mohair (buy or sell, except through the Board), unless such a person or firm is registered with the Board as a trader. A price stabilisation levy on mohair farmers was introduced on 18 October, 1974 [1009].

There are presently (1992) some 4 000 mohair farmers in South Africa, farming with some 2 million goats producing some 6.7m kg of mohair (average annual greasy mohair production per goat is 3.8 kg at an average clean yield of about 85%)[533]. Mohair is mainly produced in the Cape Province, more specifically the Eastern Cape area. The annual value of the South African mohair clip was less than 100 million rand (30 million US dollars) in 1992, with that of the end-product about 2 000 million rand[1077].

A large proportion of the SA mohair clip is delivered in containers containing a mass of less than 100 kg and this must be binned. The minimum bale weights are 120 kg for Adult hair and 100 kg for Young Goat and Kid hair. Before each sale, the contents of many thousands of containers must be inspected and correctly evaluated before being blended and packed into bales to form homogeneous lots.

One result of improved breeding in South Africa has been that in 1980 the mohair production per goat was 4.35 kg compared to 3.70kg in Texas or 2.25 kg in Turkey, 1.00 kg in Argentina and 0.75 kg in Lesotho[566]. South African goats have a relatively high S/P ratio[163], relatively low variation in the number of secondary follicles per follicle group[337], relatively low percentages of follicles which become inactive with age[337] and a relatively greater depth of penetration of the follicles into the dermis[144,337].

The mohair from Lesotho is also marketed by the Mohair Board but is called Basutho Mohair and not Cape Mohair. **Black**[952] has described the mohair industry in Lesotho, the Angora goat in Lesotho producing about 1 kg of hair per animal per annum[952].

3.1.2 Properties of Cape Mohair

The lambing season is during June/July and the kids are first shorn during January/February, this hair being known as Summer Kid hair. The second shearing of the same animals takes place in July/August and this is known as Winter Kid hair. The third shearing (two teeth), again six months later, is known as (Summer) Young Goat hair. From the fourth shearing (four teeth), the hair is rated as Adult hair [64]. The first shearing includes qualities such as Super Summer Kids (SSK) and Summer Kids (SK). The second includes Super Winter Kids (SWK) and Winter Kids (WK), the third Super Young goats (SYG), etc. Although Cape Mohair is usually shorn twice a year, namely in December to February (Summer hair) and in June to August (Winter hair)[533,866], the frequency of shearing, may vary from once every four months to once every eight months, depending on various economic, climatic and other factors[533]. Since the two annual clips represent two sharply differing sets of climatic conditions in the traditional mohair producing areas of the Cape Province, it was conceivable that concomitant external or internal physico-chemical effects during fibre growth for these two periods could be reflected in differences in physical and chemical properties between the Summer and Winter clips. In the trade, differences between similar types for the two seasons are reflected in differences of opinion about handle (Winter hair being considered as slightly more greasy and therefore better handling), while Summer hair is considered to be more dusty and perhaps slightly finer.

Van Wyk *et al*[64] found that the Super Winter Kid hair was almost 5μm coarser than the Super Summer Kid, and also had a clean yield of only 80% compared to that of 88% of the Super Summer Kid hair. The latter also appeared to exhibit less weathering but Winter Kid hair was more uniform in length as well as diameter (ie lower CV's) than the Summer Kid hair. The Winter Adult hair was about 2μm finer and 1cm shorter than the Summer Adult hair and was more uniform in fineness and length. The Winter Adult hair was less weathered than the Summer Adult hair. There was no difference in clean yield for the Winter Adult and Summer Adult hair. Winter Adult as well as Winter Kid hair were more uniform in diameter in general than the Summer hair [64]. **Venter**[72] also found that Summer hair, over various parts of single fleeces, was more variable in both length and fineness than Winter hair.

Kritzinger[68] stated that, according to the work done at the South African Wool Textile Research Institute (SAWTRI), the Winter mohair was not markedly different from (inferior to) the Summer clip as had been widely believed. Winter Adult hair appeared to be more even in diameter along the staple than Summer Adult hair[84]. Winter hair was also generally whiter than the Summer hair when scoured[84], possibly as a result of a lower degree of weathering. He concluded that there did not appear to be sufficient justification for the wide differentiation of the past or for the retention of the designations "Winter" and "Summer" in the future[84].

Uys[104] *extended the work of* **Van Wyk** *et al*[64] by using a larger sample population (1937 samples collected over three Summer and three Winter seasons). In the case of Kids, he found Summer hair to be 33% less kempy and on average about 6μm finer than Winter hair, while Winter hair tended to be, on average, some 18mm longer than Summer hair. The grease content of Winter hair (6.0%) was also higher than that of Summer hair (4.4%) and the clean yield some 2.2% (absolute) lower. Similar trends, but of smaller magnitude in terms of absolute differences, were observed for Young goats and Adults. **Uys**[129] plotted mohair price against Bradford Count (fineness) as shown in the following graph (Fig. 7) and gave a table (Table 8)[129] of average values for the samples tested.

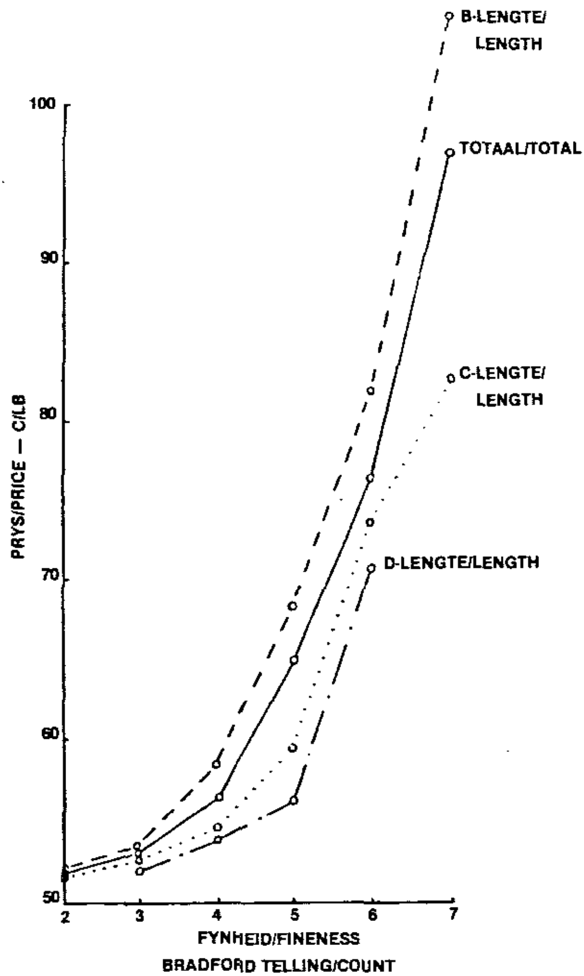

Fig. 7 The Influence of Fineness on Mohair Price, for Different Lengths and in Total[129] (Some 30 Years Ago).

The high price paid for the mohair at the time had stimulated mohair production and led to cross-breeding with ordinary goats resulting in a deterioration in hair quality as illustrated by the relatively high kemp levels. According to his analysis, the Kid hair was finer than 33μm, Young Goat hair was 33 to 37μm[129] and Adult hair over 37μm[129]. Mixed hair (MH) and Coarse hair (R) were on average over 43μm, with the Mixed hair slightly finer than the Coarse hair. He gave Table 9[104] as representative of the South African Mohair Clip at the time (ie some 30 years ago). Good breeding practices have greatly improved the quality of South African mohair over the years.

Uys[187] reported that, except for yield, mohair market price was determined by fineness, length and style and character, with soundness and kemp content also of importance. He analysed the composition of the South African

TABLE8[129]
AVERAGE VALUES FOR SAMPLES TESTED SOME 30 YEARS AGO

	Kemp %	Veseldikte Fibre diameter (Mic.)	Vet Grease %	Sweet Suint %	Stof Dust %	Skoonopbrengs Clean Yield %
Kleinbokkies .. .. .. Kids	3.41	31.1	5.44	2.18	11.2	81.07
Jongbokke .. .. .. Young Goats	3.24	35.2	5.04	2.10	11.5	81.37
Grootbokke .. .. .. Adults	3.82	40.1	5.01	2.14	10.2	82.72
TOTAAL .. .. .. TOTAL	3.6	36.6	5.1	2.1	10.7	82.1

*Percentage by number.

TABLE 9[104]
AVERAGE COMPOSITION OF RAW MOHAIR SOME 30 YEARS AGO

	% Kemp		Lengte (cms) Length (cms)		Veseldikte Fibre Diameter		% Vet % Grease		% Sweet % Suint		% Stof % Dust		% Skoonopbrengs % Clean yield	
	Somer Summer	Winter	Somer Summer	Winter	Somer Summer	Winter	Somer Summer	Winter	Somer Summer	Winter	Somer Summer	Winter	Somer Summer	Winter
Kleinbokkies Kids	4.1	3.1	8.5	11.3	27.1	33.5	4.4	6.0	2.3	2.2	11.1	12.0	82.0	79.8
Jongbokkies Young Goats	3.4	3.1	11.5	10.8	34.7	36.7	4.6	6.2	2.2	2.2	12.3	10.6	80.4	80.8
Volwasse Bokke Adult Goats	4.0	3.6	10.4	10.4	39.3	40.8	4.3	5.4	2.2	2.2	10.4	10.3	83.2	81.5
Totaal Total	3.9	3.4	10.5	10.7	34.6	38.0	4.4	5.6	2.2	2.2	11.1	10.7	82.3	80.5

*Percentage by number.

mohair clip at that time and showed the relationship between fineness, length and processing group on the one hand and price on the other hand. **Uys**[104,129] showed the effects of mohair length and style/character on price (Figs 8 and 9). In the fleece lines, clean yield varied from 60 to 92%. Fineness influenced price more for the long than for the short hair and more for fine than for coarse hair[104], good length also being more important for fine than for coarse hair. The slight drop in price for the very long hair was ascribed to the more open *and weathered appearance* of such fleeces ("ripening of the fleece"). Good style and character had a greater effect on the price of the Kid hair than on that of the Adult hair. Winter Kid mohair was coarser (6μm) than Summer Kid mohair, this being ascribed to age and the fact that the winter goats were older and also had better grazing *(nutritional) conditions*[104]. *The greater length (18mm)* of the Winter Kids was ascribed to the better feeding conditions, the age of the goats and also the fact that Summer Kids were generally shorn at 5 months and Winter Kids at 6 months[104]. Differences in grease content, between Summer and Winter Kids, were ascribed to the better feeding conditions[104].

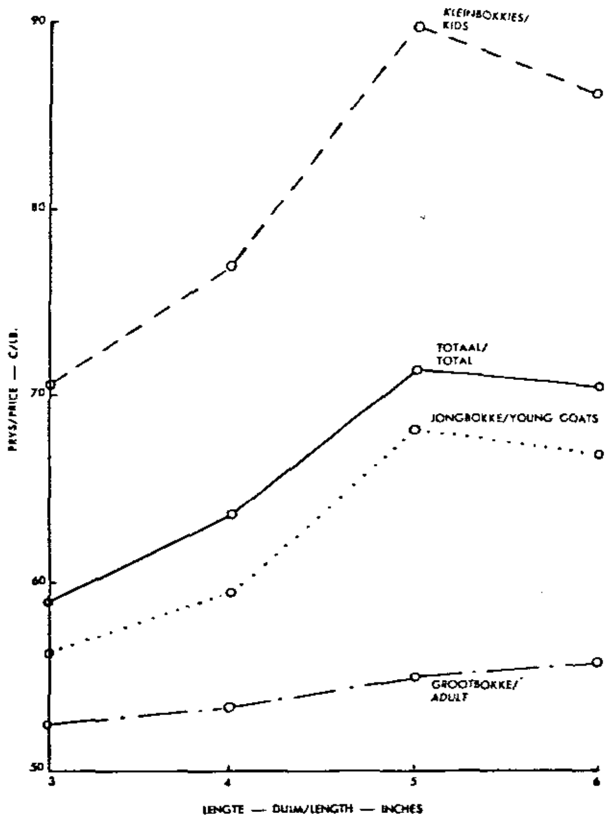

Fig. 8 The Influence of Length on Mohair Price[129] (Some 30 Years Ago).

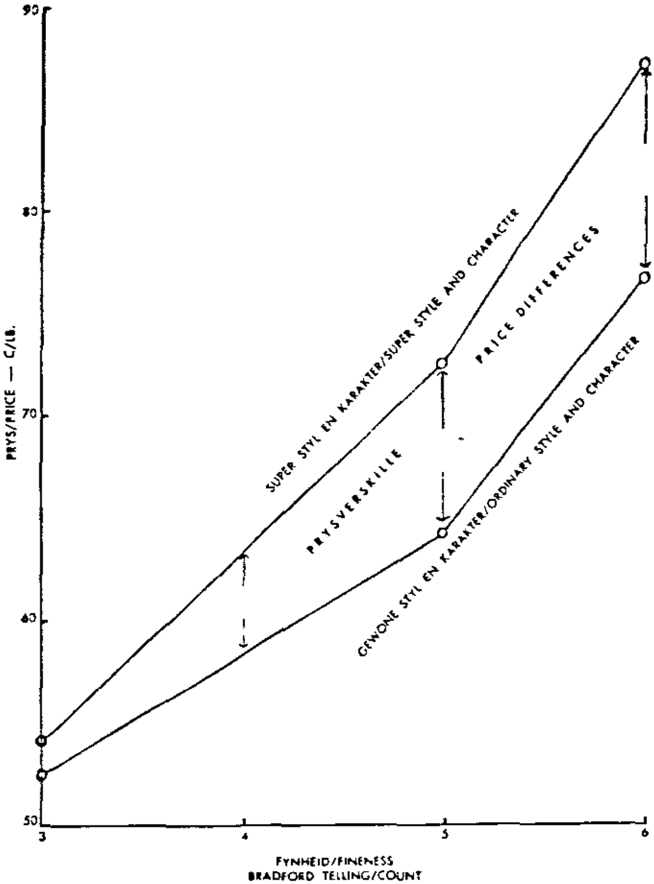

Fig. 9 The Influence of Style and Character on Mohair Price for Different Fineness Grades[129] (Some 30 Years Ago).

Uys[104] found that the average fibre length was only 60% that of the staple, with a CV of between 40 and 70%. He compared the single fibre length distributions of mohair and wool (Fig. 10[104]). The short fibres (below 25mm) were ascribed to the presence of second-cuts during shearing and to short kemp[104]. He stated that very strong hair, without style or character, should be avoided at all costs.

Robie et al[307] *carried out an* objective evaluation (mohair base and fibre diameter) of the South African produced summer clip (using core-sampling), his results indicating that the producers subjective evaluation of fineness was very good. The within (α_W) and the between-bale (α_B) standard deviations for mohair base were as follows (Table 10):

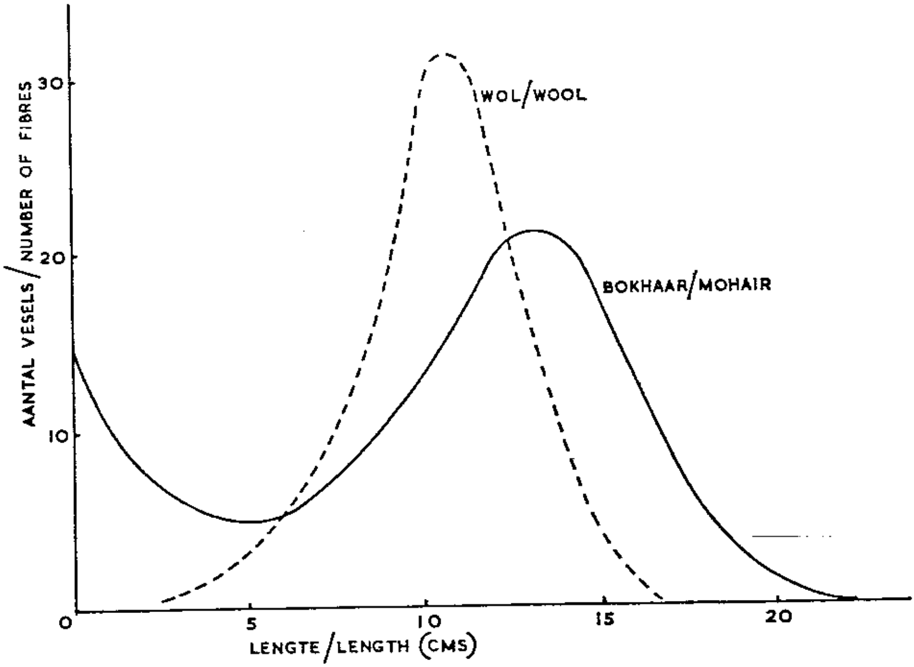

Fig. 10 Fibre Length Distribution of Mohair and Wool[104].

TABLE 10[307]
STANDARD DEVIATION FOR MOHAIR BASE (%)

Mohair Class	σ_W	σ_B
Kid Mohair	1.22	3.27
Young Goat	1.09	2.34
Adult Mohair	2.03	4.13

In a follow-up study, **Gee and Robie**[311] studied the Winter clip. They reported that:

1) The yield from Winter Kids was lower than for Summer Kids.
2) For the Summer clip, Kids and Young goats had the same yield.
3) The mature goats gave the same yield for winter and summer, the summer yield being lower than that for Kids and Young goats.
4) The Winter Kids were slightly coarser than the Summer Kids, the reverse being true for the Mature goats.

They presented the following table (Table 11[311]). The "within bale" variation for yield (expressed as mohair base) (σw) was 1.5% for all the Winter clip and for the Summer clip of Kids and Young goats. The Summer clip Mature goats had a σw value of 2.3%. The variation between bales within types was higher (3.7%) for the Winter clip than for the Summer clip (2.2%). The variation of diameter within a bale (σw) for Kids (Winter and Summer) was 0.6μm and for Adults (Winter and Summer) it was I.0 to 1.2μm, for Young goats it was 0.6μm in Winter and 1.0μm in Summer. The overall variation between bales was 1.9μm for the Winter clip and 1.4μm for the Summer clip. The above results agreed fairly well with the earlier observations of **Van Wyk** *et al*[64].

TABLE 11[311]
SUMMARY OF OBJECTIVE MEASUREMENT RESULTS FOR MOHAIR

SEASON	CLASSING GROUP	MOHAIR BASE – %			DIAMETER – μ		
		Mean	σ_w	σ_{l+b}	Mean	σ_w	σ_{l+b}
Winter Clip	Kids	70	1,5		28	0,6	
	Young Goats	70	1,5	3,7	31	0,6	1,9
	Mature Goats	70	1,5		36	1,0	
Summer Clip	Kids	73	1,5		27	0,6	
	Young Goats	73	1,5	2,2	35	1,0	1,4
	Mature Goats	70	2,3		37	1,2	

Erasmus[799] reported on the various fleece, fibre and breeding properties which are recorded in a South African mohair breeding scheme.

Turpie[705] gave Table 12 for the properties of mohair processed at SAWTRI during the 1980's.

TABLE 12[705]
AVERAGE VALUES AND RANGES OF THE VARIOUS MOHAIR PROPERTIES

	RANGE	AVERAGE VALUE
Diameter (μm)	23-45	33
CV (%)	20-33	25
Staple length (mm)	84-137	109
Medullation (%)	0,3-2,8	1,0
Curls per 10 cm	2,8-6,6	4,5
VM (%)	0,1-1,7	0,3
Grease (%)	2,9-8,0	4,6
Suint (%)	1,8-4,2	2,7
pH of Suint	3,3-6,2	5,3
Scoured Yield (%)	77-93	86
Compressibility (mm)	10-13	11

3.2 United States of America

In the United States of America as in South Africa, there are two mohair clips per year, the one termed Spring (shearing in February/March) and the other Fall (shearing in August/September)[88,165,732,1056], most of the mohair being produced in the South Western United States.

In the USA, Angoras are largely concentrated in Texas, with smaller numbers in New Mexico, Oklahoma, Michigan and other States[851]. Texas produces about 96% of the total US mohair production, with the primary range being the Edwards Plateau in South Western Texas[554,851] (about 6 million Angoras on 19.7 Million hectares)[1061] where the mild dry climate and hilly, bushy terrain are particularly well suited to their well being. Mohair in Texas is mainly grown in the area circumscribed by Uvalde, San Antonio, Austin, Fort Worth and San Angelo[91]. In Texas, mohair is sold through various warehouses in a free market system in which the producer has the final say over the sale of his product. Nevertheless the United States Department of Agriculture (USDA) administers an incentive payment scheme system, whereby an average price for all mohair sold in that year is guaranteed for direct payment to producers, hence the price of Texas mohair is supported (subsidised) if the market price drops below the support price. The Mohair Council of America was established in 1966 as the promotional organisation for United States produced mohair and is involved in Marketing, Development and Research, the executive offices being located in San Angelo. **Paschal**[749] reported on mohair production and promotion in the USA, production has also been discussed in another article[783].

The USA market has established various grades of product, based on staple or "lock" characteristics, from the "ringlets" of the finest fleece to "flat" locks in which the curl is less pronounced and takes on the form of a wave[808]. Classing is mainly associated with grading for fineness, with length also a criterion[808], with only 9 basic grades for mohair[1090], it being claimed that sorting on length is becoming too expensive. The hair is generally not skirted but is normally separated into Kid, Young Goat and Adults.

Basset and Stobart[481], in 1978 reported on the properties of Texas mohair, and gave three tables of results. Clean yield ranged from 73 to 82%, diameter from 25 to 37μm, kemp from 0.1 to 2% (defined and measured according to ASTM D2968-75 Part 33:606, kemp being fibres with medulla diameter exceeding 65% of the fibre diameter)[481]. Med fibres ranged from 0.1 to 1.1% (same method as for kemp fibres, but Med fibres having their medulla diameter less than 65% of the fibre diameter) and vegetable matter ranging from 0.1 to 1.5% for the samples tested[481].

Performance testing of Angora goats is undertaken at the Texas A & M Centre[1061]. Recently **Lupton** *et al*[999], discussed the performance testing of Angora goats in Texas and reported that during the 8 year period under consideration average clean mohair production of yearling buck increased from 4.6 to 5.5 kg (180 day basis), while clean yield, fibre diameter and staple length remained constant, at about 69%, 40μm and 150mm respectively, with kemp (0,4%) also remaining approximately constant, but medullation increasing from about 1.3 to about 3.3% (average about 2%). Kemp content was not correlated with any of the measured characteristics except medullation, where the correlation was 0.33.

3.3 Turkey

In Turkey there is normally only one clip per year[84], ie the goats (which are generally quite tame) are shorn once a year during May[1056] (ie Spring). An official grading standard exists, with the hair normally sorted by exporters into First Kid, Best Average (Young Goat), Good Average (Fine Adult), Fair Average (Low Adult) and Mountain Konia (Mountain Hair about 31/32μm). The clean scoured yield is about 70 to 75%.

Mohair growing in Turkey is concentrated in the central provinces of the Anatolian peninsula (within a radius of approximately 160 km from Ankara) where the summers are hot and dry and the winters cold with frequent snowfalls. The mohair clip is sold in its unclassed state, although exporters do grading before exporting hair. Mohair for export is divided into two categories viz "Principal Mohair" and "Secondary Mohair", with the former divided into nine classes and the latter into eight.

Some 20 years ago it was estimated that, at that time, approximately 8% of the Turkish clip contained coloured fibres. **Müftüoglu and Örkiz**[571] studied the production and quality of mohair in Turkey and gave average values for the various mohair characteristics at that time. For example, clean mohair content ranged from 69 to 88%, the average yearly fibre growth was 13.5 cm and average crimp was 3.2 per 10 cm. The average fibre diameter was 32μm, with average kemp and medullated fibres being 3.7 and 1.4%, respectively[571].

In Turkey a reddish brown mohair, containing a colour pigment, and known as Gingerline, is produced. The grease content is usually less than 4%. The best grades are clear white.

3.4 Australia

Angora goats were first imported into Australia in 1856[851], with the Australian mohair industry starting to expand in about 1970[785]. In Australia, the Angora goats are mostly shorn twice a year[1056] (in the past, sometimes at 9 months) and graded into standard qualities (various grades of Kids, Young Goats and Adults), depending upon quality and kemp content. Classers grade mohair into super, good and average style and character categories. Cotting is classed into soft and hard cott[828]. Pigmentation is severely penalised. Stains must be skirted from the fleece, it increasing with increasing coverage and fleece weight[828]. The scoured yields are of the order 88 to 90% and the colour good[1056]. Australian mohair is considered to be relatively fine and kempy[933,948,1086] it being reported[948] that it needed to be 4μm finer than South African (Cape) mohair to be accepted in the same category. Kemp is present to varying degrees, from FNF (free/nearly free) to very kempy cross-bred[1056].

Harmsworth[902] gave some details of Australian mohair as seen through the eyes of some Bradford merchants, while aspects of mohair production in Australia have been discussed by **Stapleton**[828], **and others**[929,1049]. According to **Stapleton**[451,688] **and Gifford** *et al*[681], as quoted by **Stapleton**[828], Australian mohair has a yield of about 90%, a mean fibre diameter ranging from 24μm at the first shearing, 26μm at the second, 30μm at the third and fourth shearing and about 33μm at later shearings, with the kemp levels about 2%. Fleece mass increases rapidly to the third shearing, reaches a peak at the fifth or sixth shearing and then gradually declines showing some seasonal effect[828]. In Australia the maximum greasy fleece weights range from about 1.4 to 1.9 kg, at six months.

Developing a mohair-producing flock from feral or milch females is stated to take at least five generations[828]. Development of the Australian mohair industry is also discussed elsewhere[708].

The following grading lines (Table 13) have been suggested [977] for Australian Mohair:

TABLE 13[977]
AUSTRALIAN MOHAIR: SUGGESTED GRADING LINES

For small to medium-sized herds, suitable lines for grading are as follows:

Kids	AAASFK	Superfine kids 23μ over 150 mm
	AASFK	Superfine kids 23μ 100 mm to 150 mm
	AAAFK	Fine kids 23–27μ over 150 mm
	AAFK	Fine kids 23–27μ 100 mm to 150 mm
Young goats	AAAYG	Young goats 27–30μ over 150 mm
	AAYG	Young goats 27–30μ 100 mm to 150 mm
Adults	AAAH	Adults 30–33μ over 150 mm
	AAH	Adults 30–33μ 100 mm to 150 mm
	AAASH	Adults 33μ and coarser over 150 mm
	AASH	Adults 33μ and coarser 100 mm to 150 mm

In all cases, all very short fibre should go to one line and be branded 'A mohair'. One line should be made of stain, which would carry the brand 'Mohair Stain'.

There is now a single classing standard for Australian[1084] mohair.

Recent infusions of new bloodlines from (South Africa and Texas) are stated[1081] *to be one of the most potentially beneficial events in the history of* Australian Angoras. Reference has been made[1084] to the MOPLAN performance recording system in Australia.

3.5 New Zealand

In about 1860, Angora goats were brought to New Zealand from Australia[768], some 20 000 Angora goats being imported into New Zealand from Australia during the early 1980's. New Zealand also produces Cashgora. **Woodward**[662] discussed the increasing production of mohair and Cashgora in New Zealand, explaining the breeding strategies of goat farmers. In 1992 the New Zealand Clip was marketed through two separate companies[1070]. At the turn of this decade, New Zealand produced about 2% of the world mohair[1007]. Shearing takes place every six to nine months. The scoured yield is mostly around 88 to 90%, with the colour good. Kemp is present to varying degrees, from nearly free to very kempy crossbred[1056]. **Bingham** *et al*[996] state that the levels of kemp and medullation in New Zealand mohair are high relative to those in Texas and Cape mohair.

Mohair production in New Zealand (and Australia) has been discussed in various articles[768,928,933,995], the mohair tending to be relatively fine, high yielding[768] and kempy (with only about 4% having less than 2% kemp)[933] but steps to rectify this, such as the use of imported low-kemp breeding stock and a dekemping process, were in progress [1006].

3.6 United Kingdom

Ryder[823,941,1035] reported on the production of mohair in the United Kingdom and on the development of the Angora goat industry.

3.7 Argentina

In Argentina there are generally two clips per year, viz March (short) and November (long)[1056]. Sorting is mostly done by the exporters, the scoured yields are approximately 75 to 80% with the colour good but the hair is relatively kempy[1056]. In 1985 guidelines for the classing and types of mohair were approved by the Department of Agriculture for application in the entire country[626]. Other papers[627,628,629] also deal with mohair production in Argentina.

CASHGORA

Cashgora[817], shorn from the Cashgora goat[1023], is considered the first new natural textile fibre of the last 100 years. The name "Cashgora" has been accepted as a generic term by the IWTO, it being the progeny (Cashgora goat) of a cross between a male Angora goat (ram) and a female down-bearing (cashmere bearing) feral goat (the first crossing producing the finest fibres[967]), which is predominantly reared in New Zealand[798,1003,1027]. The Cashgora fibre (or hair) is the "down" component of the fleece of the Cashgora and is defined as being under 22μm, (18 to 23μm in Australia)[1069] with a length of 30 to 90mm (or 40 to 60mm)[1003], being shorn twice a year. It has to be dehaired (ie the down fibre has to be mechanically separated from the coarse hair)[657] and has a low (gentle)[1003] lustre and is soft and delicate to the touch[1027]. Cashgora *is also described as a down fibre averaging between 18.5 and 22μm in* diameter[1003]. Cashgora is dehaired, using the same criteria as for cashmere, viz fibres coarser than 30μm are classified as guard hair[817,823,891], the fine inner down representing approximately 50% of the mass of the fleece.

It has also been stated that Cashgora is normally produced in the first and *second cross and can be regarded as fine mohair*[785]. *In Australia, the first* cross between a female feral goat and a male Angora goat, is called Cashgora[657], the fibre being considered to have some of the characteristics of both cashmere and mohair[657] (ie it is a cross between the two)[823]. Australia has four crossbred grades, the finest is classed as coarse cashmere and the coarsest as kempy mohair. One of the Cashgora grades ranges from 19 to 21μm and the other from 21 to 23μm[870].

In the Kid and Young Goat stage (up to 2 years of age) the fleece of the Cashgora contains fibres which are similar to cashmere and also fibres which are of the mohair type, both with lustre (**G. Smith January, 1987**). As the animal ages there-after, the fine cashmere type fibres disappear and the fleece reverts to Superfine mohair in characteristics. A Guard Hair is always present. The mean diameter ranges from 19 to 24μm (CV 25%), although the range around each mean is fairly wide. Finer fibres are down to 12μm, with the coarser end *running up to 45μm. The fibres are medullated in some cases, and the fleece* has the same lustrous appearance of mohair, none of the fibres being crimped.

Phan *et al*[971] discussed the morphological features of Cashgora, showing that they differed sufficiently from those of Cashmere to allow the two types of fibres to be distinguished. Nevertheless, Cashgora fibres are considered to possess either the cashmere-like features (ie cylindrical and semi-cylindrical scales) or the characteristics of mohair with "splits", lance-shaped scales and subscales[895]. (See Figs 11 and 12).

Phan *et al*[1033] stated that the scale structure of Cashgora is more similar *to that of mohair than to that of cashmere. Cashgora fibres ranged from a* bilateral to non-bilateral structure, some resembling the bilateral structure of cashmere, others resembling the non-bilateral structure of mohair, with the majority being intermediate[899,984]. **Bingham** (quoted in Refs[718,737]) gave comparative diameters for cashmere, Cashgora and mohair (see Fig. 3).

New Zealand produces 95% of the world production of Cashgora[1023]. It accounts for more than half the goat fibre exported from New Zealand, with the production during 1990/91 being 140 000 kg[1027]. (In 1988 New Zealand produced 200 000kg Cashgora)[981]. Production of Cashgora was estimated at 200 000kg in 1990[1047].

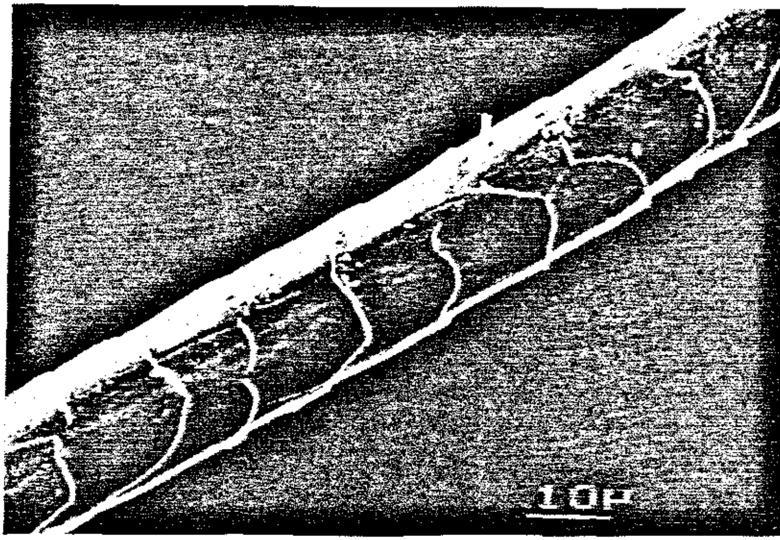

Fig. 11 Cashgora, Cashmere-Like[895].

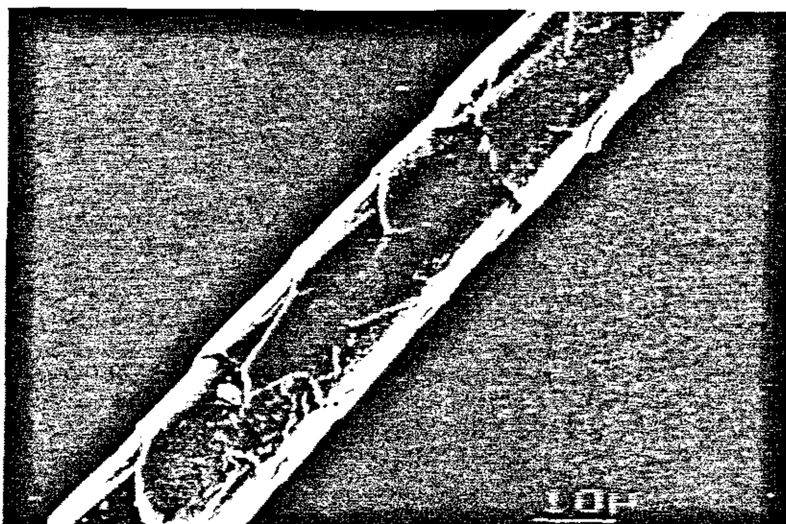

Fig. 12 Cashgora, Mohair-Like[891].

Friedlin[817,891], reported on the production and characteristics of New Zealand Cashgora. New Zealand Cashgora has been defined[945] as the down component from a two coated fleece (down and guard hair) having a mean fibre diameter between 17.5 (*sometimes it can be as fine as 17μm*) [817,891] and 23μm, a standard deviation below 6μm, a CV of fibre diameter below 28% and less than 6% of fibres coarser than 30μm. It contains both ortho-cortex and para-cortex, with fewer fibres exhibiting a bilateral structure than is the case for cashmere. It has low to medium lustre and is predominantly white[945]. New Zealand Cashgora fleece has also been defined[1012] as being under 22μm in mean diameter with a high down yield of 45% or more, staple length of 30 to 90mm, yielding a fibre of low lustre or brilliance, which is soft and delicate to the touch.

There are three types of Cashgora, ranging from the top end (18.5μm), *marketed as "Ligne Or", the medium range (20μm) marketed as* "Ligne Emerande" and the lower range (just below 22μm) marketed as "Ligne Saphir"[1023].

At René Friedlin the dehaired Cashgora is classified into three classes according to diameter viz;

17 to 18.5μm
19.5 to 21μm and
22 to 23μm[891]

Cashgora is used in most articles of clothing (eg jackets, coats, scarves and stoles)[895]; with the exception of underwear and socks. The rest is all on the market, including blankets[823,891]. It is considered more suitable for the weaving trade for high-grade light weight suiting fabrics[891]. **Albertin** *et al*[967] compared the behaviour and properties of Cashgora and Cashmere during finishing operations.

Shlomm[989] discussed the luxury fibres, such as Cashgora, from a buyers point of view.

Tucker *et al*[899] gave Table 14 for the amino-acid composition of Cashgora and certain other speciality animal fibres.

TABLE 14[899]
AMINO ACID COMPOSITION (MOL %) OF SPECIALITY ANIMAL FIBRES

	SAMPLE AND FIBRE DIAMETER (MICRONS)					
Amino Acid	Aust.Cash.*	Chinese Cash.815	Aust.Cashgora+	Aust.Cashgora	Mongolian Yak	Camel
	12.7-17.9	17.1 ± 2.4#	3-089	YZ-3		
			16.2 ± 3.3	21.2 ± 1.3	18.4 ± 1.9	18.7 ± 2.6
Cysteic	0.1-0.2	0.1	0.1	0.2	0.4	0.3
Aspartic	6.6-7.1	6.7	7.1	7.1	6.6	8.1
Threonine	6.6-7.3	7.0	6.9	7.1	6.5	6.6
Serine	10.7-12.7	10.9	11.5	11.3	10.3	10.4
Glutamic	11.2-13.0	13.0	13.5	13.4	12.5	13.6
Proline	8.1-9.0	7.7	7.5	7.9	7.5	7.2
Glycine	9.0-10.2	8.8	8.4	7.8	9.3	7.8
Alanine	5.8-6.2	5.5	5.7	5.7	5.8	5.9
Cystine	4.2-5.6	5.5	4.8	4.8	5.4	4.6
Valine	5.0-5.7	5.7	6.0	5.9	5.9	5.9
Methionine	0.3-0.5	0.4	0.4	0.5	0.5	0.7
Isoleucine	2.5-3.0	3.1	3.2	3.3	3.4	3.3
Leucine	7.4-8.4	7.4	7.7	7.5	8.0	7.7
Tyrosine	3.4-4.1	4.1	3.5	3.4	3.5	3.3
Phenylalanine	2.6-3.0	2.9	2.8	2.8	3.2	3.0
Lysine	2.5-3.0	2.8	2.8	2.9	3.0	2.7
Histidine	0.6-0.8	0.8	0.6	0.8	1.0	0.8
Arginine	6.4-7.2	7.5	7.4	7.8	7.5	8.0

* 10 Samples from Individual Goats; + Sample from One Goat; # Mean ± S.D.

MOHAIR GREASE AND OTHER FLEECE CONSTITUENTS

The fleece of the Angora goat, when shorn, contains natural and applied impurities (usually a total of 10 to 20% of nonfibre is present), with the sweat (suint, the water soluble component) and grease (wax) combined, making up what is termed "yolk". The grease (wax) is secreted by the sebaceous glands and the sweat (suint) by the sudiferous glands(977). Other natural impurities contained in mohair include sand and dust (ie inorganic matter), vegetable matter (eg burr, grass, seed) and moisture. Applied impurities include branding fluids, dipping compounds etc. Generally, mohair contains considerably less grease than wool (4 to 6% on average, compared to an average of about 15% for wool). Because the yolk content of mohair is lower than that of wool, shearers or said to have to change combs and cutters more often than with wool. The yolk acts as a cooling (and lubricating) agent and prolongs the sharpness of combs and cutters(506). Australian mohair contains around 5 to 6% of "yolk"(977). Increased feed is thought to increase grease levels(1061).

Tucker *et al*(992) presented the following table for various speciality fibres (Table 15).

TABLE 15(992)
THE COMPOSITION OF RAW WHOLE FLEECES

Fibre	Moisture(%)	Grease(%)	Water Solubles(%)
Wool[1]	11.0-11.7	9.5-27.0	3.9-7.1
Mohair[1-3]	12.0-14.4	1.2-8.0	1.8-4.2
Aust.Cashmere[1,3]	10.7-13.9	0.7-2.5	1.2-3.5
Chinese Cashmere[1]	11.1-12.9	5.0-7.2	2.3-3.0
Cashgora[1]	13.2	1.2-2.8	0.6
Llama[3]	12.0	2.8	-
Alpaca[3-6]	10.9-14.4	2.8-3.9	0.6-2.4
Camel[3,4]	9.9	0.5-1.1	-
Yak[3]	10.4	12.3	-

1 Tucker et al; 2 Turpie; 3 Tucker et al; 4 von Bergen;
5 Pumayalla and Leyva; 6 Villarroel

The amount of wax (the purified form is known as lanolin) on mohair generally varies between about 4 and 6%(110), wool containing 3 to 5 times as much. Mohair by virtue of its open fleece structure on the goat, is more exposed to weathering than wool and it could therefore be expected that its wax was more oxidised than that of wool[115], making it also more difficult to remove during scouring[533]. It had been suggested (**C.A. Anderson** quoted in Ref. [115]) that the main part of the unoxidised wax from the root portions of the staple is removed in the first bowl and the oxidised wax from the tip is mainly removed in the second bowl. This may be due to the higher surface activity of the oxidised wax or to the smaller percentage of wax normally found on mohair fibres (or both)[115].

Ilse[59] compared the composition of mohair, karakul and merino wool waxes (Tables 16 and 17) and concluded that the mohair and karakul waxes had the usual merino wax components in surprisingly similar proportions.

TABLE 16[59]
CHARACTERISTICS OF THE WAXES

	Merino wax	*Mohair wax*	*Karakul wax*
Wax content of the wool, %	14—16[3]	5	3
Saponification value (mg KOH/gm.)	92—102[1,4]	128	110
Acid value	4[1]	14	9
Hydroxyl value[5]	54	57	58
Iodine value	15—30[3]	36	56
Acids, %	49[1]	55	50
Unsaponifiable material, % ...	51[1]	45	50

TABLE 17[59]
COMPOSITION OF THE UNSAPONIFIABLE FRACTION

	Merino wax[1]	*Mohair wax*	*Karakul wax*
Hydrocarbons	1	1	2
Urea complexing alcohols ...	15	11	14
"Isocholesterol"	44	42	44
Cholesterol	33	30	34
Diols	3	6	4
Unresolved residue	3	8	1

Grové and Albertyn[116,134] modified the column-and-tray method of residual grease determination on wool to make it suitable for mohair. The main changes involved cutting the mohair fibres to short lengths and blending them with fat-free cotton-wool. Subsequently[150] they showed that a laboratory cutting mill could be used to eliminate the cutting by hand.

Mohair from Kids and Young Goats contains more grease than that from *adults, with the grease content higher in winter than in summer*[104] *and also* higher towards the root (eg tip = 2.0%, Middle = 4.6% and root = 6.0%). **Uys,** quoted by Kriel[131], defined the grease as that which was extracted in a Soxhlet using petroleum ether. He found an average grease content of 4.5% for summer hair and 5.8% for the winter hair, with a melting point of 39°C. He found the acid value to be 14.6 compared to a published value of 14. The unsaponifiable fraction was 46%.

Kriel[131] published Table 18 for the chemical constants for mohair grease.

TABLE 18[131]
CHEMICAL CONSTANTS FOR MOHAIR GREASE

	Value	Literature
Saponification Value	126-135	128
Acid Value	14.6	14.0
Iodine Value	14.8	36
Percentage Acids	54	55
Percentage Unsaponified Fraction	46	45
Ester Value	117	114

Kriel[131] also determined the cholesterol content of mohair grease and two of its fractions, namely the unsaponified fraction and the filtrate of the unsaponified fraction.

Tucker *et al*[691,992] gave the following comparative tables (Tables 19 to 21) based upon a limited number of samples.

TABLE 19[691]
THE ANALYSIS OF RAW WHOLE GOAT FLEECES

Sample No. and Type	Down (%)	Fibre Dia. (µm) Mean ± SD	Grease			
			Content (%)	Sap. Value	Iodine Value	Melt. Pt. (°C)
2-127, Aust. Cashmere	51	16.6 ± 2.4	1.7	153	15	34 - 38
2-024, Aust. Cashmere	18	17.0 ± 3.3	0.7	129	10	34 - 36
71, Chinese Cashmere[a]	70	16.4 ± 3.3	5.4	152	7	30 - 32
3-225, Aust. Cashmere/ Angora	56	16.4 ± 3.5	1.2	145	14	35 - 38
3-436, Aust. Cashmere/ Angora	76	15.6 ± 4.8	2.1	151	14	35 - 38
A39, Aust. Mohair	-	41.8 ± 10.6	1.2	162	15	35 - 37
Wool	-	-	5 - 25[b]	95 - 120[c]	15 - 30[c]	35 - 40[c]
South African Mohair[d]	-	-	5	128	36	-

[a] Yield determined by hand sorting, fibre dia. by projection microscope; other samples by AWTA (see text).

[b] M. Lipson and U.A.F. Black; [c] E.V. Truter; [d] D. Ilse.

TABLE 20[691]
THE ANALYSIS OF FIBRE FROM CASHMERE AND CASHMERE/ANGORA GOATS

Sample No. and Type	Yield[a] (%)	Fibre Dia. (μm) Mean ± SD	Moist.[c] (%)	Surface Grease[d] (%)	Water Solubles[d] (%)	Internal Lipids[e] (%)
2-012, Aust. Cash. Fleece	-	-	13.9	1.8	1.2	3.1
2-012, Down	19	15.6 ± 3.5[b]	13.6	2.6	0.9	1.1
2-012, Guard Hair	81	72.5 ± 28.0	13.5	1.0	0.3	4.8
3-436, Aust. Cash./Angora Fleece	-	-	13.2	2.8	0.6	3.2
3-436, Down	58	15.6 ± 4.8[b]	13.4	2.9	0.5	3.6
3-436, Guard Hair	42	39.6 ± 20.7	13.6	1.8	0.6	4.1
71, Chinese Cash. Fleece	-	-	12.9	5.0	3.0	1.8
71, Down	85	16.4 ± 3.3	13.3	3.2	3.8	0.7
71, Guard Hair	15	-	-	-	-	-
Chinese 1, Fleece	-	-	11.1	7.2	2.3	-
Chinese 1, Down	89	14.3 ± 2.7	-	-	-	2.3
Chinese 1, Guard Hair	11	64.4 ± 19.1	-	-	-	-
Chinese 2, Fleece	-	-	-	-	-	-
Chinese 2, Down	87	15.3 ± 3.0	12.7	2.0	1.5	2.1
Chinese 2, Guard Hair	13	49.3 ± 8.3	12.1	0.8	-	-
Wool	-	20	11.0 - 11.7	9.5 - 27.0	3.9 - 7.1	1.1 - 1.9

[a] Yield from hand sorting, expressed on clean dry mass basis.

[b] Dia. by FFDA. [c] Of clean cond. fibre. [d] Expressed as percentage of (clean, dry fibre + grease + water solubles). [e] Expressed as percentage of (clean, dry fibre + int. lipids).

TABLE 21[691]
UNSAPONIFIABLE AND TOTAL FATTY ACID CONTENTS OF THE GREASE SAMPLES

Sample No. and Type	Unsap. Content (%)	Total Fatty Acid (%)
2-012, Aust. Cash., Fleece	42	56
2-012, Down	47	53
2-012, Guard Hair	46	55
3-436, Aust. Cash./Angora Fleece	40	55
3-436, Down	41	55
3-436, Guard Hair	42	53
71, Chinese, Fleece	44	54
71, Down	47	52
Chinese 1, Down	51[a]	48
Wool[b]	45 - 50	50 - 55
Mohair[c]	45	55

[a] Cholesterol content 26.0%. [b] E.V. Truter. [c] D. Ilse.

Tucker *et al*[992] gave the following table (Table 22) of values for the free fatty acid composition of surface greases.

TABLE 22[992]
FREE FATTY ACID COMPOSITION OF SURFACE GREASES
(mg/g DRY MASS)

Sample	C10:0 RRT 0.18	C12:0 0.25	C14:0 0.44	C16:0 0.81	C18:0 1.18	C18:1 1.21	C18:2 1.32	C20:0 1.68	C22:0 2.50	Others
Wool(T62)	0.66	0.22	2.74	2.40	1.59	0.64	4.27	0.80	0.78	Many
Cash(8114)	-	0.18	0.48	2.26	2.04	1.58	1.30	0.78	2.84	C18:3 0.29 RRT 1.84 1.88
Cash/Ang(P3)	0.15	0.16	0.34	1.66	1.40	1.21	0.81	0.56	1.68	C18:3 0.26 RRT 1.84 1.56
Mohair(F)	0.24	-	1.97	6.9	3.42	3.04	2.72	0.91	2.08	RRT 0.54 5.5 RRT 0.94 5.7
Camel	0.25	0.38	1.23	4.26	3.76	1.35	0.67	0.59	0.44	RRT 0.37 1.98 RRT 1.84 1.73 RRT 1.92 1.93
Yak	0.98	1.21	6.34	5.68	2.79	3.30	13.25	0.46	-	RRT 1.84 29.5 C22:1 3.46

RRT Retention time rel. to C17:0

Tucker *et al*[992] also gave the following tables of values (Tables 23 and 24) for the volatile and non-volatile fatty acids from the fleeces of Australian goats and sheep. They reported that the saponification values (SV) of the grease from the goat fleeces range from 129 - 153 and are significantly higher than that from wool, suggesting that the former probably contain lower molecular weight material than the esters in the latter. The iodine values (IV) for cashmere, cashgora and Australian mohair fleeces were lower than those for wool and South African mohair[992].

TABLE 23[992]
VOLATILE FATTY ACIDS* FROM THE FLEECES OF AUSTRALIAN GOATS
(μg/g DRY FIBRE)

Table 4: Volatile Fatty Acids* From the Fleeces of Australian Goats (μg/g Dry Fibre)

Acid	Mohair		Cashmere		
	A39(B)	5097(B)	5291(B)	5113(D)	5712(D)
Ethanoic	11	13	12	16	14
Propanoic	4	4	2	8	7
2-Mepropanoic	15	21	27	298	234
Butanoic	3	5	4	10	12
2-MeButanoic	16	32	35	136	127
4-Mepentanoic	-	-	-	1	2
Hexanoic	2	2	1	2	1
Heptanoic	3	2	2	3	3
Octanoic	2	6	3	2	1
4-Etoctanoic	9	3	3	-	-
Nonanoic	2	3	4	-	3
Decanoic	7	5	18	-	-

* Diethyl ether extract: grease saponfied and acids determined as free acids.
B buck; D doe

TABLE 24[992]
NON-VOLATILE FATTY ACIDS* FROM THE FLEECES OF AUSTRALIAN GOATS AND SHEEP (μg/g DRY FIBRE)

Acid	Mohair		Cashmere			Wool#
	A39(B)	5097(B)	5291(B)	5113(D)	5712(D)	
Dodecanoic	-	-	-	3	3	40
Tridecanoic	-	1	1	2	-	80
Tetradecanoic	10	12	14	12	6	220
12-MeTetradec	15	35	46	48	11	304
Pentadecanoic	13	3	4	-	-	87
14-MePentadecan	2	-	1	2	-	409
Hexadecanoic	22	27	33	48	19	245
14-MeHexadecan	16	32	44	48	8	280
Octadecanoic	9	9	12	28	11	84
9-Octadecenoic	3	4	5	2	6	47
17-MeOctadecan	11	17	25	41	6	-
9,12-Octadecadien	3	4	5	4	6	231
18-MeNonadecan	-	-	-	-	-	318
Eicosanoic	4	2	5	8	2	30
18-MeEicosan	-	-	-	-	-	320
20-MeHeneicosan	4	7	-	-	-	141
Docosanoic	5	4	9	45	11	17
13-Docosanoic	-	-	2	21	-	-

* Chloroform/methanol(2:1) extract; grease saponified and acids deter.as methyl esters; B buck; D doe; # sex unknown

OBJECTIVE MEASUREMENT

6.1 General

The textile processing performance, applications and general quality, and *therefore value and price, of mohair are* largely determined by the characteristics of the raw (greasy) mohair. It is therefore hardly surprising that considerable effort has been directed over the years towards the objective (ie instrument) measurement of these characteristics, as opposed to the subjective techniques traditionally used. Today, characteristics, such as fibre diameter, yield etc., can be, and are, measured objectively with high accuracy.

Properties that need ultimately to be measured to completely characterise *greasy mohair include the following:*

1) Fibre Diameter and its Distribution.
2) Mohair Yield.
3) Staple Length and Strength.
4) Vegetable Matter Content and Type.
5) Inorganic Matter Content.
6) Colour.
7) Lustre.
8) Medullation/Kemp.
9) Style/Character.

Yield, for example, is difficult to assess accurately visually to a level better than 2 to 3%[1016] and the rapid objective measurement of this important property, particularly from a price point of view, is of considerable economic importance.

Douglas[890] *discussed the advantages* of Objective Measurement of mohair. He stated that the mohair top must achieve strict specifications to satisfy the spinning requirements, these include requirements for:

- Quantity of Top
- Mean Fibre Diameter
- Mean Fibre Length
- Distribution (CV%) of Fibre Length
- *Max % Short Fibres* less than 30mm
- Max % Dark Fibre Content
- Max % Vegetable Matter Speck Contamination
- Max % Entanglement (Neps)
- Max Fatty Matter Content
- Moisture Regain, and specifically for mohair:
- Max % kemp content.

In addition, some spinners may have specifications which include:[890]

- Colour
- Distribution (CV%) of Fibre Diameter
- Bundle Strength.

These specifications, some with very tight tolerances, enable the spinner to be confident that on high speed automatic spinning machinery, the fibre can be processed efficiently. If specifications are incorrect, quality and productivity *fail*[890]. **Douglas**[890] *also stated that the* impact of synthetic fibres in the textile industry necessitated that growers and users of natural fibres introduce objective specification to define their product, synthetic fibres being manufactured to tight tolerances and such that they easily meet rigid specifications. He concluded[890] that unless wool, cotton, mohair and cashmere are specified they are severely disadvantaged from a processing point of view. He stressed that the variability of natural products, such as mohair, necessitated proper (representative) sampling and adequate testing in order to obtain an accurate and reliable result. He repeated the importance of clean yield, average fineness (diameter) and kemp content in terms of mohair quality and value, with length, strength, colour and lustre being of lesser importance. AWTA Ltd commenced trials in mohair objective measurement in Australia in 1981, with the Angora Breed Society, and provide a core testing service for brokers and other fibre marketing organisations and a fleece measuring service for growers and breeders[890]. Most of the sampling and testing methods are based upon those in use for wool.

Mohair Base (ie the amount of clean dry fibre, free from all impurities, expressed as a percentage of the greasy fibre mass) is converted into the IWTO scoured yield basis[890]. This relates the tested yield to normal commercial yields for scouring greasy mohair. This yield is calculated from the Mohair Base to include all vegetable matter, standard residuals of grease and dirt (which would normally be retained in commercial scouring), and allows for moisture regain of 17% (yields of over 100% are therefore possible). In addition to the foregoing, mid-side fleece samples, submitted by breeders, are washed and dried and a similar washing yield is calculated[890]. The AWTA uses the airflow for measuring average fibre diameter and the FDA when the fibre diameter distribution is also required.

Gee[493] reported on the objective measurement of mohair imported into South Africa during 1978. He gave the following table (Table 25) summarising his results:

TABLE 25[493]
MEAN VALUES FOR EACH TYPE AND VARIATION (σ) BETWEEN LOTS

Type	Staple Length (mm)		Yield (%)		Vegetable (%)		Fineness (μm)		Kemp (%) *	
	mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ
BKL	136	7	90,4	2,7	2,2	1,5	25,6	0,8	3,9	1,5
BKS	125	9	92,0	0,8	1,4	0,9	25,1	1,5	3,1	2,4
BFM 1	174	—	90,9		1,1					
2	158	—	88,4	2,6	3,0	1,0	27,6	1,8	3,3	1,7
3	131	8	91,1		1,8					
BML	156	26	91,9	2,6	1,4	0,9	31,2	3,1	4,2	2,6
BMS	130	14	91,4	1,9	2,1	1,1	29,9	3,0	4,3	2,6
BSL	163	8	92,0	3,7	1,5	0,9	30,6	1,0	4,7	1,7
BSS	137	11	92,6	1,4	1,5	1,4	32,6	3,7	2,9	2,3
BST	142	15	87,1	4,3	2,3	1,3	29,5	2,6	6,6	3,3
BSDY	134	12	87,1	2,8	4,8	2,7	28,2	2,0	8,2	4,6
BCM	125	14	90,0	3,4	2,4	1,6	28,2	2,4	9,7	4,9
BLOX	131	14	81,3	5,6	4,1	2,2	30,4	2,1	9,0	5,0
BGREY	130	13	88,5	2,7	2,8	2,0	29,2	1,2	7,3	4,0

*Shirley Analyser Test

The statistical distribution of wool and mohair length and fineness has been reported by **Marsal**[701].

Bhalla *et al*[1022] reported on the physical and chemical properties of Indian crossbred adult mohair. They found an average fibre diameter variability along mohair fibres (CV_W) to be between 7 and 8%, compared to 11 to 17% for the wools they tested. They reported fibre length variabilities ranging from 15 to 45%, with three out of the four types of mohair having a CV 15, 21, and 25%. They found the Wax (grease) content of their mohair to vary from 1.8 to 5.1%, Suint from 3.3 to 6.2%, Vegetable matter from 0 6 to 2.5%, Ash content from 0.9 to 1.5% and alcohol extractable matter from 0.7 to 1.8%.

6.2 Sampling for Objective Measurement

Lineberry *et al*[345] reported on the core-sampling of bags of Texas grease mohair matchings and gave the following within (w) and between (b) bag standard deviations (σ) for fibre diameter and yield:

Clean Fibre Yield	Average Fibre Diameter
σw 1.56%	σw 1.35μm
σb 2.21%	σb 2.83μm

It was calculated that a sampling precision of 1.0% yield of clean fibre could be achieved by taking 1 core from each of 24 randomly selected bags (from a consignment of 100 bags), if two cores are taken per bale then only 20 bales need to be sampled. **Gee**[738,804] investigated the effect of taking different sizes (12 and 18mm) and numbers of cores from mohair bales on the top fibre length distribution. He concluded that, up to about 50g of core material (10 cores) from a bale could be regarded acceptable but not 250g. The 50g of core, could be expected to lead to an increase of 0,4% in short fibre content in the top and a decrease of 1mm in Hauteur and tail length. He concluded that the taking of up to 8 cores on a bale should have almost a negligible effect on the fibre length distribution, including the short fibre content.

CHAPTER 7

FINENESS AND CROSS-SECTION RELATED PROPERTIES

7.1 General

There can be little doubt that mohair fineness (diameter) is one of its most important characteristics from the point of view of price and textile application and performance, with a 1μm change in diameter having a significant effect on price. It is therefore not surprising that fibre diameter, which can be measured by airflow, projection microscope, FDA, OFDA or LaserScan, is generally the first objectively measured mohair characteristic. Mean fibre diameter is the parameter most generally measured and reported, although the distribution of fibre diameter, in terms of CV and coarse fibres, is also regarded as being of textile significance. Mohair fibres tend to be more even in diameter along their lengths than wool, although certain lustrous wools are also even in diameter (the CV of fibre diameter within a lock is about 17% for mohair(98)). A major step forward in improving and standardising the interlaboratory measurement of mohair fibre fineness occurred upon the introduction of the Mohairlabs International Round Trials and associated issuing of Mohairlabs stamps (see "MOHAIRLABS").

Uys(112) found that the Airflow method could be applied successfully to the measurement of mohair fibre diameter provided a specimen mass of 3.5g (as opposed to the 2.5g for wool) was used, with kemp and fibre length, within the ranges covered, having little effect on the readings obtained. **Slinger and Robie**(243) subsequently showed how the airflow method for mohair could be improved by precise control of sample preparation and using a modified test cell having a greater height clearance in the test chamber (32mm as opposed to 16mm)(243). **Ray** *et al*(346) found a correlation of 0.98 between Port-Ar airflow and projection microscope measurement of fibre diameter. **Hadwich**(334) compared the airflow and projection microscope methods of measuring the fineness of mohair top, concluding that the latter was superior to the unmodified airflow method. **Schenek**(856) reported the results of Bremen Round Trials on the fineness of mohair tops, as measured by projection microscope and airflow and concluded that the accuracy of the results had improved significantly since 1982. **Blakeman** *et al*(837) described a computer supported sonic digitizer technique for measuring the medullation of mohair. **Ryder**(786) discussed the Bit-pad measurement of fibre diameter and medullation.

Smuts *et al*(698) investigated the effects of CV of diameter and degree of medullation on the airflow measurements of mohair diameter. They found that CV of diameter had a statistically significant effect on the air-flow reading, the effect, however, being only about half that predicted by theory. Compared to samples having a CV of about 27%, a change of 5% (absolute) in the CV of diameter generally resulted in a change of less than 0.5μm in the air-flow measured diameter. Contrary to *a priori* considerations, the degree of medullation had no apparent effect on air-flow measured diameter within the fairly wide range of levels (≈0.5 to 6% area medullation) covered. Their investigation showed that, within the ranges covered, the air-flow estimated fibre diameter is a good measure of the projection microscope mean diameter, the effects of CV of diameter and medullation, particularly the latter, being small(698).

Hunter *et al*(707) studied the projection microscope measured diameter and variation in diameter of some 852 samples of raw and scoured mohair and 380 mohair tops. They found that, although standard deviation tends to increase with increasing mean fibre diameter, the relationship was a tenuous one and the scatter large. For CV of fibre diameter, the relationship was even less precise, since the scatter was larger, there being a tendency for CV to decrease as mean fibre diameter increased up to a mean fibre diameter of somewhere around 35μm after which the reverse occurred. For most practical purposes, however, the CV of diameter could be regarded as independent of mean fibre diameter, with an average value of approximately 27%, the standard deviation of the CV being 2.9%. Some 95% of the CV values lay between approximately 23 and 32%. The average standard deviation of fibre diameter for the samples was 8.7μm, with more than 95% of the values lying between 6 and 12μm. They gave the following table (Table 26) of "average" (typical values) for CV of fibre diameter.

TABLE 26[707]
"AVERAGE" (TYPICAL) VALUES OF CV OF FIBRE DIAMETER CORRESPONDING TO DIFFERENT MEAN FIBRE DIAMETERS

Mean Fibre Diameter (μm)	CV of Fibre Diameter (%)
25	30
30	27
35	26
40	27
45	29

Turpie and co-workers[942,943,944,1026,1090] reported on the calibration and application of the FDA200 for the rapid measurement of mohair fibre diameter and its distribution. It was concluded that, with the ranges covered, kemp level had little effect on the relationship between FDA, projection microscope and airflow diameter values, contributing only about 0.2% towards the total fit of some 98%. They also concluded that the FDA represented a reliable method for measuring mohair diameter, and a new cubic calibration procedure was proposed[944]. **Turpie** *et al*[1090] reported on differences between the calibrations for wool and mohair on the OFDA and FDA200, **Blankenburg** *et al*[1085] ascribing this to interaction between crimpiness and ellipticity, with snippet length also playing a role. **Blankenburg** *et al*[1085] investigated the correlation of the fibre ellipticity (contour ratio), snippet length and embedding medium with the mean fibre diameter (projection microscope) of mohair and wool, finding no correlation in the case of mohair. The ellipticity (ratio of major to minor axis) of the 8 IMA mohair calibration tops varied from 1.163 to 1.282, with a mean of 1.223. Their results appeared to explain the problems encountered by **Turpie** *et al*[1090] when they attempted to measure wool tops by means of an OFDA calibrated using mohair, **Turpie** *et al*[1090] finding that different calibrations are required for mohair and wool on both the FDA200 and the OFDA. The FDA system is applied in South Africa for the routine measurement of fibre diameter and distribution of greasy mohair cores[1008].

Various ASTM and USDA test methods and standards for the fineness of mohair (greasy and top) and the assignment of Grade have been published over the years[308,381,382,429,528, 584,832]. The fineness measurement of some US commercial mohair top is given in Table 27[34].

TABLE 27[34]
FINENESS MEASUREMENTS OF COMMERCIAL MOHAIR TOPS

Grades		*Average (microns)*	*Deviation (microns)*	*Coefficient of Variation (per cent)*	*Standard Error (microns)*	*Average Range (microns)*	*Dispersion Range (microns)*
Super kid	Kid	25.7	6.30	24.5	0.19	25.2 to 26.3	10 to 45
40's	Kid	27.0	5.29	19.1	0.17	26.5 to 27.5	10 to 45
36's	Kid	28.7	6.23	21.7	0.19	28.1 to 29.2	10 to 50
32's	Kid	30.0	6.89	22.9	0.22	29.4 to 30.7	10 to 50
28's	First	32.2	7.81	20.5	0.24	31.5 to 32.9	10 to 55
26's	First	34.0	7.99	23.5	0.25	33.3 to 34.8	15 to 55
24's	First	35.7	9.25	25.7	0.29	34.8 to 36.5	15 to 60
Low—Second		41.4	10.60	25.6	0.30	40.5 to 42.3	20 to 70

Phan *et al*[895] (quoted in Ref. [978]) gave the following comparative table of SEM measured fibre properties (Table 28[978]).

TABLE 28[978]*
DATA OF SPECIALITY FIBRES EXAMINED BY MEANS OF SEM

Fibre type	Number of samples	Number of checked fibres	$\bar{d}$ / µm	s / µm	CV / %	mean scale frequency ~/100µm
Vicuna	1	200	10.4	2.2	22	11
Angora rabbit	20	2100	12.3	5.4	44	not measured
Cashmere	65	6525	14.1	3.5	25	6 - 8
Iranian cashmere	12	1260	16.5	4.4	26	6 - 8
Cashgora	2	400	16.6	4.2	25	6 - 7
Camel hair	31	3255	18.9	7.0	37	6 - 8
Yak hair	10	1050	18.8	6.4	34	9 - 10
Alpaca	32	3360	26.1	8.9	34	10
Llama	34	3570	27.5	10.4	36	10
Mohair	63	6615	31.9	9.5	30	6 - 7

$\bar{d}$: mean diameter
s : standard deviation
CV : coefficient of variation

Kim-Ho PHAN et al. SFS '87 — Table 6 : Data of specialty fibres examined by means of SEM — DWI

*From Phan *et al*[895]

Phan *et al*[895] also gave another comparative figure (Fig. 2).

Kritzinger[1066] discussed the variation in diameter within a mohair fleece and the importance of reducing this variability, particularly with respect to coarse fibres, to a minimum. He found a correlation of 0.84 between the standard deviation of fibre diameter at the age of 8 months (just before second shearing) and that at 14 months of age (just before the third shearing). Standard deviation was also related to mean fibre diameter.

Van der Westhuysen[538] reported on fibre diameter distribution as affected by mohair age and type (see Fig. 12a)[538].

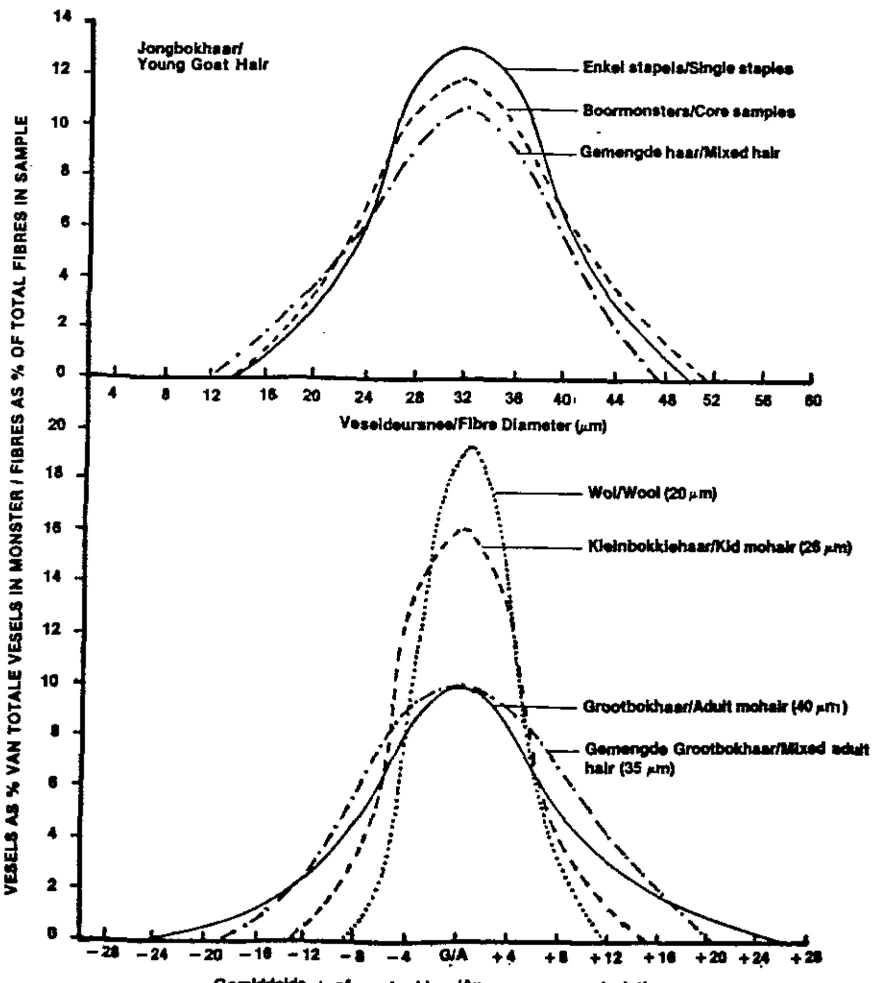

Fig. 12a Variation in Fibre Diameter Influenced by Age and Type[538].

7.2 Vibroscope Measurement of Mohair Fineness

Barella and Vigo[407,415,436] found differences between wool and mohair in terms of inter- and intra-fibre linear density variability (inversions) as measured by means of a vibroscope. The inter- and intra-fibre variability in linear density as well as the percentage of fibres exhibiting inversions of linear density were generally higher in wool than in mohair. This fact was used in the development if empirical formulae which could possibly have some potential in the differentiation of wool and mohair in homogeneous fibre assemblies. **Hunter and Smuts**[453] showed that vibroscope linear density for mohair agreed well with the values calculated from fibre diameter and density, the latter generally being slightly higher than the former, possibly due to the slightly non-circular nature of the fibres.

7.3 Fibre Cross-sectional Shape

Mohair is generally practically circular, with the ratio between the major and minor diameters generally 1.12 or lower[34] (usually 1.0 to 1.1[18], and rarely exceeding 1.2[202]), with that of wool often greater than 1.2[18], lower grades, grades of mohair fibres are stated to be generally less circular than the better grades[36]. **Klenk**[45] compared the cross-sectional shape of various animal fibres, including mohair. Many fibres show black dots or little circles under the microscope, which are caused by airfilled pockets or vacuoles[34,202].

Fouda *et al*[954] used the diffraction from a He-Ne laser beam to measure the dimensional parameters, transverse sectional shape and area of mohair fibres. Multiple beams were used to measure the refractive indices and birefringence of mohair. They found that the shape of the mohair fibres was predominantly elliptical.

7.4 Fineness Relationship of Grease Mohair, Card Sliver and Top

Keller and Pohle *et al*[241,306] investigated the fineness relationship of grease mohair, card sliver and top, finding the average fibre diameter of the grease mohair about 0.6μm finer than that of the top, the card sliver fineness was *on average 0.4μm finer than that of the top.* They derived the following two empirical relationships:

Grease Mohair Diameter (μm) = -0.58 + 0.9996 Top Diameter
$n = 69$; $r = 0.98$

Card Sliver Diameter (μm) = -0.24 + 0.99601 Top Diameter
$n = 110$; $r = 0.99$

STAPLE LENGTH AND STRENGTH

Turpie and co-workers(680,704,705,751,757,815) reported results for the staple length, strength and profile of mohair as measured automatically by means of the SAWTRI Automatic Staple Length/Strength tester. Using the staple cross-sectional profile (taper diagrams) and a technique of best fit trapeziums, they showed that the staple profile and length distribution could be used to predict the fibre length distribution of the staple and the top. There was a reasonably good correlation between mohair staple length measured manually and that measured by an automatic staple length/strength tester. An attempt was also made to relate staple profile to style and character. Figs 13 to 15 illustrate some of the results obtained by **Turpie and co-workers.**

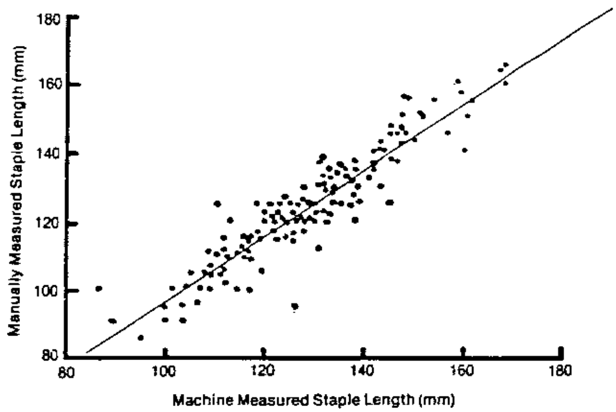

Fig. 13 Machine Measured versus Manually Measured Staple Length for Mohair(704).

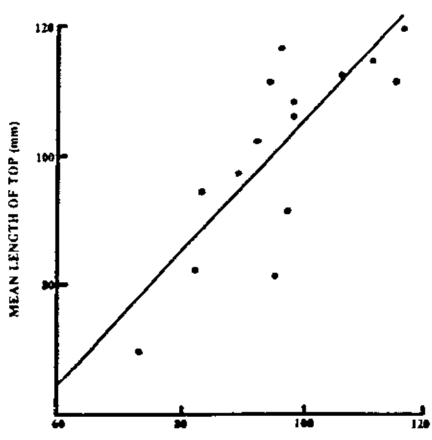

Fig. 14 Mean Length of Top versus Mean Length Derived from Greasy Staple Diagram(705).

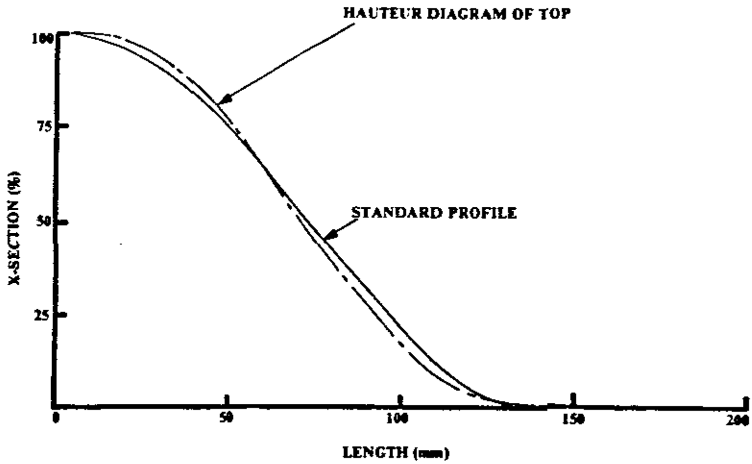

Fig. 15 "Standardised" Grand Mean Profile for a Lot of Kid Mohair with Hauteur Diagram of the Top Produced from it Superimposed[(705)].

Pohle *et al*[(306)] found that average unstretched staple length of mohair was much closer to the top fibre length than was the case for the stretched staple length. The average fibre length of mohair is reported to be only 60% of the lock length, with a coefficient of variation of 40 to 70% compared to 20 to 25% for wool[(533)].

Turpie[(705)] applied the SAWTRI staple length/strength tester to mohair, illustrating the useful information it provided in terms of mohair staple profile, length and strength, fibre length distribution and the production of the mohair top length distribution, as well as possibly quantifying differences in mohair style and character (see Fig. 16).

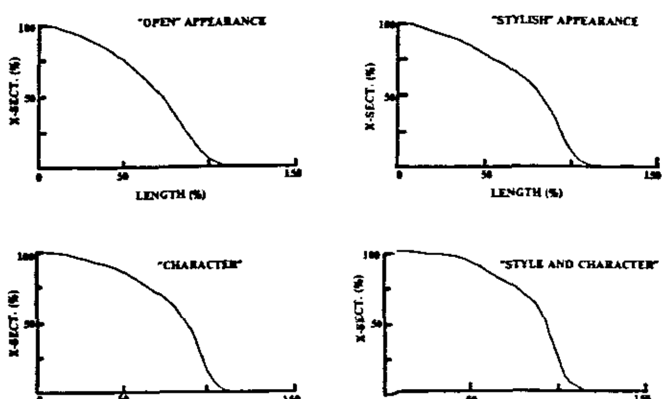

Fig. 16 "Standardised" Grand Mean Profiles Obtained from Various Styles of Adult Mohair[(705)].

QUALITY AND RELATED CHARACTERISTICS

9.1 General

The quality of mohair is described as a combination of style and character, freedom from kemp, lustre, handle, yolk and uniformity of length and fineness[1011]. The presence of kemp is often the most undesirable quality characteristic of mohair. Mohair of good lustre and handle, solid staple, uniform in length and practically free from kemp is defined as mohair of good quality[99]. Handle is largely determined by fineness, although a soft natural yolk and oleaginous dips also improve softness of handle[99] (dipping before shearing (at least 3 days in summer and 7 to 10 days in winter) can be applied to mohair so as to close the mohair staple thereby improving the style and to give the mohair a kinder handle and better lustre)[867].

Mohair characteristics of economic importance are[599,728] fineness (fibre diameter), length, style and character, contamination (kemp, coloured fibres and vegetable matter), and clean yield and uniformity in general. Based upon mohair processing and price (and end-use), fibre diameter is the most important parameter and kemp is generally next in importance[728,894], with length having a smaller, though still important, effect on price and processing than diameter, provided the mohair is not shorn shorter than about 75mm, ie not less than about 4 months growth (good staple length growth is considered to be at least 25mm per month [533], the average fibre length being only about 60% of the lock (staple) length, with a coefficient of variation of fibre length of 40 to 70%, compared to about 20 to 25% for wool)[533].

Van Wyk *et al*[64] correlated price differences with differences in clean yield, fineness and fineness distribution, weathering and length. According to **Van der Westhuysen**[566] quoted by **McGregor**[784], mohair price (averaged over a ten year period) decreased by about 5% for each 1μm increase in fibre diameter, stabilising at about 34μm with a price of about 55% of the maximum value (paid for 26μm mohair). Price was less affected by length, the maximum price being paid for about a 15cm staple length. Since there appears to be no benefit in production efficiency from shearing more than twice per year, there is no economic justification for shearing hair of under 75mm[728].

Major burr and grass seed contaminants of mohair results in serious price penalties (**McGregor**[1015]) and so does kemp levels, vegetable fault mohair fetching about half the average price of other mohair types[1015]. Any undesirable contaminant, which will either affect the quality of the final product or will have to be removed, decreases the economic value of the mohair[728]. Coloured (eg black or red) fibres may be present and could affect the finished cloth, particularly if light shades are dyed, and thereby the value of the mohair. Burrs or excessive vegetable matter in the fleece also have to be removed[728]. Urine and certain types of soil and vegetable matter contain substances which stain mohair permanently[728]. These affect the dyeing and value of the mohair and the quality of the final product. Precautions must be taken to limit such stains, particularly urine stains[728]. Clean yield (ie the percentage of actual fibre plus commercially allowed moisture content in raw mohair) generally varies between about 80 and 90% in most fleece classes, but may be as low as 60% in some outsorts, such as lox, the remaining portion being made up of grease, dirt, dust and sweat.

Style and character are judged subjectively, high quality style being described as solid-twisted ringlets (staples or locks), while character is described as the waviness or crimp shown in the staple[533,728]. Style without character or vice versa, is undesirable and a good balance between these two characteristics is considered to be of paramount importance[533,728].

McGregor[1015] gave the following table summarising the effects of various mohair quality characteristics on price and processing.

TABLE 29[1015]
THE INFLUENCE OF VARIOUS CHARACTERISTICS OF MOHAIR ON BUYERS LEVEL OF DISCOUNT AND ON THE LEVEL OF PROCESSING PERFORMANCE OF MOHAIR

Character	Range of Buyer Discounts	Effects on Processing
Fibre Diameter	0-45%	50-300%
Length	0-18%	25-40%
Kemp Content	0-20%	50-100%
Vegetable Fault	0-50%	no data
Style and Character	no data	5-10%
Lustre	no data	no data

9.2 Mohair Classing and Quality

The importance of good classing of mohair has been stressed by **Venter**[99], and **Marwood**[893] also discussed the merits of good classing (shed or store) on maximising profits. The simplest description of good classing has been given[533, 761] as uniformity within each class of length, fineness, style and character and degree of contamination (kemp, vegetable matter and stain). Uniformity of the mohair within the bale or bag is very important[99]. An important objective of classing is to achieve uniformity of "quality", particularly fineness (diameter), and classing standards and regulations are laid down and continuously updated in most of the important mohair producing countries, and particularly in South Africa. Classing must separate the different parts of the fleece which differ in fineness, colour (stain) etc. Fibre diameter may vary markedly within the same fleece, with mohair from the neck and britches often coarser than that from the rest of the fleece. Even within a staple, the fibre diameter varies considerably[728] between fibres, mohair fibres generally are finer towards the tips, due to the fact that mohair fibres become coarser as the goat ages (up to the age of about eight years[13,72]). **Venter**[72] found that the longest and coarsest fibres occurred around the neck, particularly below it, and should be kept apart (classed separately), while the hair on the back and rump, which is generally shorter, finer, more kempy, wasty and weathered, should also be classed separately. The hair on the shoulder, side and thigh should be grouped together, generally being "average" in terms of length and diameter but has the best quality hair in the fleece[72] (the belly, if not stained or seedy, could possibly also be classed into this group).

Hobson[867] discussed the classing of Cape Mohair, stating that classing *aimed to achieve uniformity of fineness and uniformity of length, and uniform*ity of style and character and quality (standard of breeding and general appearance of the mohair), kempy hair being kept apart and packed separately. The fleeces are skirted, mohair containing kemp or seed is removed, so too the britch ends and often also the neck (unless it is very light and attractive in appearance), with the back being removed if it is "wasty" or "spongy".

Style, character and lustre are considered important quality characteristics, not only because of their aesthetic appeal but also because they can be related to the weathering of the hair on the goat[1010] (and to various other important characteristics). Style and character are discussed in more detail in the next section (see also Ref. [637]).

9.3 Style and Character

"Style and Character", as a "composite measure" of mohair quality, is considered difficult to define precisely[1011] and the role of style and character in *textile processing behaviour and product quality remains to be established.* Style refers to the twist and spiral formation (ie type of ringlets) of the mohair fibres in the staple (and also the "brightness and bloom" of the fibre) or strand[1011], while character refers to the wave or crimp that appears in the staple (ie its waviness or crimp). In essence, therefore, "style" refers to the twist (curls) in the staple, while "character" refers to the wave (or crimp) frequency[684], with the presence of kemp also playing a rôle.

Essentially two types of locks (staples) are recognised viz "ringlet" (tight lock) and "non-ringlet" (mostly flat lock type), although there are basically three primary types of mohair fleeces based upon the formation of the lock, viz. the tight lock type (solid twisted ringlet), the flat lock type and the fluffy or open type. Angora breeders generally prefer a well developed tight lock, or ringlet, although some prefer the flat lock which is also associated with a very desirable type of mohair[34,977]. The tight lock type has ringlets (curls or twists in the staple) throughout almost its entire length, and is usually associated with fineness of *fleece*[34,977]*, while the flat lock type is usually wavy, has large crimp* (waves), an absence of ringlets and forms a more "bulky" fleece. This type is usually associated with heavy and coarser fleeces, and a satisfactory quality of hair. The fluffy or open fleece type usually lacks in a distinct style and character, and probably stands lowest in character, and is objectionable on the farm since it is easily broken and is torn out to a great extent by the brush. Flat lock type goats generally produce more greasy mohair but of a lower yield, than tightlock ("ringlet") types and tend to be coarser. The different lock types are not considered to be identifiable after scouring. Ringlet types are also thought to be associated with more uniform staple length[965].

High quality style in mohair may be described as solid, twisted ringlets (staples), a balance between style and character being required[533,728]. Good style and character reflect a healthy, well protected fleece[728]. A good balance between style and character is reflected in an evenly crimped staple, while the fibres in the staple are symmetrically and spirally twisted forwards and backwards, ending in a blunt point that turns back[1010]. An excess or absence of one of these qualities will result in undesirable staples[1010]. The pitch of the spiral of the ringlets varies from about 4 to about 8 per 10cm[6]. Ringlet perfection is generally associated with fineness[6], ringlet frequency (density of spiral turns) being correlated with fineness of the fibres contained in the ringlet[6]. **Duerden and Spencer**[6] stated that a distinct well-formed ringlet is only produced where the fibres are fine and uniform, with the turns closer and more per unit length as the fibres become finer. Style and character can change as the goat ages, there being some link between fineness and quality, the younger the goat the better the style and character[99] tending to be (well grown Kids and Young Goats hair, with super style and character, often not being as fine as it appears to be)[99]. **Badenhorst**[1063] reported a poor correlation between mohair style at the age of 10 months and that at the age of 18 months, that between the ages of 14 months and 18 months being higher. Style and character had a correlation coefficient of 0.58. The flat lock type tends to remain that, over the age of the goat (except as young Kids), whereas the ringlet type is not always uniform or permanent, ringlet "type" on Kids can revert to another lock type later, it could also change to another lock type over the posterior portion of the body[965]. Recently, **Badenhorst** *et al*[1058] found that nutrition affected all mohair quality characteristics, with the exception of style and evenness of fleece, improved nutrition increasing kemp, fibre diameter (31 to 40μm), fleece mass (2.1 to 3.7 kg), "fleece density" and character, style and character being influenced differently by nutrition.

Style and character, in South Africa, is judged according to five classes that vary in quality and are described in the following descending order: Super, Good, Plus Average, Average and Poor. Results by **Turpie**[705] indicated that style and character may be reflected in the uniformity of the mohair staple cross-section (Fig. 17).

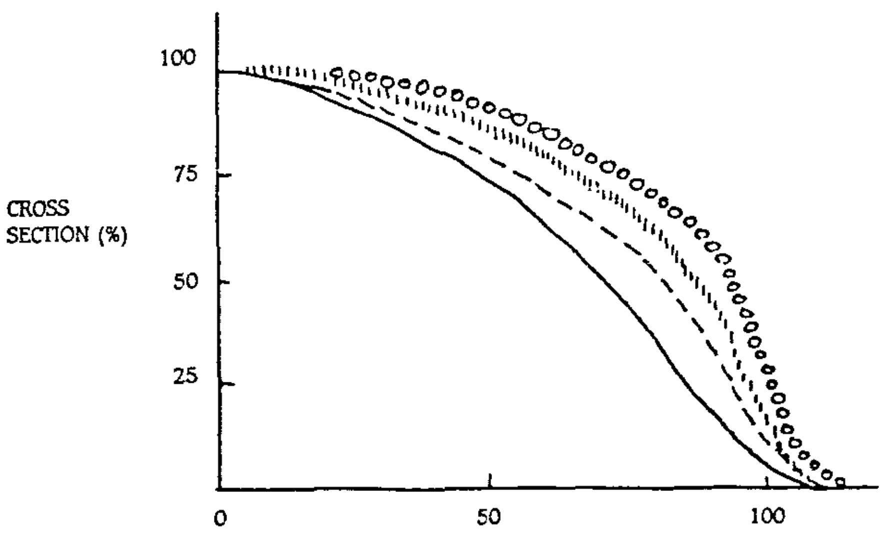

Fig. 17 Standard Mean Cross Section Profiles from 'Open Mohair' (—), Stylish Mohair (--). Mohair with Character (////) and Mohair with 'Style and Character' (ooo)[705,1015].

9.4 **Grades****

Much of the information in this section is merely of historical interest, since the trend is today to categorise (grade) mohair on the basis of objectively measured characteristics, notably diameter (fineness). The grades of mohair vary in different countries(36). In general the best grades of mohair are from Kids under six months old (ie first shearing). Some individual fibres in this grade are as fine as 6 to 10μm in diameter(36). **Venter**(72) found large variations in fibre diameter within a grade, resulting in considerable over-lapping between the grades. A marked improvement occurred in this respect, once the mohair was classified into trade types. According to his work, **Venter**(72) suggested the following fineness limits for the different mohair trade types (Table 30).

TABLE 30(72)

PROPOSED LIMITS OF FINENESS FOR MOHAIR TRADE TYPES

Type*	Limits of Fineness (μm)
8	≤ 27.6
7	27.7–30.2
6	30.3–33.1
5	33.2–36.2
4	36.3–39.7
3	39.8–43.2
2	≥ 43.3

***Bradford Spinning Count.**

He stated that for Trade Type 1, "character" and "style" were the decisive factors while trade Types 9 and 10 could perhaps be grouped with Trade Type 8. There was some indication, that, for the same greasy mohair Trade Type (typed by the broker), tops (typed by the manufacturer) generally tended to be much finer than the unprocessed mohair. This was considered a tentative result, however, as only one manufacturer was involved.

Venter(72) found a linear relationship between Trade Type and the logarithm of fibre diameter.

According to **Uys**(104), the South African type SFK of that time, would fall into Bradford counts 8 or 7, types SK and K into 7 or 6, types SYG and YG into 5, types SFH into 4, types SH and H about 3 and types MH and R about 2. **Uys** related mohair quality to the description of the goat as follows:

Kids (first and second shearing): 6's to 8's (first shearing Kid is generally the finest at 8's or even finer).

Young Goats (third shearing) : 5's

Young Ewes and Kapaters (fourth shearing) : 4's

Old Ewes and Kapaters (fifth shearing) : 3's

Rams, Older Ewes and Kapaters : 2's

Very Strong : 1's

See also **"SPINNING LIMITS AND QUALITY"

Nowadays the fineness (in micron), rather than the age of the goat at shearing, determines the fineness classes[260].

The USDA has also given recommendations concerning the sampling and fineness testing of mohair at various stages [429]. Various ASTM Standard specifications for the fineness of wool and mohair and the assignment of grade in the USA, have been given[675,694]. The following table (Table 31) represents the official standards of the United States for Grades (based upon average fibre diameter and variation in fibre diameter) of Grease Mohair (effective 1 August, 1971) [381,429,830]. It also covers mohair that is in the pulled, washed or scoured state or in the form of card sliver[381, 429].

TABLE 31[429,1057]
SPECIFICATIONS FOR THE OFFICIAL GRADES OF GREASE MOHAIR

Grade	Range for Average Fiber Diameter, µm	Standard Deviation, max, µm
Finer than 40s	under 23.01	7.2
40s	23.01 to 25.00	7.6
36s	25.01 to 27.00	8.0
32s	27.01 to 29.00	8.4
30s	29.01 to 31.00	8.8
28s	31.01 to 33.00	9.2
26s	33.01 to 35.00	9.6
24s	35.01 to 37.00	10.0
22s	37.01 to 39.00	10.5
20s	39.01 to 41.00	11.0
18s	41.01 to 43.00	11.5
Coarser than 18s	over 43.01	

[A] The specifications in this table conform to the Official Standards of the United States for Grades of Grease Mohair as promulgated by the U.S. Department of Agriculture, effective Aug. 1, 1971.

Table 32 represents the US grades (based upon average fibre diameter and variation in fibre diameter) for mohair top, yarns and fabrics of the worsted type[381,429,831,1091]. Grade must not be confused with "quality", such as the Bradford "Quality".

TABLE 32[429]
SPECIFICATIONS FOR THE OFFICIAL GRADES OF MOHAIR TOP

Grade	Fineness Range, µm	Fiber Diameter Distribution, %						
		30 µm and Under, min	40 µm and Under, min	50 µm and Under, min	30.1 µm and Over, max	40.1 µm and Over, max	50.1 µm and Over, max	60.1 µm and Over, max
Finer than 40s	under 23.55	80	...	...	20	1	...	...
40s	23.55–25.54	74	...	...	26	4	...	...
36s	25.55–27.54	67	...	...	33	6	...	...
32s	27.55–29.54	57	...	...	43	8	...	...
30s	29.55–31.54	47	...	...	53	13	...	...
28s	31.55–33.54	...	80	...	...	20	3	...
26s	33.55–35.54	...	73	...	...	27	5	...
24s	35.55–37.54	...	64	...	...	36	8	...
22s	37.55–39.54	...	56	...	...	44	13	...
20s	39.55–41.54	...	...	82	...	...	18	6
18s	41.55–43.54	...	...	77	...	...	23	a
Coarser than 18s	over 43.54	...	...	...	...	...	...	...

[A] In each grade, the minimum percent and the first maximum percent total 100 %. The second maximum percent distribution permitted for any grade is part of, and not in addition to, the first maximum percent.

[B] The requirements in Table 2 are the same as the Official Standards of the United States for Grades of Mohair Top as promulgated by the U.S. Department of Agriculture, effective Jan. 1, 1973.

The incidence of kemp influences the English 1 to 7 system of grading (1 being coarse and 7 being fine), so that, for example, Turkish mohair in the range of 2's to 5's tends to be classified in a lower grade than Cape mohair of equal fineness, because of differences in kemp content[426]. Grade 3 mohair was used to make lofty open shawls and scarves, as well as hand knitting fancy-effect yarns, whilst Grades 2 and 3 were often used to produce curly pile rugs[426]. Grades 4, 5 and 6 were used in considerable amounts in blends with lustre and medium crossbred wools to make tropical suitings. They were also used to produce pile fabrics. The lowest quality pieces were used in the production of interlinings [426].

Table 33 is an attempt to consolidate and rationalise some of the different systems of quality, fineness and grades encountered in the literature.

TABLE 33
SOME APPROXIMATE/QUALITY TYPES

Spinning Count	English Grades	Fineness /Quality Bradford Count	Age Grp	Crimp* per 5 Inches	Max. Mean Diam (μm)	Mean Fibre Diam. (μm)	Description ***	Age Yrs
58-60's	-	8	Kids	8-10	25	< 26	SSK	½
56's	Kid	7	Kids	7-8	28	26-28	SWK	1
50-54's	30	6	Kids	7	30	29-30	WSK	-
-	-	6/5	-	-	32	-	-	-
46-48's	32	5	YG	6-7	34	31-34	SYG	1½
44's	34	4	A	5-6	36	35-36	SWH	2
							SSF	2½
36-40's	36	3	A	4-5	39	37-39	SFO	2
							WHO	2
32-36's	38	2	A	3-4	-	> 40	ARH	-
28's	40	1	-	2-3	-	-	CBH	-

*** Preliminary**

*****SSK - Super Summer Kids**
WSK - Winter/Summer Kids
SWH - Super Winter Hair
SFO - Summer First & Older
ARH - Adult (Ram's Hair)
SWK - Super Winter Kids
SYG - Summer Young Goats
SSF - Super Summer Ferals
WHO - Winter Hair & Older
CBH - Cross-Bred Hair (Adult)

9.5 Spinning Limits and Quality*

Mohair is often considered to be very difficult to spin because of its smoothness and lack of cohesion. Nevertheless, provided the correct processing additives and conditions and raw materials are used, very high quality

*See also **"GRADES"**

mohair yarn can be spun with acceptable efficiencies. The finest yarn which can be spun largely depends upon the mohair fibre diameter or fineness, traditionally expressed in terms of "quality or quality counts", being related to the minimum number of fibres in the yarn cross-section. Today mohair fineness is almost solely expressed in terms of the objectively measured mean fibre diameter.

According to **Wood**[51], the finest mohair yarns were originally spun on the flyer method, using the Bradford Worsted System. The thread wrapped around the flyer leg during spinning, kept the fibres in line and prevented them from being battered on the separators. He stated that spindle speed was an important factor in producing quality mohair yarns, although given a good roving, excellent yarns could be spun at spindle speeds from 5 000 to 7 000 rev/min on the ring-frame, provided the ring was of the proper size. He[51] further stated that, according to experience, the finest mohair yarn which could be spun was one containing 24 fibres in the cross-section, this applying to all classes and types of spinning equipment (a 4's mohair has a fineness of about 1.17 tex and could be spun to about a 30 tex yarn, as a limiting count).

Villers[82] described the traditional processing of mohair, and gave the following table (Table 34) comparing the spinning limits of mohair with its quality, stating that mohair was rarely spun finer than a 40's worsted count.

TABLE 34[82]
COMPARING THE SPINNING LIMITS OF MOHAIR WITH ITS QUALITY

Spinning Limit		Mohair Quality
Worsted	Tex	
16's	55	1's
24's	37	2's
28's	32	3's
32's	27	4's
40's	22	5's
44's	20	6's
50's	18	7's

A similar table was also given in another article[1].

Mohair grades (probably US grades) extend from 45's which is the top quality (Super Kids) to 16's or 18's, the lowest quality. The 45's quality is roughly equivalent to 58's to 60's grade sheep wool. A 7's to 6's quality mohair was usually held to be equivalent to a 56's merino wool (26 - 28μm) in terms of fibre fineness[6], mohair fibres generally being coarser at the root than at the tip[6].

Fineness of mohair used to be expressed in terms of the old Bradford mohair quality count, where 8's equalled the finest Kid hair and 2's the coarsest Adult hair[736]. Counts of 6's, 7's and 8's were generally Kids and 2's, 3's and 4's generally Adult hair.

Another report[15] gave the following table (Table35):

TABLE 35[15]
MOHAIR SPINNING LIMITS

French Classification	Bradford Classification	Diameter Limits (μm)	Linear Density (dtex)
II	56	26.5 - 28.5	7.20 - 8.35
III	50	28.5 - 30.8	8.35 - 9.75
IV	48	30.8 - 33.5	9.75 - 11.55
V	46	33.5 - 36.5	11.55 - 13.70
VI	40/44	36.5 - 40.0	13.70 - 16.40
-	36	40.0 - 44.4	16.40 - 20.35
-	32	44.4 - 50.0	20.35 - 25.80

Dantzer and Roehrich[15] also gave the following table (Table 36):

TABLE 36[15]
MOHAIR SPINNING LIMITS

* Class	Diameter Limits (μm)	Mean Diameter (μm)	Linear Dens. (dtex) Limits	Linear Dens. (dtex) Mean
6	27.9 - 30.9	29.4	8.00 - 9.84	8.92
5	30.9 - 34.3	32.6	9.84 - 12.10	10.97
4	34.3 - 38.0	36.1	12.10 - 14.88	13.41
3	38.0 - 42.2	40.1	14.88 - 18.31	16.59
2	42.2 - 46.8	44.5	18.31 - 22.52	20.41

*Appears to be the old Bradford mohair quality count.

FIBRE PHYSICAL AND RELATED PROPERTIES

10.1 Single Fibre Tensile Properties

Single fibre tensile properties are important from a textile point of view, fibre strength playing an important role in fibre breakage during mechanical processing, including spinning, yarn strength, fabric manufacturing and in the ultimate strength of the fabric. Generally, in the case of animal fibres, fibre strength increases almost linearly with the fibre cross-sectional area, more particularly the cross-sectional area of the thinnest place along the fibre. The fibre strength divided by the fibre cross-sectional area (preferably at the thinnest place) is therefore almost constant for a particular type of fibre. The modern approach is to express fibre strength as specific strength or tenacity in which case the fibre strength (now usually in cN) is divided by fibre linear density in tex (where tex is the mass in g per 1 000m of fibre, or more realistically the mass in μg per mm). More correctly, the force to break the fibre (ie the fibre strength) should be divided by the fibre cross-section (or linear density) at the thinnest place within the test length.

According to **Meredith**[20] (quoting other workers), the rate of increase of fibre strength with an increase in rate of loading is similar for most fibres, a tenfold increase in rate of loading increasing strength by 10%.

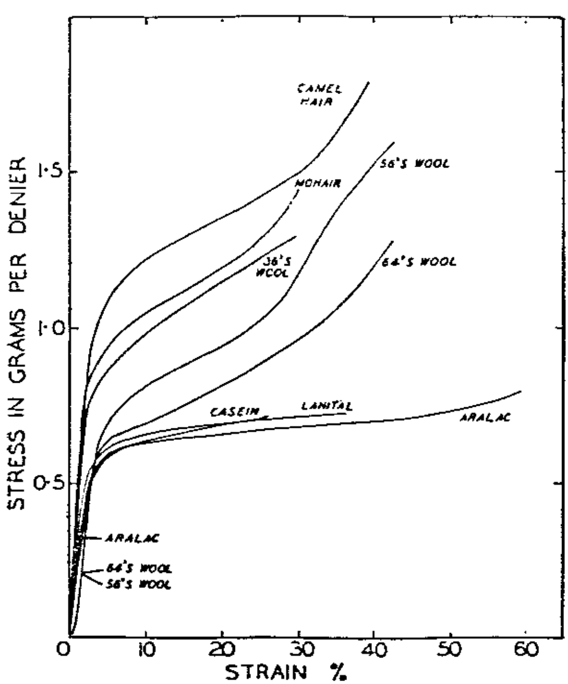

Fig. 18 Stress/Strain Curves for Wool, Hair and Casein Fibres[20]**.**

$F/F10 = 1 + 0.1 \text{ Log } (R/R10)$

Where F is the load at any given rate of loading R, and F10 is the load at a standard rate of loading R10, R being the quotient of the known rate of loading *in g/min and the average linear density of the sample tested.*

Meredith[20] found that mohair and camel hair have a greater yield stress than the coarsest wool and about the same initial Young's Modulus (see Fig. 18).

Initial Young's Modulus is that part of the stress-strain curve where the stress is proportional to the strain[20]. The yield point refers to that part in the stress-strain curve where the extension increases suddenly with a small increase in stress. The significance of the yield point is that fibres stretched beyond this point will not show complete immediate recovery although they may creep back slowly to their original length. Work-of-rupture (area enclosed by the stress-strain curve) provides a measure of the ability of a fibre to absorb energy[20].

According to **Meredith**[20] the tenacity of the Turkish mohair he tested was about 12.7 cN/tex, extension 30%, initial modulus 348 cN/tex, yield point stress 7.8 cN/tex, yield strain 3.4%, work-to-rupture 2.66 cN.cm./tex and work factor 0.70 (where "work factor" is the ratio of the actual work-to-rupture to the product of breaking load and breaking extension). For a material obeying

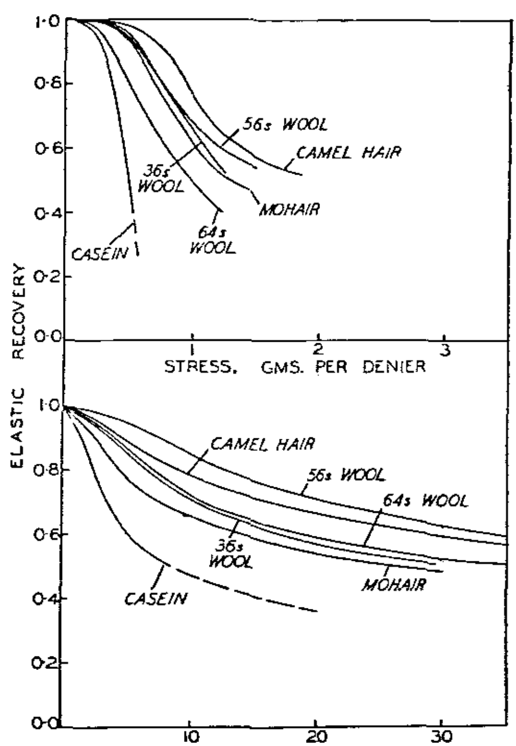

Fig. 19 Wool, Hair and Casein Fibre[21].

Hooke's law, the Work Factor is 0.5[20]. **Meredith**[21] illustrated the excellent elasticrecovery of mohair and wool (Fig. 19). The excellent elasticity of mohair compared to other fibres, is also illustrated in Fig. 20[27].

The higher the values in Figs 20, 21 and 22 the better the fibre elasticity and potentially also the better the crease (wrinkle) recovery, provided factors such as changes in ambient conditions and visco-elastic properties are not considered[27]. Wool and mohair have similar elastic properties[30], with outstanding elastic recovery in the dry state, which is improved after mechanical conditioning and when wet[30].

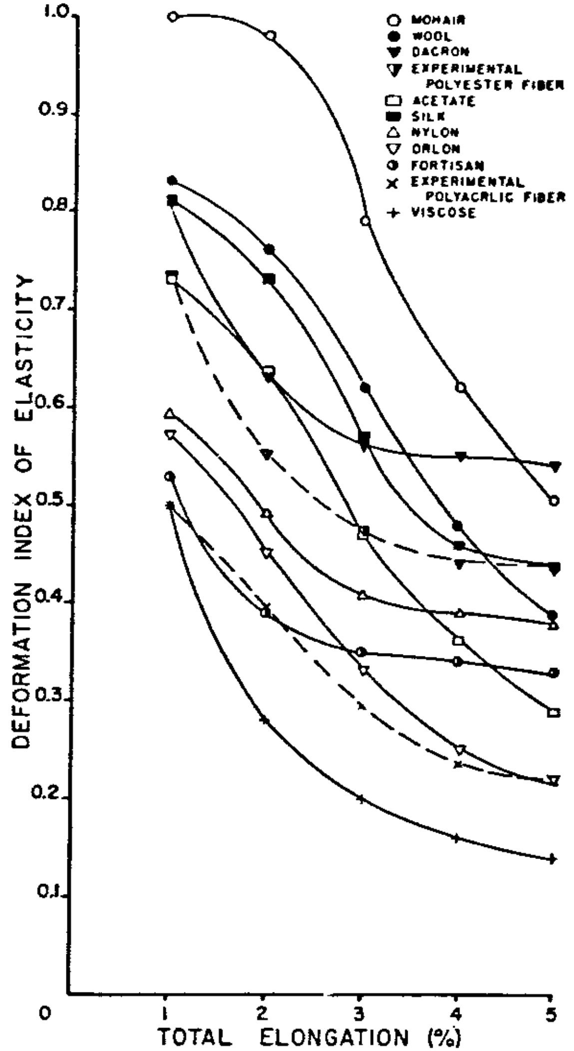

Fig. 20 Deformation Index of Elasticity vs Total Elongation[27].

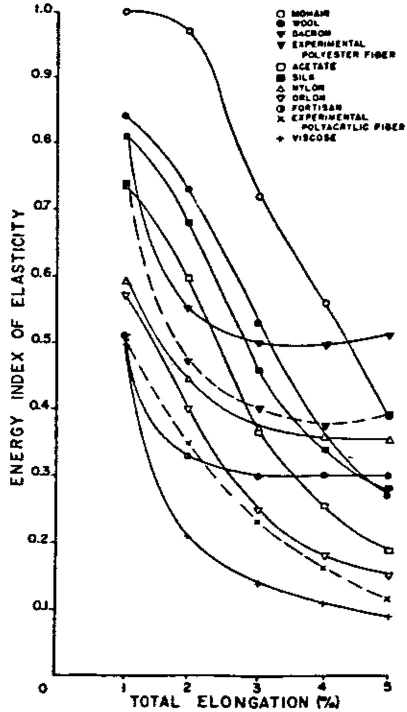

Fig. 21 Energy Index of Elasticity vs Total Elongation[27].

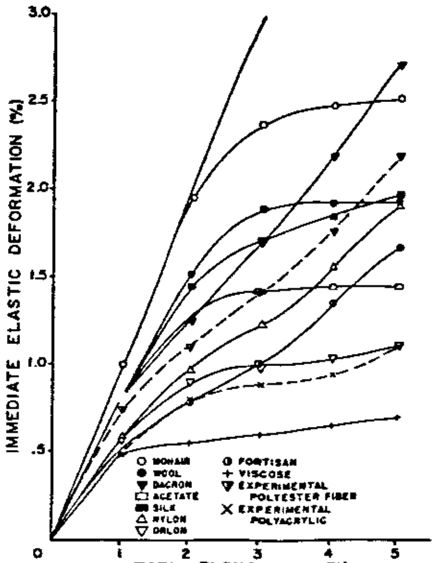

Fig. 22 Immediate Elastic Deformation vs Total Elongation[27].

Susich and Zagieboylo[30] gave the following stress-strain curves for mohair and other textile fibres, Fig. 23[30]. The differences in the stress-strain curves of the single fibres and the yarns were considered to be due to the effect of the yarn structure. The low extensibility of the mohair yarn was ascribed to fibre slippage resulting from the smooth surface, absence of crimp and relatively low twist[30]. The stress-strain curves for the wet state are shown in Fig. 24[30].

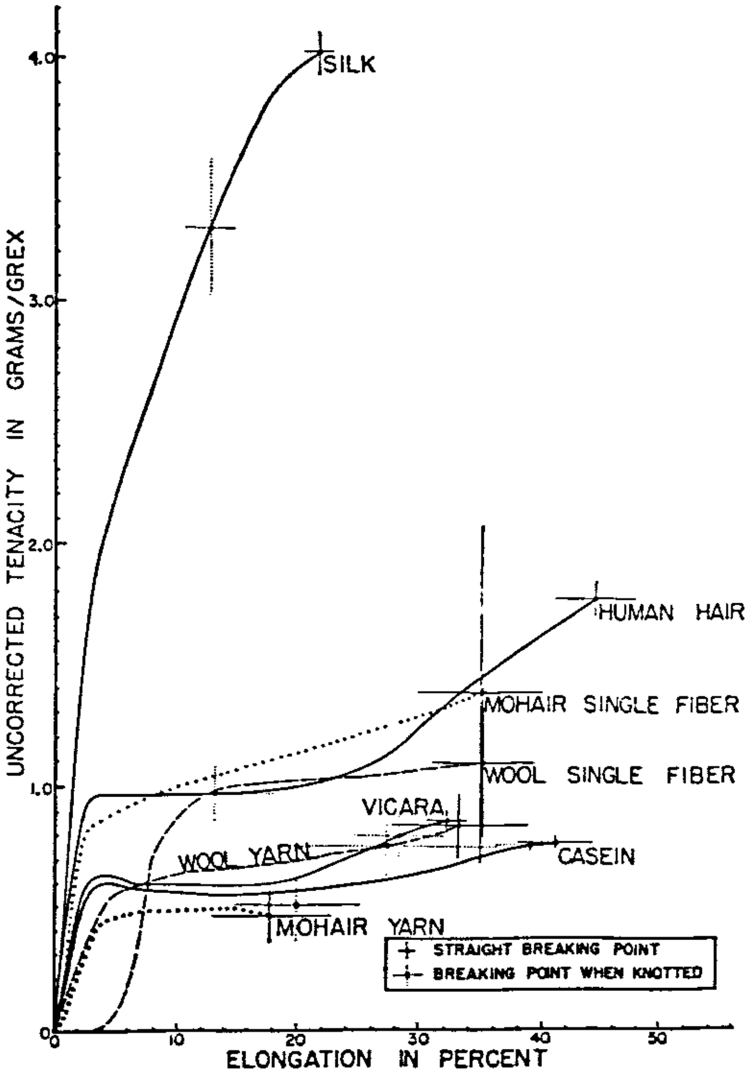

Fig. 23 Stress-Strain Curves for Original Fibres. Vertical and Horizontal Lines Indicate Standard Deviations of Ultimate Values[30].

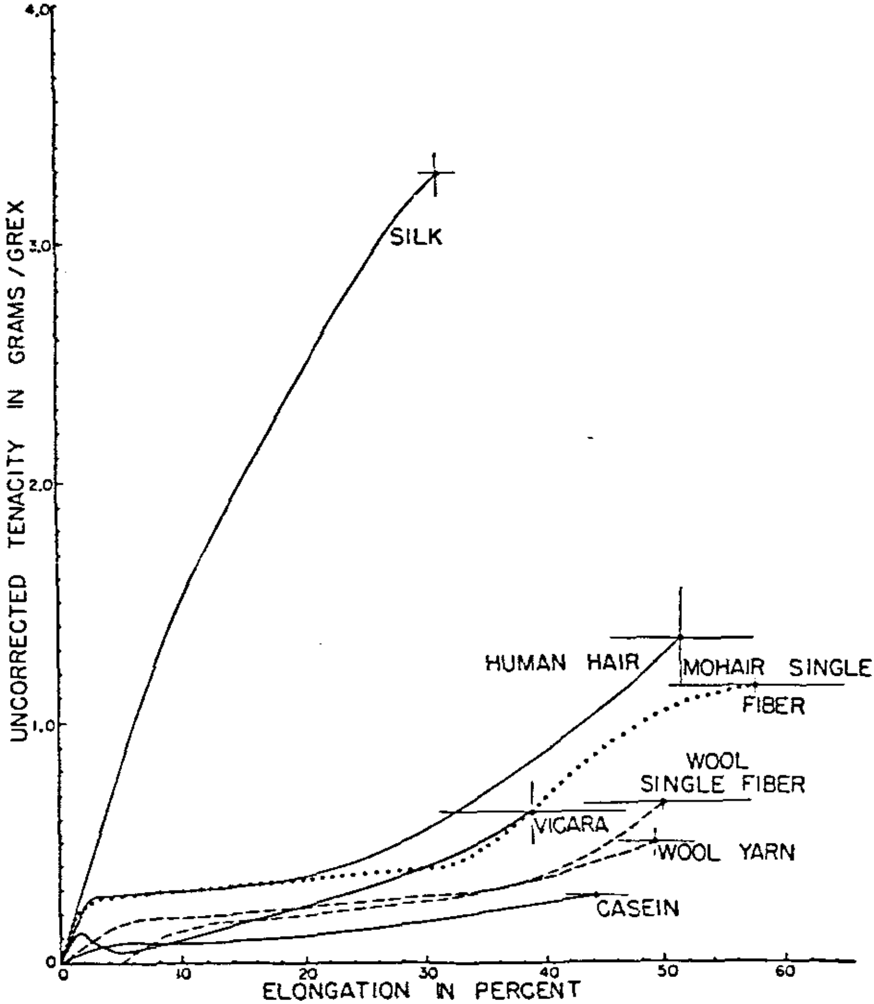

Fig. 24 Stress-Strain Curves for Wet Fibres. Vertical and Horizontal Lines Indicate Standard Deviations of Ultimate Values[30].

Susich and Zagieboylo[30] found that mohair (and human hair) have relative wet tenacities around 80%, being less affected by water than wool. Its relative resistance to swelling in water was partly ascribed to its morphology and chemical composition. Graphs are also given showing the recovery behaviour of mohair fibre and yarns as well as that of other fibre types. It was concluded that the recovery behaviour of dry and wet human hair, wool and mohair fibres was similar. **Hearle**[100] gave the following table of mohair fibre properties (Table 37).

TABLE 37[100]
FIBRE PROPERTIES

	Mohair	Camel hair	Silk (Japanese)	Tussah silk
Tenacity, g./tex.	13	16	39	37
Breaking extension, %	30	39	33	37
Work of rupture, g./tex.	2·7	4·7	6·1	7·6
Initial modulus, g./tex.	360	300	750	500
Elastic recovery from:				
half breaking load	0·78	0·82	0·57	0·40
half breaking extension	0·59	0·67	0·38	0·41
Wet strength/dry strength × 100%	—	—	75 - 95	
Density, g./c.c.	1·32	1·32	1·33	1·33
Moisture regain at 65% R.H.	(13)		1·33	1·33
Refracture index:				
light vibration ∥ axis	—	—	1·591	—
light vibration ⊥ axis	—	—	1·538	—
Electrical resistance at 65% R.H. (ohm-g/cm.^{2})	—	—	5×10^9	—
Effect of sunlight, prolonged exposure	Similar		Loss of strength, affected more than cotton	
Attack by moths	to wool		May be attacked, more resistant than wool	
Attack by mildew			Not usually attacked	

To convert g/tex to cN/tex, multiply by 0.98.

Crewther[135] investigated the stress-strain characteristics of mohair and other animal fibres after reduction and alkylation. He found that the strain at the end of the yield region and the residual disulphide content was the same, within experimental error, for all fibre types[135]. Reduction followed by reaction with ethylene dibromide did not greatly affect the stress-strain properties of the fibres. It was concluded that side-chain interactions between helical structures and matrix molecules containing many interchain disulphide bonds were chiefly responsible for stiffening the fibre in the Hookean region[135].

Watson and Martin[157] gave the following table (Table 38) of the tensile properties of speciality fibres.

Hunter and Kruger[153,172] compared the single fibre tensile properties of kemp, mohair and wool fibres (at 10mm gauge length and 20%/min rate of extension). They found that the Uster Evenness Tester could be used to measure the linear densities of the fibres. They found that the breaking extension of the mohair, merino, German merino and kemp fibres were similar, whereas the specific breaking strengths (breaking tenacities) of the merino and German merino fibres were significantly lower than those of the mohair and kemp fibres[153,172]. The extension of the various fibres was 40 and 45%. The following relationship was found between the breaking strength and linear density of the different fibres.

Breaking Strength (in cN) = 12.7 (Linear density in Tex)$^{1.0283}$

TABLE 38[157]
TENSILE PROPERTIES OF SPECIALITY HAIR FIBRES

A. Dry properties	64's wool top, de-greased	Scoured 26's mohair matchings	Scoured fawn alpaca fleece	Dehaired Mongolian cashmere	Dehaired Mongolian camel hair	Dehaired vicuna
Number of fibers tested	*42*	*35*	*34*	*34*	*36*	*32*
Denier	4.62	12.56	8.28	2.84	3.99	1.80
Standard deviation	1.53	3.52	3.40	0.85	1.82	0.63
Tenacity, g/den	1.26	1.82	1.53	1.55	1.57	1.29
Standard deviation	0.20	0.22	0.21	0.24	0.19	0.27
Elongation at break, %	30.7	40.4	35.8	35.6	36.8	22.8
Standard deviation	10.5	6.4	8.9	11.1	6.9	14.0
Elastic modulus, g/den	28.8	40.8	36.1	36.3	35.5	32.9
Standard deviation	3.9	3.4	2.1	3.7	2.9	4.2
Work recovery:						
after 2% extension	93	96	91	92	89	91
after 5% extension	68	47	53	42	45	43
after 10% extension	33	28	30	25	26	26
Length recovery:						
after 2% extension	96	95	94	95	96	94
after 5% extension	79	75	77	66	71	63
after 10% extension	54	54	54	49	51	43
B. Wet properties						
Number of fibers tested	42	39	38	35	38	36
Denier	4.33	13.82	8.57	2.80	3.47	1.86
Standard deviation	1.66	4.34	3.72	0.72	1.40	0.61
Tenacity, g/den	1.14	1.57	1.45	1.34	1.60	1.15
Standard deviation	0.21	0.19	0.38	0.14	0.47	0.21
Elongation at break, %	47.2	49.9	47.5	41.2	47.0	36.7
Standard deviation	5.8	5.4	4.3	3.8	5.9	6.6
Elastic modulus, g/den	13.3	20.4	16.4	19.1	17.9	17.4
Standard deviation	1.9	1.8	4.9	1.3	3.5	2.2
Work recovery:						
after 2% extension	85	79	82	72	69	74
after 5% extension	54	51	60	47	52	49
after 10% extension	42	42	46	37	44	41
Length recovery:						
after 2% extension	86	91	89	88	86	84
after 5% extension	82	87	88	80	86	82
after 10% extension	78	85	81	71	80	73

To convert g/den to cN/tex x 8.83.

Although the exponent of linear density did not vary significantly from 1, there were certain differences in the mean specific strength (tenacity) of the various types of fibres. The specific breaking strength (tenacity) of the mohair was 15 cN/tex and that of the merino and German merino was 11.4 cN/tex.

King[181] found the bending and extension moduli of mohair not to differ significantly. Bending tests on kemp fibres led to the conclusion that there were two distinct types of kemp fibres, differing significantly in their bending moduli. He thought that the difference was due to cell filled and partly cell filled medullae. Bending and stretching of the hollow type of kemp did not significantly vary and the values were in agreement with those of mohair. The bending and extension moduli of mohair were found to be about 290 cN/tex while the bending modulus of the Type I (medulla almost devoid of cells ie hollow) fibres was 79 cN/tex and that of Type II (medullae packed with cells) 362 cN/tex. The stretching (extension) moduli of the two types of kemp fibres were similar. For the Type II kemp fibres, the bending modulus was always larger than the extension modulus. Where-as for the Type I kemp fibres they were similar. The extension modulus was about 92 cN/tex for both types.

Carter *et al*[195] found that the stress at 15% extension and certain other fibre tensile properties in water were similar for mohair and wool from certain breeds of sheep, the relative initial modulus and relative post yield slope decreasing as the variation of fibre diameter along the fibre increased, while the relative yield slope increased. **Kondo** *et al*[237] found that the shoulder of the stress-strain curve of mohair was much more angular than that of wool, this was thought to be due to the scales of mohair being more strongly bonded to each other than those for wool, thereby resisting the extending force up to a certain point. **Smuts and Hunter**[343] compared the single fibre tensile properties of kemp and mohair fibres, at various gauge lengths from various Cape and Lesotho (Basuto) mohair types. At a gauge length of 10mm, the extensions of

TABLE 39[545]
AVERAGE VALUES FOR SOME TENSILE PROPERTIES* OF WOOL AND MOHAIR

PROPERTY	MEAN	SD	CV (%)	RANGE	n
WOOL* **					
Fibre diameter (μm)	22,7	3,3	15	18,1 — 33,1	56
Linear density (dtex)	6,6	2,0	30	3,5 — 12,8	56
Staple crimp (cm^{-1})	4,2	1,2	27	1,9 — 6,5	56
Resistance to compression (mm)	17,5	2,8	16	13,6 — 24,7	56
Bulk/diameter ratio (mm/μm)**	0,79	0,19	24	0,41 — 1,29	56
Tenacity (cN/tex)**	12,7	0,9	7	10,9 — 15,0	56
Initial modulus (cN/tex)**	290	27	9	230 — 392	56
Extension at break (%)	37,0	2,6	7	31,5 — 41,2	56
MOHAIR					
Fibre diameter (μm)	32,1	5,8	18	20,7 — 44,3	29
Linear density (dtex)	11,9	3,3	28	5,8 — 20,1	29
Tenacity (cN/tex)	16,7	0,7	4	14,6 — 18,1	29
Initial modulus (cN/tex)	407	13	3	384 — 430	29
Extension at break (%)	42,7	2,1	5	38,0 — 45,8	29

*- 20 mm test length and rate of extension 20 mm/min

**- since these values depend on crimp a table of typical (average) values is given later (Table IV) showing the dependence of these properties on crimp

***- Low crimp wools excluded

the mohair and kemp fibres were similar, where-as at the longer gauge lengths (40, 50 and 100mm) the extension of the mohair fibres was generally, but not consistently, higher than that of the kemp fibres (possibly due to greater fibre cross-sectional irregularity or damage in the kemp fibres). Few kemp fibres in the Cape mohair were long enough to be tested at a gauge length of 50 mm or longer. The absolute breaking strength of the kemp was generally higher than that of the mohair although their cross-section (fineness) corrected strength (ie specific strength or tenacity) was almost always lower, this confirming the results of earlier studies.

In a study on the single fibre tensile properties of wools produced in South Africa, **Smuts** *et al*[545] also included some results for mohair. They showed that the single fibre pre-yield slope (initial modulus) and tenacity were affected, more by fibre crimp than by fibre diameter, both decreasing with an increase in fibre crimp. Mohair generally had a higher tenacity, initial modulus and extension at break than wool of the same diameter, and the mohair tensile characteristics were fairly constant over the whole range of diameters, probably because of the absence of crimp and variations in crimp and any associated fibre characteristics. Lustre wools (eg Lincoln and Buenos Aires) had tenacities and initial moduli close to those of mohair[545]. See Table 39 for average (or typical) values.

There was some indication that the extension of the Summer hair was lower than that of the Winter hair[343]. The following tables are reproduced from the report by **Smuts and Hunter**[343] (Tables 40 to 43).

TABLE 40[343]
EFFECT OF GAUGE LENGTH ON THE AVERAGE TENSILE VALUES

GAUGE LENGTH (mm)	EXTENSION AT BREAK (%)			TENACITY (gf/tex)		
	Mohair	Heterotype	Kemp	Mohair	Heterotype	Kemp
10	47,9	–	46,6	18,3	–	15,1
40 or 50	38,3	–	34,9	15,8	–	12,7
100	30,2	26,2	21,8	12,9	11,0	9,0

TABLE 41[343]

SOME TENACITY* AND EXTENSION VALUES OBTAINED ON MOHAIR AND KEMP BY OTHER WORKERS

Source of Data	Gauge Length (mm)	Rate of extension (%/min)	Type of Mohair	Tenacity (gf/tex)	Extension (%)
Watson and Martin[4]	25,4	100	Mohair	16,4	40,4
Fröhlich[5]	10	–	S.A. Mohair	19,0	49,6
Fröhlich[5]	10	–	Texas Mohair	15,1	48,5
Hunter and Kruger[3]	10	20	S.A. Mohair	15,0	42,2
			Kemp	15,3	45,2
			Kemp	13,5	–
Harris[6]	10	–	Mohair	13,0	30,0
Hearle[7]	..	–	Mohair	13,0	30,0
Srivastava[2]	20	100	**S.A. Summer Kid**		
			Kemp	–	27,8
			Mohair	–	41,3
Srivastava[2]	20	100	**S.A. Summer Kid**		
			Kemp	–	38,3
			Mohair	–	38,8
Srivastava[2]	20	100	**S.A. Adult**		
			Kemp	–	37,3
			Mohair	–	44,9
Srivastava[2]	20	100	**Turkish Adult**		
			Kemp	–	26,3
			Mohair	–	39,7
Srivastava[2]	50	100	**S.A. Adult**		
			Kemp	–	28,1
			Mohair	–	33,3
Srivastava[2]	50	100	**Turkish Adult**		
			Kemp	–	23,9
			Mohair	–	30,0
Srivastava[2]	50	100	**Basutoland Adult**		
			Kemp	–	18,1
			Mohair	–	39,0
Srivastava[2]	50	100	**2^S Cape**		
			Kemp	–	24,9
			Mohair	–	38,5

*To convert gf/tex to cN/tex multiply by 0.98. New Reference Numbers:
4 = 157; 3 = 153,172
5 = 197; 6 = 31
2 = 309; 7 = 100

TABLE 42[343]
TENSILE VALUES OBTAINED ON WINTER AND SUMMER MOHAIR AND KEMP FIBRES

SAMPLE	WINTER				SUMMER			
	Tenacity (gf/tex)		Extension (%)		Tenacity (gf/tex)		Extension (%)	
	Mohair	Kemp	Mohair	Kemp	Mohair	Kemp	Mohair	Kemp
10 mm Gauge Length								
BSK	17,4	13,7	47,9	48,6	17,4	16,0	48,4	47,8
BSK	19,4	14,6	47,5	43,7	–	–	–	–
BYG	16,9	15,3	47,9	48,4	17,3	13,5	46,7	46,2
BSFH	19,8	18,0	50,8	51,5	18,7	14,9	45,8	45,1
BSFH	20,8	16,5	53,1	51,3	–	–	–	–
Mean	18,9	15,6	49,4	48,7	17,8	14,8	47,0	46,4
40 mm Gauge Length								
BSK	14,4	11,1	36,7	29,9	11,2	10,7	30,9	27,7
BSK	15,9	13,2	36,5	32,0	–	–	–	–
BSFH	16,9	13,4	40,1	38,2	16,1	13,2	37,7	32,1
BSFH	17,7	13,5	43,5	39,6	–	–	–	–
BSH	17,8	12,6	42,0	34,7	16,9	14,0	39,1	36,3
Mean	16,5	12,7	39,8	34,9	14,7	12,6	35,9	32,0

TABLE 43[343]
AVERAGE TENSILE VALUES OBTAINED ON WINTER AND SUMMER MOHAIR AND KEMP FIBRES

GAUGE LENGTH	FIBRE TYPE	WINTER		SUMMER	
		Extension (%)	Tenacity (gf/tex)	Extension (%)	Tenacity (gf/tex)
10 mm	Mohair	48,8	18,9	46,6	17,6
	Kemp	47,2	15,0	45,4	15,6
40 mm	Mohair	40,4	16,8	37,5	15,3
	Kemp	35,9	12,6	33,3	13,0

Smuts *et al*[532] gave the following comparative graph (Fig. 25) for the single fibre strength of mohair and wool.

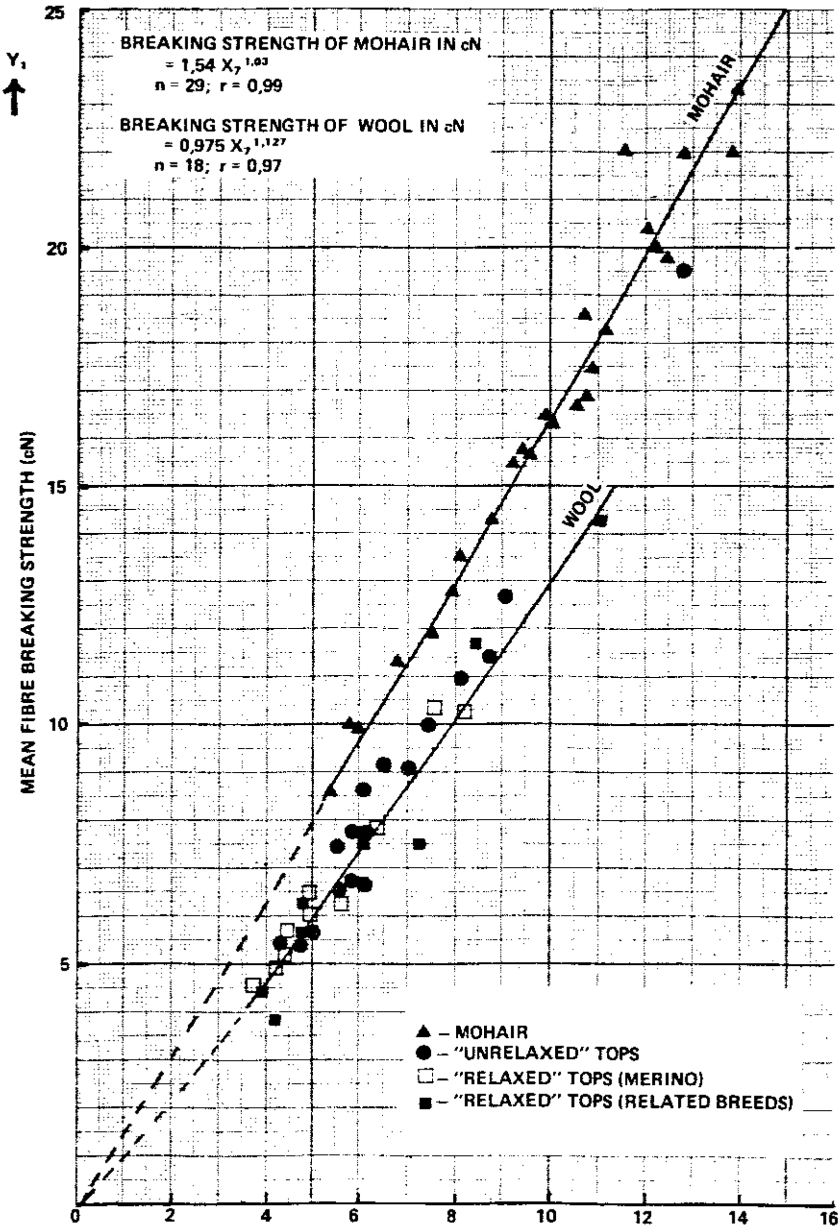

Fig. 25 Relationship between Mean Fibre Breaking Strength and Measured (Vibroscope) Linear Density for Wool and Mohair[532].

Van der Westhuysen[728] gave the following comparative table of fibre tensile properties:

TABLE 44[728]
A COMPARISON OF THE BREAKING AND TENSILE* STRENGTHS OF MOHAIR WITH OTHER FIBRES

Type of fibre	Fineness (μm)	Breaking strength of single fibres (g/μm)	Tensile strength (kg/cm²)
Mohair	25.4	0.4177	2154
Wool	25.8	0.3116	1510
Camel hair	26.6	0.3902	1808
Human hair	58.6	1.1324	2439

*To convert kg/cm² to cN/tex multiply by 0.0075.

Kawabata and co-workers[844,911,1019] gave the following table (Table 45) of comparative single fibre properties:

TABLE 45[844,911,1019]
YOUNG'S MODULI OF SINGLE FIBRES E_L LONGITUDINAL, E_T TRANSVERSE, G SHEAR

Fibre	*Diameter* μm	*Modulus (GPa)* E_L	E_T	G	E_L/E_T	Bending Stiffness (nNm²)	Torsional Stiffness (nNm²)
NZ Wool							
Corriedale	35	4.25	1.25	2.42	3.40	35.2	46.9
Coopworth	35-37	3.93	0.94	0.73	4.18	39.5	13.5
Mohair Fine	32	3.91	0.95	0.76	4.12	27.6	15.0
Kid	28	4.95	1.27	0.61	3.90	25.6	15.0
Merino	22	4.12	1.11	1.08	3.71	8.40	8.74

Niwa and co-workers[386,986,1019] compared the performance of New Zealand wool and mohair under repeated loading.

10.2 Fibre Bundle Tenacity Properties

Mauersberger[32] gave values of about 16.3 cN/tex for the bundle tenacity (75mm gauge length) for mohair, the value being very similar for tops ranging in fibre diameter from 25 to 36μm.

Onions *et al*[445] reported on the development of a newly developed bundle tensile tester for determining the bundle tensile properties, at a gauge length of 40mm, of mohair and wool. They found that, for the mohair tops, the tensile results were higher for the coarser and longer mohair lots.

Hunter and Smuts[542] measured the bundle and single fibre tensile properties of a large number of mohair lots ranging in mean fibre diameter from 21 to 44μm. Leather linings were found to be more suitable than cardboard linings for the Stelomenter bundle tensile tests. Both bundle and single fibre tenacity (ie cross section corrected strength) were found to be independent of mohair fineness, although the initial modulus increased slightly with an increase in fibre diameter. They gave the following table (Table 46) of "average" or "typical" tensile properties for mohair.

TABLE 46[542]
TYPICAL TENSILE PROPERTIES OF MOHAIR

Property	Bundle Test*	Single Fibre Test
Tenacity (cN/tex)	14,0	16,7
Extension (%)	14,6**	43,0
Initial Modulus (cN/tex)	—	407

*Leather linings were used and the tenacity values obtained were multiplied by a correction factor of 1,16
**The bundle test is not considered to give reliable extension values.

10.3 Fibre Bending Stiffness*

King[146,173,181] and **King and Kruger**[244] reported on some work aimed at measuring the elastic moduli of wool, mohair and kemp, by means of ultrasonic pulse techniques and described an instrument for measuring the static bending modulus of fibres which was used on mohair and kemp. The Instron Tensile Tester was used for determining the extension modulus. **King**[146,173] found that the bending and extension moduli of mohair fibres were similar and of the order of 308 cN/tex. He reported[173] that the medullae of kemp fibres differed in optical density, indicating different cell densities, and this affected the bending but not the extension moduli. Two types of kemp, one with a filled medulla and the other with a virtually empty medulla were postulated. For the empty medullae, the bending and extension moduli of the kemp were similar at about 77 cN/tex whereas the filled medullae gave a bending moduli of about 365 cN/tex which was higher than that found for mohair[173]. The extension moduli of the two types of kemp fibres were similar indicating that any material in the medullae did not contribute to the tensile properties of the fibre, which was in agreement with the results of **Hunter and Kruger**[153,172].

*See also "SINGLE FIBRE TENSILE PROPERTIES".

10.4 Fibre Friction*

As in the case of wool, mohair fibres have a lower friction when rubbed from the root to the tip (ie with the scales) than when rubbed in the opposite direction (ie from tip to root, termed against-scale). The relatively low against-scale friction of mohair, which is one of its distinguishing features, is largely attributed to its relatively smooth (unpronounced) scale structure. It is this characteristic which gives mohair its low felting propensity. Mohair has a very small directional friction effect (DFE)[94], due to the extremely thin distal edges in mohair easily being deformed and also the absence of tilted outer surfaces and

*See also **"FIBRE FRICTION"** under **"FIBRE IDENTIFICATION"** and **"CORONA TREATMENT"**.

other high asperities. The against-scale (μ_2) to with-scale (μ_1) friction ratio of mohair is about 1.1 compared to about 1.8 for merino wool[98]. The "scaliness" $(\mu_2-\mu_1)\times100/\mu_1$ of mohair, measured dry, is about 5 compared to about 60 for a fine merino wool **Speakman and Stott**[10] quoted by **Onions**[98], when measured wet the respective values are about 16 for mohair and 120 for merino wool.

Martin and Mittelmann[22] found the coefficient of friction (μ) of wool and mohair to decrease with increasing load and with decreasing fibre diameter, the latter thought to be due to a relationship between diameter and scale structure. **Kruger and Albertyn**[127] found that the friction of mohair fibres was higher than that of kemp. In the case of mohair, the frictional force decreased with increasing diameter when the fibres were not cleaned, but increased with increasing fibre diameter when the fibres were cleaned. **Frishman** *et al*[24], quoted by **Harris**[31], gave the following table (Table 47) of fibre friction:

TABLE 47[24]
FIBRE FRICTIONAL PROPERTIES*

Fibre	μ_1	μ_2	$\mu_1 - \mu_2$	$\mu_1 + \mu_2$
Wool	0.40	0.22	0.18	0.66
Mohair	0.23	0.15	0.08	0.38
Human Hair	0.19	0.09	0.10	0.28

μ_1 : Against-scale

μ_2 : With-scale

Landwehr[385] reported on the effects of various chemical treatments on the fibre friction of mohair.

10.5 Moisture Related Properties

Although mohair, as in the case of wool, can absorb large quantities of moisture (up to about 30%) without feeling wet or damp, its surface is naturally water repellent, largely due to the presence of a strongly bound thin surface layer of waxy or lipid material which requires a strong chemical action to remove it.

The moisture related properties of textile fibres are extremely important as they play a crucial role in the comfort of the fibre and in the behaviour of the fibre during wet treatments and drying. It is generally accepted that the moisture absorption and other related properties of animal fibres, such as mohair, impart highly desirable comfort properties to the wearer. Temperature and

* Measured in distilled water against felt

moisture also play an important role on the visco-elastic properties of wool and mohair, **Tao and Postle**[920] (as quoted by **Zahn**[994]) which, in turn, play an important role in fabric wrinkling behaviour.

Speakman[7] published the following table (Table 48) illustrating the absorption and desorption of moisture by wool and mohair at different relative humidities.

TABLE 48[7]
THE ADSORPTION AND DESORPTION OF MOISTURE BY WOOL AND MOHAIR AT DIFFERENT RELATIVE HUMIDITIES

Relative humidity %	Percentage increase in weight of wool					
	Geelong 80's, Merino	Southdown	Oxford Down	Leicester	Wensley-dale	Mohair
7.0	3.40	3.37	3.17	3.40	3.46	3.41
25.0	6.96	6.90	7.03	6.96	7.01	6.93
34.2	8.41	8.62	8.79	8.54	8.67	8.64
49.8	11.22	11.48	11.68	11.44	11.59	11.51
63.3	13.97	14.19	14.41	14.46	14.51	14.41
75.0	16.69	17.03	17.30	17.43	17.44	17.33
92.5	23.81	44.17	24.49	24.59	24.90	24.24
100.0	33.3	32.9	35.3	32.9	33.9	31.8
			Desorption			
92.5	24.70	25.70	26.33	25.98	26.13	25.82
75.0	18.69	18.79	19.05	19.02	19.16	18.91
63.3	16.12	16.16	16.43	16.28	16.46	16.26
48.7	13.36	13.38	13.47	13.39	13.46	13.46
34.2	10.57	10.55	10.64	10.58	10.63	10.68
7.0	4.77	4.73	4.83	4.79	4.76	4.87

Von Bergen[70,74,202] gave the following comparative tables (Tables 49 to 52) for the moisture related properties of mohair and other fibres. He concluded that adsorption and desorptive powers of the speciality hair fibres were very similar to those of wool, with the affinity of water possibly increasing slightly as the fibre becomes coarser, confirming earlier findings of **Speakman**[7].

TABLE 49[70,74]
MOISTURE PICKUP OF SAMPLES WET OUT AND CENTRIFUGED

Sample	Moisture pickup, %	Sample	Moisture pickup, %
Kid mohair	40.0	Angora rabbit	54
Adult mohair	36.0	Common French rabbit	97
Chinese cashmere	54.4	Common California rabbit	92
Mongolian cashmere	44.0	Common grey rabbit	75
Alpaca	41.0	Beaver, cut	49
Vicuna	52.0	Beaver, boiled	70
Camel hair	43.0	Muskrat	71
Wool	44.0	Wool top	55

TABLE 50[70,74]
MOISTURE REGAIN OF SPECIALITY HAIR FIBRES AT 70°F

	20% RH		65% RH		90% RH	
	Dry	Wet	Dry	Wet	Dry	Wet
Mohair						
Kid	8.7	8.9	14.7	16.7	21.9	23.6
Adult	8.4	9.2	14.9	17.6	22.1	23.2
Cashmere						
Chinese	8.1	7.4	12.6	16.6	19.0	23.2
Mongolian	—	8.4	—	16.8	—	22.2
Alpaca	8.3	8.4	14.4	17.2	21.4	24.5
Vicuna	8.4	7.8	13.3	16.4	20.6	24.4
Camel hair	8.0	8.4	14.3	17.4	21.9	—
Wool	7.5	8.3	14.0	17.8	21.9	20.7

Regain is defined as the mass of water (moisture) absorbed, expressed as a percentage of the dry mass of the fibre.

TABLE 51[70,74,202]
COMPARISON OF MOISTURE REGAIN DATA ON MOHAIR

Speakman			This study				
				Kid		Adult	
Relative humidity, %	Adsorption	Desorption	Relative humidity, %	Dry	Wet	Dry	Wet
7	3.41	4.87					
25	6.93	8.6	20	8.7	8.9	8.4	9.2
63.3	14.41	16.26	65	14.7	16.7	14.9	17.6
92.5	24.24	25.82	90	21.9	23.4	22.1	23.2

TABLE 52[70,74]
COMPARISON OF AVERAGE MOISTURE REGAIN DATA AT 70°F FOR HAIR AND FUR FIBRES

	Specialty hair fibers	Fur fibers
Relative humidity, %	Moisture regain, %	Moisture regain, %
20	8.4	6.6
65	15.5	13.1
90	22.3	19.7

The moisture absorbency of mohair and other fibres has been investigated[711] (see also Ref. [602]).

Swanepoel and Van Rensburg[230] found good agreement between the moisture content of mohair protein obtained by a automatic elemental analyser method and drying and weighing methods respectively.

Watt presented the following comparative table (Table 53) of equilibrium water content (regain) for seven keratins including mohair.

TABLE 53*
EQUILIBRIUM WATER CONTENTS FOR SEVEN KERATINS AT 35°C (in %)

Relative humidity	Merino wool	Corriedale wool	Lincoln wool	Mohair	Monkey hair	Horsehair	Rhinoceros horn
5	2.6	2.5	2.5	2.5	2.2	2.3	2.5
10	3.9	4.0	4.0	3.7	3.3	3.5	3.8
20	5.9	6.1	6.1	5.7	5.1	5.5	5.6
35	8.6	9.0	9.0	8.3	7.5	7.9	8.4
50	11.3	11.8	11.5	10.7	10.0	10.7	11.4
65	14.4	15.0	14.5	13.7	12.4	13.8	14.8
80	18.6	19.6	19.2	17.5	16.3	18.2	20.1
90	23.6	25.0	25.4	22.2	21.4	22.7	28.0
95	27.7	28.2	29.7	26.1	24.9	26.9	35.5
100	34.2	33.5	36.0	32.3	30.0	32.8	49.0

***Watt**

Horikita *et al*[955] determined the moisture sorption isotherms for 15 kinds of wool and hair fibres, including mohair, analysed in terms of the adsorptive energy factor (C), maximum volume of adsorbed water in mono-layer per gram of dry material (Vm) and maximum number of layers in multi-layer adsorption (Nmax). They found that these parameters were similar for the various fibres with Vm related to the degree of non-crystallinity (see Fig. 26 and Table 54)[955]. The moisture sorption process was also investigated by thermo-dynamic means as a function of moisture regain of the specimen from dryness up to saturation.

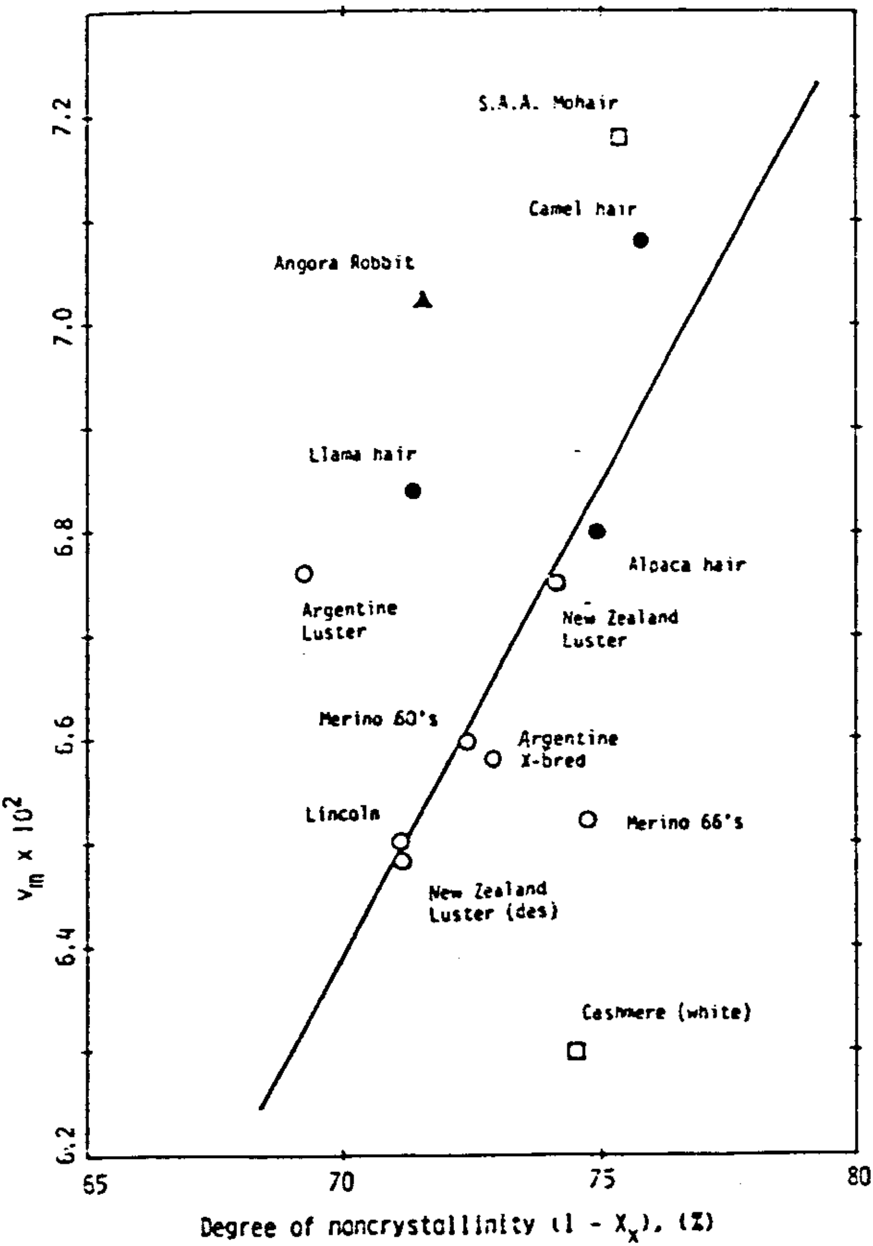

Fig. 26 Plots of the Value of BET's Parameter, Vm Against the Degree of Noncrystallinity, (1 -Xx), for all of the Test Specimens. Open Circle: Sheep Family, Open Square: Goat Family, Dot: Camel Family and Triangle: Rabbit Family[955].

TABLE 54[955]

MOISTURE SORPTION CHARACTERISTICS OF WOOL AND HAIR FIBRES IN TERMS OF THE BET'S MULTILAYER ADSORPTION PARAMETERS AT 30°C

Specification	B. E. T.'s parameters			Moisture regain at 95% r. h.			Moisture regain at 65% r. h. in bulk (%)
	v_m	C	n^*_{max}	$n = 1$ (%)	$n_{max} \geq n > 1$ (%)	$n > n_{max}$ (%)	
(sheep family)							
Australian Merino 66's wool	0.0652	10.28	6	5.8	15.5	6.5	14.6
Australian Merino 64's (descaled)	0.0574	11.72	6	5.4	13.3	6.2	12.8
Australian Merino 60's wool	0.0658	10.36	6	5.9	15.7	7.6	14.8
Argentine X-Bred 56's wool	*0.0659*	*10.27*	*6*	5.9	15.7	7.8	14.8
Argentine Luster wool	0.0676	10.08	6	6.1	16.1	9.6	15.2
New Zealand Luster 48's wool	0.0673	9.66	5	6.0	13.0	6.6	13.9
New Zealand Luster 48's (descaled)	0.0648	9.40	5	5.8	12.2	7.6	13.3
Lincoln wool	0.0650	10.62	6	5.8	15.6	5.6	14.2
(goat family)							
Cashmere wool (white)	0.0630	11.04	6	5.7	14.9	8.1	14.4
Cashmere wool (brown)	0.0640	11.32	6	5.8	15.2	7.7	14.4
South Africa Adult Mohair	0.0718	9.34	5–6	6.4	15.2	7.8	14.7
(camel family)							
Camel hair	0.0708	10.53	5–6	6.4	15.1	8.1	15.0
Alpaca hair	0.0680	10.28	6	6.2	16.2	7.6	15.0
Llama hair	0.0684	10.14	6	6.2	16.2	8.0	15.1
(rabbit)							
Angora Rabbit	0.0702	10.18	6	6.3	16.7	6.5	15.5

* Maximum number of adsorbed layers below which the calculated isotherm by B. E. T.'s model is closest but never exceeds the observed isotherm.

Centrifuged mohair was found to have a regain of about 39%, which is similar to that of wool[56]. The moisture absorbency of mohair and other fibres was also investigated[711] elsewhere, while **Philippen**[448] studied the contraction of mohair and other keratin fibres upon dehydration.

Ahmad[292] found that the water imbibition of mohair was about 42.5% (that for ethanol about 25%, acetic acid about 90%, dichloromethane about 15% and trichloroethylene almost 10%). The imbibition values of the mohair were, in almost all of the cases, slightly lower than those for Lincoln wool, with treatment with 5% DCCA not altering the imbibition values to any great extent except in the case of low molecular weight carboxylic acid. The equilibrium absorption values for water were found to be 37.9% (at 22°C). The equilibrium absorption values (ie the imbibition values corrected for external liquid) were similar for wool and mohair[292].

Turpie and Steenkamp[878] reported that studies carried out on 30 lots of material, covering a wide range of wool, karakul and mohair scoureds, as well as some carbonised wool, wool noils and card burrs, had shown that the regain of the material could be accurately assessed over a wide range of values during high density pressing by means of the *Forte System 8500, provided that the* values of certain physical characteristics of the material, which affect the Forte number, were known.

A subsequent report(1089) dealt with the achievement of an acceptable commercial calibration of a Forte in-press system for the measurement of the regain of tops.

10.6 Scale Pattern

Mohair, wool and hair are covered by a layer of sheet-like hardened cuticle cells (scales) which overlap each other with their exposed edges toward the tip of the fibre(502). The cuticle plays an important role for the whole fibre because it is, on the one hand, exposed to environmental influences and on the other hand, responsible for the surface properties of the fibre. The cuticle or scale structure is largely responsible for the felting behaviour of wool(502) and mohair.

Although, under a microscope mohair is similar in appearance to wool, in contrast to wool, the epidermal scales (cuticle scales) of mohair are only faintly visible (the cuticle scales are quite thin and flat, generally being less than about 0.6μm in thickness) and hardly overlap(105) being anchored much more closely to the body of the fibre(34,179, 202,994) (*ie they lie close to the stem or are piled* more closely upon one another)(289), giving the fibre a very lustrous smooth appearance. In general, mohair has a relatively low scale frequency, with a wide distance between the cuticle scale margins. The number of scales per 100μm is generally of the order of 5 against 9 to 11 in fine wools (see Fig. 27),

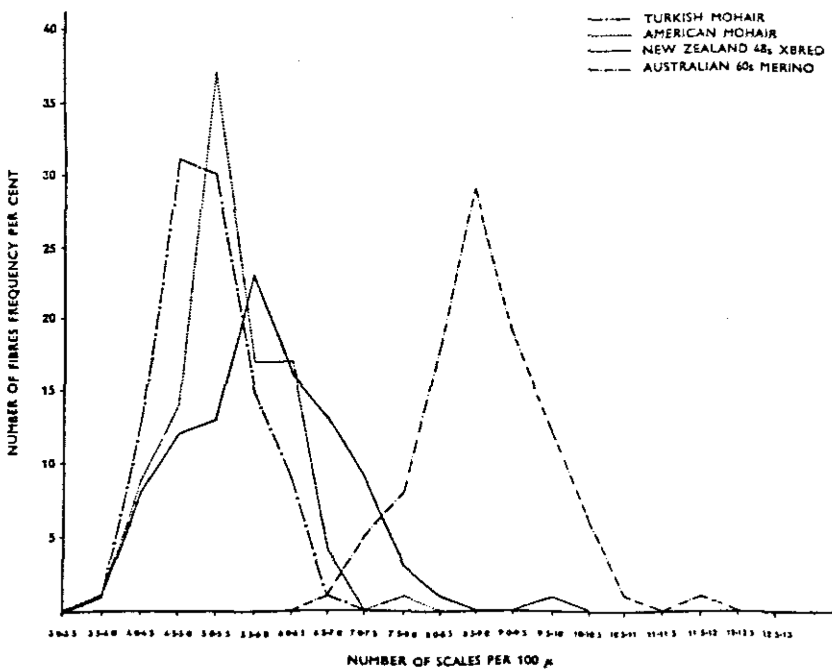

Fig. 27 Some examples of Scale Length Distributions(36).

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*See Also "**FIBRE IDENTIFICATION AND BLEND ANALYSIS**" and "**LUSTRE**".

with the scale lengths ranging from 18 to 22μm. The scale structure described above, is responsible for mohair's smooth handle, high lustre[34,994], low against scale friction and very low felting propensity. The width to length ratio of mohair fibre scales is of the order 2[1002].

In the case of kemp, the number of scales per 100μm is 10 or more, which is twice that for mohair; and are arranged in a coronal or ring pattern, with smooth margins[202].

Speakman and co-workers[10,11] found that, in extreme cases, such as merino wool and mohair, a direct relationship between scaliness and milling properties was observed. They found that the scaliness measured under water was greater than that measured in air, ascribed to the greater flexibility of wet fibres and to fibre swelling. They concluded that scaliness was the determining factor in milling, but that the rate and extent of shrinkage were also affected by differences in fibre crimp. Increasing the resistance of a fibre to stretching in water or decreasing its recovery from extension will generally reduce felting[11].

Appleyard[77] gives the following table (Table 55) describing the microscopic appearance of mohair fibres.

Dobb *et al*[94] showed that the profile of mohair fibres appeared to be relatively smooth, revealing an almost complete absence of tilted cuticle surfaces and unusually thin distal edges of cuticle. They believed that examination of the fibre profiles by transmission type of electron microscopy could be used to distinguish between wool and mohair.

Satlow *et al*[128] compared the scale structure, scale length in particular, of mohair, camelhair, Alpaca, cashmere and wool, as a means of identifying the different fibre types.

Fourt[154] related differences in the lustre of wool and mohair mainly to differences in the scale structure, with crimp and fibre irregularities from the contributing factors. Decreased scatter from scales was one factor in the greater lustre of mohair compared with wool[154]. A shift in the reflectance peak away from the mirror angle, and dependant upon the root-to-tip orientation of the fibre, was found. The angular shift of this peak with reversal of fibre orientation was four times the angle between the scale surface and the fibre axis. This angle was larger for wool (a range 2.7° to 4.5° with an average of 3.7°) than for mohair (range 1.2° to 1.7° with an average of 1.5°). The scale angle was independent of fibre diameter.

A table (Table 56) has been given for the scale dimensions of wool and mohair[160,162].

Weideman and Smuts[692] found the average scale thickness of mohair to be about 0.5μm and that of wool about 1μm, with the average scale lengths about 23 and 18μm, respectively.

Ryder and Gabra-Sanders[835] found that the Width to Length (W/L) ratios of scales from various goat fibres showed a clear sequence from the wild ancestor (Capra Aegagrus) on the one hand to mohair on the other. They defined the scale width as equal to the fibre diameter. Indications were that the W/L ratio was independent of fibre diameter. They presented a table (Table 57) of results.

Many of the cuticle scales, particularly the "subscales", tend to be arrowhead- lance-shaped[895], "splits" on the scales also tending to be considered a characteristic of certain mohair fibres[895].

TABLE 55[77]
DESCRIPTION OF THE MICROSCOPIC APPEARANCE OF MOHAIR FIBRES

WHOLE MOUNT			CROSS-SECTION		CROSS-SECTION		SCALE PATTERN*		
Profile	Medulla	Pigment Distribution	Contour	Medulla	Cuticle	Pigment Distribution	Base	Mid-length	Tip
Fine									
Regular diameter, scales very shallow, frequently short streaks or vacuoles in the cortex	None	None or occasionally very sparse	Circular to oval	None	Thin	None or occasionally very sparse	Irregular waved mosaic, smooth; near to distant margins		
Medium									
Regular diameter, scales very shallow, frequently short streaks or vacuoles in the cortex	Fragmental	None or occasionally very sparse	Circular tp oval	Circular to oval	Thin	None or occasionally very sparse	Irregular mosaic mostly smooth, sometimes slightly rippled or crenate; near margins		Waved, crenate; near margins
Course									
Regular diameter, scales very shallow, frequently short streaks or vacuoles in the cortex	Fragmental or continuous	None or occasionally very sparse	Circular to oval	Circular to oval	Thin	None or occasionally very sparse	Irregular mosaic, smooth; distant to near margins, *or* simple waved, slightly crenate; near margins. These patterns may occur at random along the length of one fibre		
Kemps									
Fairly regular diameter, scales not very prominent	Continuous wide lattice	Usually none, occasionally sparse	Irregular, some ribbon type	Wide concentric	Thin	Usually none, occasionally sparse and even	Waved, crenate and near margins, *or* irregular, slightly waved mosaic, smooth; near margins. Some transitional between the two patterns		

TABLE 56[162]
THE SCALE DIMENSIONS OF SOME WOOLS

Fibre Type	Diameter (μm)	Number of Scales per mm	Scale Height (μm)
Australian Crossbred 46's	38	62	1,1
Australian Merino 90's	17,3	95	1,1
Australian Merino 60's	25	72	1,3
Romney Marsh 48's	35	66	1,1
Lincoln 36's	48	52	1,8
Cheviot 46's	49	52	1,3
Wensleydale 44's	47	41	1,1
Mohair 5's	34	50	0,4

TABLE 57[834]
CUTICULAR-SCALE MEASUREMENTS

Source/Genotype	Number of Animals (Samples)	Number of Fibres	Mean Scale Width (Fibre Diameter) (μm)	Mean Scale Length (μm)	Ratio of Mean Scale Width to Mean Scale Length	(SE)
Wild goat	1	2	8.9	8.23	1.08	±0.04
British Feral	4	19	12.3	11.3	1.10	±0.05
Australian Feral	2	8	14.1	12.7	1.14	±0.07
Chinese Fibre	4	36	12.7	12.1	1.18	±0.04
Toggenburg	2	7	13.8	11.6	1.22	±0.08
Togg X Feral	2	14	14.1	12.7	1.19	±0.06
1/4 Angora 3/4 feral	4	16	14.3	13.9	1.04	±0.05
1/2 Angora 1/2 feral	4	13	19.3	16.3	1.20	±0.03
1/2 Angora 1/2 Saanen	4	15	22.7	16.4	1.43	±0.10
Angora (mohair)	2	4	26.8	14.0	2.06	±0.31

10.7 Lustre

Lustre is one of mohair's most desirable attributes and attractions and is very important, a lack of lustre generally leading to a price penalty[977]. Mohair's excellent lustre is largely due to its relatively smooth surface resulting from its relatively thin and long scales (ie unpronounced or flat scales of relatively low frequency). *Basically, lustre relates to the manner in which light is* reflected from the surfaces. Light falling on a fibre surface can either be transmitted through or absorbed by the surface, or it can be reflected from it[605]. Depending upon the surface, the light can be reflected in two ways, firstly the surface can be such that the angle of the reflection of the light rays is equal to the angle of incidence, this being known as mirror or specular reflectance. Secondly, the light can be scattered in many directions through a number of angles of reflectance, this being known as diffuse or scattered reflection. In practice, reflected light comprises both specular and diffuse components, the higher proportion of the former the greater the lustre. Compared with other keratin fibres, light reflected from mohair fibres contains a high percentage of specularly reflected light, thereby causing the unique lustre of mohair[605], this being largely due to its relatively smooth surface as discussed above.

Fourt[154] related differences in the lustre of wool and mohair mainly to differences in the scale structure (decreased scatter from scales being one factor in the greater lustre of mohair compared with wool[154]), with crimp and fibre irregularities contributing factors. For undyed fibres, light scattering from internal points as well as reflection from scales from each side of the relatively transparent fibres could also play a role, this being eliminated when the fibres are dyed black. A shift in the reflectance peak away from the mirror angle, and dependant upon the root-to-tip orientation of the fibre, was found. The angular shift of this peak with reversal of fibre orientation was four times the angle between the scale surface and the fibre axis. This angle was larger for wool a (range 2.7 to 4.5° with an average of 3.7°) than for mohair (range 1.2 to 1.7° with an average of 1.5°). The scale angle was independent fibre diameter.

Barmby and Townend[171] found no effect of spinning speed or rewinding on yarn lustre as assessed subjectively in a woven fabric.

Maasdorp and Van Rensburg[596] investigated the goniophotometer measurement of the lustre of textile fibres, such as mohair, and showed that the lustre of mohair fibres was related to the scale characteristics, more specifically the scale thickness (height) of the fibres. **Van Rensburg and Maasdorp**[724] found that, for mohair, the mean scale height decreased with decreasing diameter. They found that the lustre of mohair was decreased by solvent extraction, heating and steaming. The inclination angles of the scales relative to the fibre axis decreased with decreasing mean fibre diameter as did the lustre. Finer fibres appeared to give higher lustre values than coarse fibres except when they were sputter coated, in which case the reverse applied[724].

It is always important that the good lustre of mohair be retained at all costs, it being particularly sensitive to pH, temperature and time during wet finishing (eg scouring, dyeing and finishing). Lustre can, for example, deteriorate during extended dyeing at boiling point, and reduced dyeing temperature (ie below the boil) and time are desirable provided dye exhaustion and fastness are not adversely affected. SAWTRI studied this problem by investigating various factors which may contribute to the problem[366,370]. Good quality Kid's hair was treated for increasing periods of time in various buffer solutions at various pH levels and at temperatures varying between 50° and 95°C. Yellowing (related to lustre) was found to be dependent on time and temperature, and to a lesser extent on pH. Subsequently, dyeings were performed on the mohair with three acid milling dyes at both 100° and 85°C. An economic dyeing formulation, utilizing the lower temperature (85°C), was found to require a chemical auxiliary to promote dyestuff absorption, as well as a lowering of the bath pH to increase the affinity of the dyestuffs for the mohair. Acidity or alkalinity of the aqueous medium in which the mohair was dyed also had an effect on lustre, there appearing to be a direct relationship between lustre and yellowing, the more yellow the mohair became, the poorer the lustre. The least loss in lustre was observed when the aqueous medium was slightly acid[366].

Van Rensburg *et al*[760] discussed the effects of scale structure and various dyeing techniques, including radio frequency (RF) dyeing, on mohair lustre. It appeared that RF dyeing had merit from the point of view of retaining the lustre of mohair.

Turpie[705] mooted the use of a gaseous chlorination treatment to improve the lustre of low lustre mohair.

10.8 General

The following information has also been published on other mohair fibre properties and mohair fibre properties in general.

TABLE 58[11]
SPECIFIC VOLUME IN BENZENE

Temperature °C.	Specific Volume in Benzene of				
	Southdown 56's	Wensleydale	Corriedale	Merino 60's	Mohair
25·0	0·7657	0·7667	0·7651	0·7641	0·7665
40·0	0·7665	0·7680	0·7668	0·7655	0·7680
55·0	0·7672	0·7692	0·7686	0·7670	0·7695

TABLE 59[11]
APPARENT SPECIFIC VOLUME OF DIFFERENT FIBRES IN WATER

Corriedale Temp. °C.	Corriedale Apparent Specific Volume		Australian Merino 60's Temp. °C.	Australian Merino 60's Apparent Specific Volume		Southdown 56's Temp. °C.	Southdown 56's Apparent Specific Volume
16·1	0·7134	...	0·0	0·7084	...	0·0	0·7064
26·4	0·7185	...	14·2	0·7148	...	15·5	0·7142
29·9	0·7193	...	25·0	0·7191	...	25·3	0·7180
35·0	0·7209	...	30·0	0·7205	...	31·3	0·7200
39·5	0·7229	...	34·8	0·7225	...	37·6	0·7217
44·8	0·7247	...	40·8	0·7244	...	44·8	0·7238
49·8	0·7265	...	45·6	0·7265	...	49·8	0·7248
53·7	0·7280	...	49·3	0·7274	...	55·1	0·7271
57·4	0·7294	...	55·2	0·7293	...	59·1	0·7291
		...	59·8	0·7296	...	65·0	0·7312
		...	64·3	0·7291	...		
		...	68·8	0·7289	...		

Mohair Temp. °C.	Mohair Apparent Specific Volume			Wensleydale Temp. °C.	Wensleydale Apparent Specific Volume	
0·0	0·7071	0·7073	...	0·0	0·7086	0·7082
15·2	0·7138	0·7133	...	13·3	0·7142	0·7138
25·9	0·7177	0·7177	...	25·8	0·7190	0·7189
30·3	0·7194	0·7194	...	30·9	0·7211	0·7107
34·4	0·7208	0·7208	...	35·9	0·7226	0·7224
39·6	0·7226	0·7224	...	40·4	0·7243	0·7242
45·1	·0·7249	0·7247	...	45·2	0·7261	0·7259
50·5	0·7267	0·7265	...	50·6	0·7278	0·7277
54·5	0·7280	0·7280	...	55·5	0·7295	0·7289
59·4	0·7296	0·7295	...	59·3	0·7304	0·7299
64·8	0·7315	0·7311	...	64·0	0·7323	—

The average specific gravity (relative density) of mohair and various other textile fibres has been given[31,994], the density (numerically equal to specific gravity or relative density) of mohair being of the order 1.27g/cc[299,343], although it is also quoted[994] to be 1.30g/cc and often assumed to be the same as that (1.31) for wool. The specific volume of wool and mohair in benzene is given in Table 58 while that in water is given in Table 59, the values being summarised and plotted in Fig. 28[11].

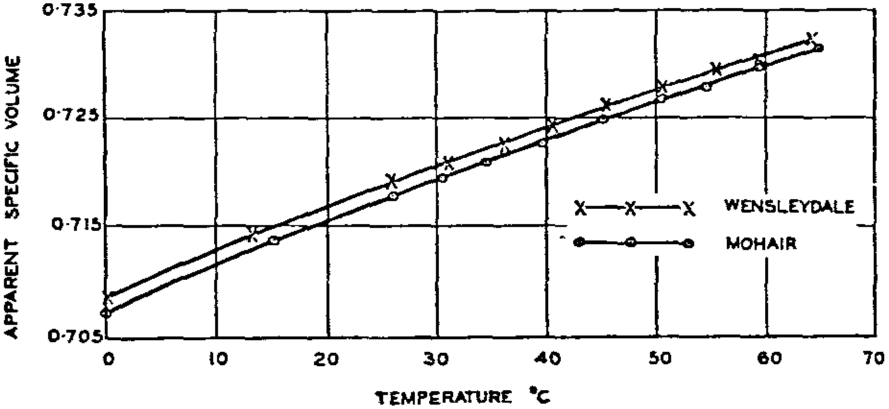


Fig. 28 Apparent Specific Volume as a Function of Temperature[11].

Kägi[108] discussed mohair and its use and presented a table of comparative properties.

Gurtanin and Blankenburg[219] reported on the chemical and physical properties of Turkish mohair (including naturally coloured) and summarised their results in the following two tables (Tables 60 and 61):

TABLE 60[219]
CHEMICAL PROPERTIES

Proben-Nr	Proben-Bezeichnung	pH-Wert	Alkali-löslichkeit in %	Harnstoff-Bisulfit-Löslichkeit in %	Alkaligehalt in %	Cystin-plus Cystein in %	Cystein in %	Cysteinsäure in %
1	Merinowolle	9,7	13,6	23.8	< 0,05	11,4	0.22	0,23
2	Teppichwolle	9.7	21.0	19.8	< 0,05	9.8	0.21	0.37
3	1. Kid-Mohair	—	23,2	66.8	< 0.05	10,9	0.24	0.26
4	2. Kid-Mohair	—	23,9	61,8	< 0,05	10,6	0,23	0,23
	Schwarzes Mohair:							
5	Schulterpartie	6.3	10,8	60.5	< 0,05	11,7	0,49	0,43
6	Seitenpartie	6,4	11,1	63.4	< 0,05	11.1	0,39	0,42
7	Beinpartie	6,7	11,3	59,3	< 0,05	11,8	0,45	0,43
	Braunes Mohair:							
8	Schulterpartie	6,1	12,3	64,0	< 0,05	11,7	0.30	0,27
9	Seitenpartie	6,3	14.2	66.0	< 0,05	11.5	0.27	0.24
10	*Beinpartie*	6,7	13,9	64.3	< 0,05	11,7	0,28	0.25

TABLE 61[219]
PHYSICAL PROPERTIES

Proben-Nr.	Proben-Bezeichnung	mittlerer Faser-Ø in µm	Variations-koeffizient des Faser-Ø in %	mittlere Filzdichte in g/cm³	Zusammendrückbarkeit in % bei den Belastungen: 12 p	20 p
1	Merinowolle	21,7	25,9	0,114	12,8	20,2
2	Teppichwolle	26,5	41,3	0,184	5,8	8,1
3	1. Kid-Mohair	25,8	31,5	0,125	20,0	32,5
4	2. Kid-Mohair	27,1	24,9	0,138	19,0	30,7
	Schwarzes Mohair:					
5	Schulterpartie	45,2	24,9	0,105	20,5	30,7
6	Seitenpartie	45,0	25,0	0,101	22,1	33,3
7	Beinpartie	42,6	34,5	0,113	18,8	30,3
	Braunes Mohair:					
8	Schulterpartie	45,2	23,6	0,100	13,4	25,3
9	Seitenpartie	45,4	25,0	0,093	20,5	29,5
10	Beinpartie	39,2	27,3	0,101	12,4	24,1

According to **Koch and Satlow**[125] (as quoted by **Fröhlich**[197]) mohair ranges from 10.3 to 11.3% in cystine content, from 11.2 to 16.8% in alkali solubility, from 9.6 to 12.2% in acid solubility and from 40 to 66% in urea-bisulphite solubility.

Fröhlich[197] found the fatty matter of scoured mohair to mostly range from 0.8 to 1.4% and the regain at 65% RH to range from 13.6 to 14%. He gave the following tables summarising his results (Tables 62 to 64).

TABLE 62[197]
PHYSICAL PROPERTIES OF DIFFERENT MOHAIR LOTS

Lfd. Nr.	Quellung in %	Sorption bei 65% r. h.	Filzkugel ø in mm a	b	Originallänge in cm	Feinheit in Mikron	Bruchlast kg/mm² trocken	naß	Dehnung in % trocken	naß
1	40,7	13,9	26/27	24/25	11,5	32,8	25,4	21,0	51,4	71,5
2	41,0	14,0	27/28	26/27	13,2	33,8	28,4	22,5	51,0	69,1
3	40,8	13,8	26/27	25/26	11,9	33,6	24,0	21,2	48,4	68,3
4	42,4	13,8	29/30	27/28	10,5	33,2	22,1	20,0	49,8	75,1
5	38,4	13,9	26/28	25/26	11,2	36,1	23,9	21,0	50,4	68,9
6	41,5	13,7	28/29	26/27	10,5	36,7	28,1	24,6	50,2	70,1
7	40,5	13,6	27/28	25/26	9,7	40,1	--	—	—	—
8	39,5	13,7	26/27	26/27	11,2	39,6	22,3	19,8	46,1	60,8
9	46,7	13,6	—	25/26*)	—	36,7	19,8	18,2	48,5	67,3
10	47,2	13,8	—	25/26*)	—	42,6	—	—	—	—

*) Muster 9 u. 10 lagen nur in gekrempeltem Zustand vor

a) Prüfung b. voller Länge, b) Prüfung b. gekürzter Länge (ca. 2,5 cm)

TABLE 63[197]
MOHAIR FIBRE LENGTH CHARACTERISTICS

Lfd. Nr.	mittlere Stapellänge in mm nach dem Krempeln Häufigkeitsstapel	Gewichtsstapel	V in %*)	Länge der Locken vor dem Krempeln in cm	Kurzfaseranteil in % bis 10 mm Länge a	b	bis 20 mm Länge a	b
1	47,1	85,9	90,7	11,5	26,9	3,3	39,1	7,2
2	51,1	87,3	84,1	13,2	21,5	2,2	34,5	6,2
3	48,4	86,1	85,2	11,9	22,6	2,0	35,1	6,5
5	46,3	80,4	81,5	11,2	18,8	1,4	30,2	5,9
6	63,9	90,1	65,9	10,5	0,0	0,0	15,9	4,4
7	44,9	73,8	78,4	9,7	10,7	1,0	25,3	4,8
8	49,5	86,3	86,4	11,2	12,7	1,1	24,9	4,5
9	51,2	80,6	75,7	—	1,7	0,3	13,7	4,1
10	49,3	87,3	87,7	—	23,3	2,6	36,6	6,9

*) Variationskoeffizient der Längen
a) nach der Faserzahl
b) nach dem Fasergewicht.

TABLE 64[197]
COMPARATIVE VALUES FOR MOHAIR GIVEN BY SATLOW AND FRÖHLICH

Kennzahl	Mittelwerte u. Vertrauensbereich*) nach Satlow 14)	nach Fröhlich
Alkalilöslichkeir (0,1 n NaOH	13,6 ± 1,4	16,4 ± 4,2
Säurelöslichkeit in % (4,5 n HCl)	11,1 ± 0,8	8,8 ± 2,2
Harnstoff-Bisulfitlöslichkeit %	59,5 ± 3,3	57,5 ± 5,9
Cystingehalt in %	10,7 ± 0,7	10,6 ± 0,2
Quellung in %	36,9 ± 1,7	41,5 ± 2,2
Sorption in %	14,1 ± 0,4	13,8 ± 0,1

*) Vertrauensbereich mit 95 % gesichert

Lai and Onions[319] investigated the lateral crushing (compression) of mohair and other fibres, the deformation of mohair fibres with changing load being relatively small, plastic flow occurring at a given lateral pressure, distinctive for each fibre type[319]. **Smuts** *et al*[666] investigated the effect of certain fibre properties on the bulk resistance to compression of mohair, the latter increasing very slightly as the fibre diameter or degree of medullation, or both, increased. A value of about 12mm compressed height (SAWTRI Compressibility Test) was typical for mohair, this being lower than the value of 13.7 found for lustre wools[666]. Steam relaxation of the scoured mohair and the mohair tops only increased the bulk resistance to compression very slightly.

Patni *et al*[656] compared the physical and mechanical properties of angora rabbit hair, mohair and other fibres. **Anson**[389] also reported on the physical properties of mohair. **Horikita** *et al*[955] gave the following table (Table 65) of properties for various animal fibres.

TABLE 65[955]
PHYSICAL CHARACTERISATION OF WOOL AND HAIR FIBRES

Specification	Density in bulk (gr/cc)*	Thickness in diameter (μm)	Scale density (mm^{-1})	Ortho/para/medulla ratio (%)**	X-ray crystallinity (%)
(sheep family)					
Australian Merino 66's wool	1.308_5	25	80	63/37/0	25.2
Australian Merino 64's (descaled)	1.311_1	25	(90)	68/32/0	——
Australian Merino 60's wool	1.307_1	35	88	66/34/0	27.1
Argentine X-bred 56's wool	1.300_5	35	90	71/29/0	26.6
Argentine Luster wool	1.292_5	50	57	76/20/4	30.9
New Zealand Luster 48's wool	1.306_2	35	84	70/30/0	25.9
New Zealand Luster 48's (descaled)	1.308_9	35	(84)	67/33/0	28.9
Lincoln wool	1.296_2	45	50	69/31/0	29.0
(goat family)					
Cashmere wool (white)	1.308_1	20	64	62/38/0	25.5
Cashmere wool (brown)	1.311_0	20	66	67/33/0	——
South Africa Adult Mohair	1.305_5	50	57	71/29/0	21.3
(camel family)					
Camel hair	1.306_8	20	56	indistinguishable	21.2
Alpaca hair	1.280_0	33	120	53/38/9	25.1
Llama hair	1.277_3	44	110	50/43/7	28.7
(rubbit)					
Angora Rabbit	1.258_7	20	120	87/13(M)	28.5

* Determined by a density gradient column method of n-heptane/CCl_4 at 30.0 ± 0.1 °C.

** Optical microscopy staining by methylene blue.

\+ Co-axial distribution of ortho and para cortices, instead of bi-lateral distribution.

++ Ortho and para cortices can not be distinguished.

Hori[838] also discussed the properties of mohair and other animal fibres.

CHAPTER 11

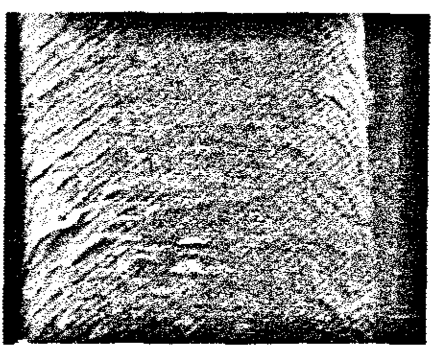
MEDULLATION AND KEMP

11.1 Introduction

Medullated fibres in mohair can be a source of problems in many end uses when they differ in appearance from the rest of the fibres which are not medullated[606,802,997]. They are characterised by having a central canal (medulla) containing cell residues and air pockets, running in either a continuous or fragmented form along their length (Fig. 29). The term "kemp" is probably more familiar, but this traditionally refers to the more problematic and extreme form of medullated fibre which is clearly visible to the naked eye. The main problems associated with the presence of kemp (perhaps more correctly termed "objectionable" medullated fibres) are their chalky white appearance and lighter appearance after dyeing [87,606,802] and also to a lesser extent their effect on handle, stiffness and prickliness[606,997]. The chalky white appearance of kemp is caused by the decreased length of the light path through the fibre material and

— Classification of Medullae*

(a) Unbroken lattice (wide)
(b) Simple unbroken
(c) Interrupted
(d) Fragmented
***Wildman**



— Kemp

— Mohair

Fig. 29 Classification of Medullae*[812]
Fig. 30 Kemp[812]
Fig. 31 Mohair[812]

light refraction at the fibre/medulla interface. This, and not poor dyeability, is considered to be the main cause of the different appearance of kemp fibres after dyeing[155,191]. Because medullated fibres (and particularly kemp) tend to lie on the surface of the yarn[495] (and therefore also on the surface of the fabric), the visual and other effects produced by kemp will normally be out of proportion to the actual quantity present in a particular mohair lot. Generally, the presence of even a small amount of kemp in a high quality mohair may have a pronounced adverse effect on its value. Higher grades of mohair are largely free from kemp and medullated fibres, the kemp content being well below 1% in well-bred mohair.

Medullated fibres, which contain a discontinuous (fragmented or broken) medulla are generally referred to as heterotype or "gare" fibres[606]. Heterotype fibres are therefore medullated (or "kemp like") in certain sections and "normal" (ie solid) in other sections. Heterotype mohair fibres containing medulated tips have also been referred to as "gare" fibres[737], it being stated (**Jones**[13] quoted in Ref. [765]) that they tend to be relatively coarse and medullated at the tip but finer and non-medullated at the base. **Harmsworth and Day**[977] refer to "gare" fibres as long kemp fibres but it appears as if heterotype and gare fibres are the same[898]. It has been stated[684] that "gare" fibres were a greater problem than kemp fibres in Australia[765]. Heterotype fibres are generally longer, and therefore more difficult to remove, than shorter kemp fibres, and are said[104] to occur more often in Summer hair.

Kemp is usually straight and oval in cross section[87]. Of all the types of medullated fibres which occur in both wool and mohair, those collectively called kemp and which tend to have a relatively large medulla and to be relatively coarse, probably are the most visible and unwanted in the final product. Kemp occurs as short kemp, long kemp and heterotype fibres. The "short kemp" is generally the most common, being short, chalky-white, medullated and pointed at each end when it has fallen out and was not shorn off[104]. Small portions of multiple medullae are also occasionally present in mohair fibres[111].

Hunter[812,813] gave an electron microscope photograph of kemp, illustrating its surface appearance (see Fig. 30 Kemp[665]) compared to that of mohair (Fig. 31).

Although there are occasions, when kemp fibres are acceptable or even desirable for special effects, such as in certain types of carpets and woollens, in most cases the presence of even a small amount of kemp in a high quality mohair, normally free and expected to be free, from such fibres, may have a pronounced adverse effect on its value. Higher grades of mohair are largely free from kemp and medullated fibres, and tend to be more circular in cross-section than lower grades[36].

Kemp is always present in the fleece of the Kid[6,104] and is present in the hair of all animals[606] to a greater or lesser extent[6]. In well-bred mohair the kemp count is generally low (less than 1% according to **Von Bergen**[105]) and after processing, a value of less than 0.3% should be aimed at, according to **Spencer**[233]. The amount of kemp can be controlled by selective breeding, although it may not be possible to eliminate it entirely[72,309]. For example, many years ago, the amount of kemp in South African mohair ranged fairly widely[72,104] but since then, due to selective breeding, the quality of South African mohair, which is now generally rated as one of the best in the world, particularly in terms of kemp, has greatly improved with respect to kemp. Nowadays South African (Cape) mohair, for example, generally contains very little kemp (considerably less than 1% kemp), mohair containing more than 1% kemp today being regarded as cross-bred. By selective breeding, the percentage kemp can be reduced to as little as 0.1% (by mass)[153,172].

Not surprising, **Srivastava**[309] found that, for both yarns and fabrics (woven as well as knitted), the main effect of kemp was a visual or aesthetic one. He did find, however, that above a certain level of kemp, yarn hairiness, irregularity and stiffness were significantly affected by the kemp content. This also appeared to apply to a lesser extent to the fabrics.

As already mentioned, kemp is a special, extreme, case of medullation but there does not appear to be a readily definable and objectively measureable distinction between kemp and other medullated fibres, particularly when they occur in semi-processed or processed mohair. There are traditional definitions of kemp but these do not consistently differentiate between visually "objectionable" and "acceptable" fibres. According to ASTM method D2968-89, those fibres with such a ratio greater than 0.6 are classified as "kemp" and those with a ratio smaller than 0.6 are termed "medfibres". Nevertheless, studies by **Hunter** *et al*[1093] have shown that fibres visually assessed as "objectionable" (ie "kemp type") have a mean ratio of about 0.5, both in the case of dyed and undyed mohair.

Apart from the appearance and coarseness of "kemp" type fibres, the length of such fibres is another very important property[4]. Much of the kemp, more particularly the shorter kemp, can often be removed during combing[34,87] (and even during carding), and is reflected as a processing loss (waste)[87]. The longer type of kemp is more unacceptable, because it is more difficult to comb out than the shorter kemp[87]. Aggravating the matter is the fact that the diameter of kemp can also increase with increasing mohair diameter[4], in certain cases the degree of medullation and kempiness (% kemp) in mohair also tending to increase as mean fibre diameter increases[309,765].

11.2 Occurrence and Growth of Kemp and Medullated Fibres

Powell[618] explained the formation of medullated and kemp fibres as follows: The apex of the papilla dome opens upward into the centre of the growing fibre allowing cells of the basal skin layer to be incorporated into the centre, forming what will become the medulla. During the keratinisation of the fibre, the skin cells may partially or completely break down and dissolve. The less hairy fibres contain a simple hollow canal medulla in which almost all of the skin cells have completely dissolved. In kemp and coarse hairy fibres the interior of the skin cells have dissolved leaving a hollow network of cell walls to form the medulla. **Clement** *et al* (quoted by **Powell**[618]) contended that this network of cells (aerian vesticles) was filled with air, the walls of which are cytoplasmic remnants of the basal layer cells. The aerian vesticles vary in protein composition from the components of a normal fibre. It has been noted that the protein of the scales (cuticle) and cortex of a normal fibre contained larger amounts of sulphur than the medulla.

Kemp is considered a sign of impure blood dating back to the crossing of Angoras with other goats[87]. In the newborn kid it represents the outer protection kempy coat (guard hair) of wild sheep and goats[6].

Fibres arising in the primary follicles tend to be coarse and may be medullated or kemp fibres[535]. Kemp usually arises from the central primary follicles but is also found in the lateral follicles[6,533], while the ordinary medullated fibres appear to grow from other primary or even secondary follicles. Kemp tends to be shed seasonally, **Duerden and Spencer**[6] stating that kemp fibres are always shed. They also intimated that a reduction in nutrition reduces fibre diameter and could lead to the disappearance of the medulla. **Margolena**[144] (quoted by **Clake and Smith**[376]) found that medullation was confined to the central primaries. The kemp content of the coat reflected the S/P ratio[765]. According to **Shelton and Bassett**[535] since primary follicles develop first and fibre production begins in these prior to birth, the kid is born with a birth coat in which fibres from primary follicles are most prominent. For the most part, these early kemp fibres will be either shed or continue to grow as a true mohair fibre without medullation. These primary follicles are almost always present, yet it has been shown that the problem of kemp can be reduced by selection [535]. Kemp hereditability is considered[785,826,984] relatively high, with selective breeding (ie genetic methods) more effective for reducing kemp than environmental methods [996]. **Van der Westhuysen** *et al*[728] also stated that kemp levels were hereditary but that the hereditary potential is influenced by environmental factors. In terms of the South African Angora goats, for example, hard white ears and a hard white face are signs which usually indicate the presence of kemp[533], hard tails also being associated with kemp. Proper selective breeding is today widely accepted as the best way of reducing kemp levels and today high quality mohair exhibits no visible signs of kemp fibres. It is not known how selection operates but the following has been suggested[535]:

1) An increase in the number of secondary follicles reduces the proportion of primaries, and thus the potential proportion of kemp fibres in the fleece.
2) Compaction resulting from increased fibre density causes the fibres arising from the primaries to be finer and thus less distinguishable.
3) The primary follicles may become cyclical in nature resulting in their fibres being shed from the fleece or may become totally non-functional[535].

Tiffany-Castiglioni[765] speculated that the factor of ultimate importance in the selection for kempless goats was the inactivation at maturity of the primary follicles or their production of non-kemp fibres. Selection for increased fleece mass could result in increased kemp and medullation levels[913,996].

The fleece of a newly born Angora Kid can consist of a large proportion (up to about 45 to 50%)[163] of relatively coarse medullated and kemp fibres but the amount of kemp then decreases rapidly (eg to about 7% at the age of 3 to 4 months)[87,163,533,984]. Shedding of the kemp fibres commences soon after birth[163] and continues up to three months of age or when most of such fibres had been shed[163], so that little remain at the time of shearing[104]. The first shearing therefore contains more loose kemp than the second shearing[104]. Although kemp fibres tend to be shed annually[87] this is generally not the case for mohair. Pronounced differences in S/P ratio, number of follicles per goat, degree of medullation and presence of medullated and kempy fibres exist between animals less than 3 months old and those older[163]. A rapid decline of both the percentage as well as degree of medullation occurs after birth, the most rapid decline reportedly being in the unbroken and interrupted medullated fibres, the fragmental medullated fibres persisting longer[163]. During the Summer medullated fibres reportedly become coarser, decreasing towards Winter [163].

In newborn kids, the kemp fibres have been reported to have an average fibre diameter of about 45μm compared to about 25μm for the mohair fibres[728]. Nevertheless, although there is a trend for medullated fibres to be coarser than non-medullated fibres[6] this is not necessarily the case. It appears that the age of the goat may not affect the diameter of medullated fibres as much as is the case with non-medullated fibres[163], the kemp and medullated fibres generally being considerably coarser than the true mohair in Kids and Young Goats but not in Adults[163]. It has been reported[6,87], for example, that the diameter of kemp fibres in the new-born kid is about 43μm on average, and that in the mature goat about 45μm. The normal increase in fibre diameter with the age of the goat, is initially offset (often more than offset) by the shedding of relatively coarse kemp and medullated fibres[163]. Recent results of **Hunter** *et al* [1093] indicate that "objectionable" medullated fibres are generally coarser (60% and more) than the mean of the parent population (see Fig. 39).

According to one study[683], kemp levels appeared to be little affected by the age of the animal, although it appeared to increase slightly with age for the rams, the rams also appearing to have more medullated fibres than does and wethers. According to other workers[13] goat age has a slight effect on kemp and medullated fibre levels, these levels increasing gradually over the lifetime of the animal after maturity[13]. Based upon studies in Turkey, **Müftüoglu** (quoted by **Srivastava**[309]) concluded, however, that kemp levels decrease with age up to a certain stage and then remain constant until adulthood has been reached, feeding appearing to have no effect on kemp. According to some sources, kemp is more commonly observed in the very young animals and in the older animal which is explained by variations in the S/P ratio or density of the fleece (the number of follicles per bundle can be represented by the S/P ratio).

The kemp fibres on a newly born kid are approximately three times the length of the genuine mohair fibres but the latter grows so rapidly that at the early stage of three months it is already twice the length of the kemp fibres. In new-born kids, the length of kemp is about 36mm and hardly changes in length there-after, where-as the length of the mohair is about 12mm and increases to about 70mm at 3 months[6]. Adult kemp fibres are stated to be usually 30 to 40mm in length and 40 to 60mm in Basuto mohair.

Up to the age of 21 months there appeared to be little difference between wethers and does in terms of levels of medullated fibres but after that age wethers had significantly more medullated hair than does, eg 4.6% vs 1.9% at two years of age[163]. The lowest number of kemp and other medullated fibres was reportedly recorded at the ages of 12 and 24 months, coinciding with Spring, with the highest number occurring in Summer[163], decreasing towards the following Spring. Fibre shedding is presumed[765] to be influenced by both hereditary and environmental factors, some animals shedding mohair in Spring[223]. Reportedly, kemp levels may be higher in Autumn than in Spring for adult males and young wethers and does[163,388,732,765], it being speculated[388] that kemp grows in a seasonal manner, more actively in Spring and Summer and less actively in Autumn and Winter. **Pohle** *et al*[306] found that there was about twice as much kemp in the US Autumn (Fall) clip than in the Spring clip, with the average percentage of kemp (defined as those fibres with a medulla diameter 65% or more of the fibre diameter) similar in the grease mohair, card sliver and top, but twice as high in the noil than in the top. Australian Summer shorn fleeces contain more kemp, kemp growth being most active from September to December[451] (**Stapleton** quoted in Ref. [828]), September shearing producing fleeces with less kemp than December shearing[828], **Stapleton** (quoted by **Ryder**[785]) stating that the amount of kemp in the fleece could be reduced by shearing earlier in Spring, whereas **Bingham** *et al*[996] stated that the choice of shearing time had little effect on kemp and medullation levels. **Ryder**[1002] stated that kemp ceased to grow in winter while hair and gare continued to grow but without a medulla.

McGregor[1018] reported on the effect of stocking rate on the incidence of kemp and medullated fibres. He[784] found that kemp incidence was unaffected by stocking rate. According to work done in Turkey, by **Müftüoglu**[97], differences in feeding did not affect the occurrence of kemp, with the amount of kemp decreasing with age up to a certain age after which it remained constant until adulthood had been reached. **Calhoun** *et al*[886] found that dietary energy had no effect on the percentage of medullated and kemp fibres in mohair. High feeding levels (ie better nutrition) may, however, increase or accentuate the presence of kemp somewhat, mainly because such feeding increases fibre diameter and makes the kemp and heterotype fibres more clearly visible[87,773,996,1011]. **Badenhorst** *et al*[1058] also found higher kemp levels to be associated with higher nutrition, while **Bingham** *et al*[996] stated that the level of nutrition required to reduce kemp levels was very low and would result in reduced fleece mass and growth rates. In apparent contrast to the above, **Harmsworth and Day**[977] stated that mohair fibres become medullated under conditions of severe nutritional stress. The precise effect of nutrition on kemp and medullation therefore appears to be unclear.

Venter[72] and other workers[533] found that the back and rump of the goat had more kemp fibres than other body regions, most kemp reportedly appearing to occur along the middle of the back[811]. According to certain workers[6], kemp is usually found to be more abundant in the britch and less so over the shoulders and along the back and sides. **Bassett**[732] found that for Adults, the rump, britch and adjacent to the tail areas contained most kemp while the midneck, side and withers had the lowest. The Kids had high levels in neck, withers, rump and britch and low levels on the back and side. On average, the animals sampled in September had more kemp than when they were sampled in January. It has been reported[733,999] that the side samples do not always produce medullation counts representation of the whole fleece.

Margolena[144] found that the type of lock was related to the degree of medullation, the ringlet type locks being associated with the lowest degree of medullation. According to **Hardy** (quoted in Ref. [309]) very lustrous mohair tended to be free from kemp.

Tiffany-Castiglione[765] reviewed the genetics and management of kemp in mohair while **Bingham** *et al*[996] discussed the manipulation of kemp and medullation in mohair by breeding and management.

11.3 Physical and Mechanical Properties

Kruger and Albertyn[127] found that the tenacity (ie fibre cross-section corrected strength) of kemp fibres was lower than that of mohair, where-as extension at break did not differ by much. Work by **Hunter and Kruger**[153,172], indicated that the medullae of kemp fibres contained a material which did not contribute significantly towards the breaking strength of the fibre but which had a dielectric constant comparable to that of the rest of the fibre. They found that the breaking extensions of merino, German merino, mohair and kemp fibres were similar, while the specific breaking strengths (tenacities) of the merino and German merino fibres were lower than those of the mohair and kemp fibres. The fibre tenacity of the mohair was 14.7 cN/tex and that of the merino and German merino wool was 11.4 cN/tex. If the linear density of the kemp fibres was calculated from the cross-sectional area of the cortex alone (ie assuming a hollow medulla) a tenacity of 15 cN/tex was obtained but if the medulla material was reckoned in, a tenacity of 13.2 cN/tex was arrived at[153,172].

King[173] reported that the medullae of kemp fibres differed in optical density, indicating different cell densities and this affected the bending but not the extension moduli. Two types of kemp, one with a filled medulla and the other with a virtually empty medulla, were postulated. For the empty medullae, the bending and extension moduli of the kemp were similar at about 77 cN/tex whereas the filled medullae gave a bending modulus of about 365 cN/tex which was higher than that found for mohair[173]. The extension moduli of the two types of kemp fibres were similar indicating that any material in the medullae did not contribute to the tensile properties of the fibre, which was in agreement with the results of **Hunter and Kruger**[153,172].

Frequency distribution curves have been given[606] for various characteristics of kemp and other medullated fibres and the relationship between certain of the characteristics have been illustrated graphically, see for example Fig. 32.

It was confirmed that the medullated fibres are generally coarser than the non-medullated fibres with the medulla diameter increasing as the fibres become coarser. For the particular samples covered, there was no relationship between the degree of medullation and the mean fibre diameter of the sample although there was a tendency for an increase in the degree of medullation to be associated with an increase in the CV of fibre diameter[606].

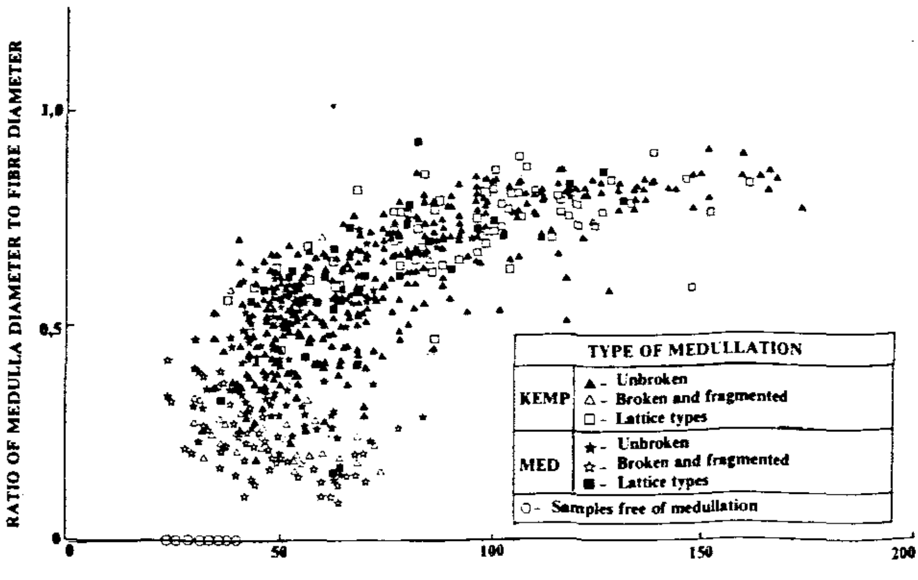


Fig. 32 The Relationship between the Medulla Diameter to Fibre Diameter Ratio and Fibre Diameter[459].

Srivastava[309] investigated the occurrence and properties of kemp and medullated fibres. He found that kemp fibres varied more in cross-section than solid (mohair) fibres and exhibited lower extensions at break. On the basis of this he designed a stretch breaking apparatus (pair of fluted rollers), a modified gill box, with the aim of stretching the fibres until the kemp broke (preferentially) after which the shorter (broken) kemp fibres could be more easily removed during combing.

11.4 Geometrical Properties

Work was undertaken by **Smuts and Hunter**[802] to establish what distinguishes kemp (ie objectionable medullated fibres) from other medullated (ie non-objectionable) fibres. To this end, the medullated fibres from 54 undyed mohair samples were visually sorted as follows:

1) Chalky white fibres (termed Kemp A) which were easily distinguishable in air and therefore "objectionable" in most quality end-uses.
2) Chalky white fibres which were less distinguishable in air and consequently less "objectionable" (boderline and termed Kemp B).
3) Fibres (termed MED or medullated fibres) which were only distinguishable in benzyl alcohol after removal of the chalky white fibres. These fibres would generally not be considered "objectionable" in practice.

The above fibres were examined on a projection microscope and the diameter of the fibre and that of the medulla recorded. It was found that the medulla diameter to fibre diameter ratio did not consistently distinguish between the various categories of medullation, especially between Kemp A and Kemp B. The more obvious "objectionable" kemp fibres (Kemp A), however, generally had ratios above 0.5 (above 0.55 for dyed fibres) while the medullated (MED) fibres, which did not appear different in air, mostly had ratios below 0.5. Later work[1093] indicated that "objectionable" medullated (ie kempy) fibres in fact had an *average* ratio of about 0.5 (see Fig. 33), varying from about 0.20 (20%) to about 0.80 (80%), this applying to both dyed and undyed fibres[1093].

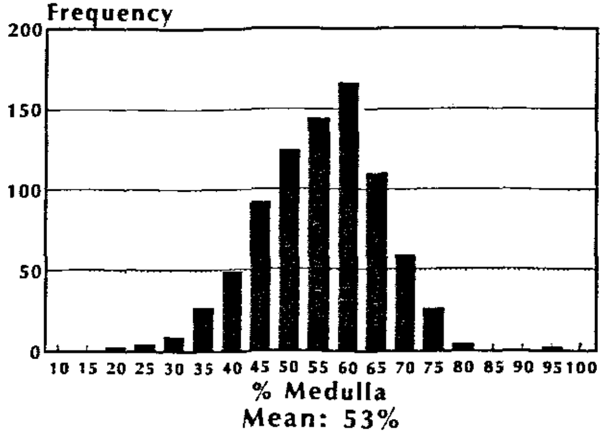


Fig. 33 Medulla to Fibre Diameter Ratio of "Objectionable" Medullated Fibres (Expressed as a Percentage[1093].

Teasdale[898] *also reported that medullated mohair fibres formed a continuum* and the medulla to fibre diameter ratio could not be used to differentiate between the different types of medullated fibres (kemp and heterotype), a ratio of about 0.4 separating "broken" medullae from unbroken ones.

The wall thickness of kemp-type fibres varied from about 5 to 20μm (approximately 10μm on average), the width of the cortical cells being about 5μm[368] (quoted in Ref. [898]). The diameter of kemp fibres varied from about 40 to 240μm, with the medulla diameter generally linearly related to the fibre diameter[898].

11.5 Chemical and Physical Nature of the Medulla

The medulla consists of a hollow network of cell walls (aerian vesticles), filled with air, which are cytoplasmic remnants of the basal layer cells (**Clement** *et al*, quoted in Ref. [618]). The chemical composition of medullary cell residues *appears to be different from that of the cortical cells*[9,23]*, the medullary cells* containing little, if any sulphur[2]. **Swart**[139] showed that the amino-acid composition of kemp was different from that of adult mohair and that the medullated fibres contained more β-keratose but less γ-keratose than true mohair. It was reported (**Mercer**[28] quoted by **Tucker** *et al*[992]) that the proteins of the medullary cells are of a non-keratin type and therefore exhibit different chemical behaviour to the keratins. They are easily broken down by proteolytic enzymes but have a high alkali stability (**Kusch and Stephani**[641], quoted by **Tucker** *et al*[992]). The levels of amino acids citrilline, glutamic, lysine and leucine, in the medullary cells, are higher than those present in the whole fibre whereas glycine, serine, proline, threonine and particularly cystine are lower (Refs [194,250]) quoted by **Tucker** *et al*[992]). Because of the failure to distinguish reliably between objectionable and other medullated fibres on the basis of dimensional (such as medulla to diameter ratio) differences, **Smuts and Hunter**[788,802,812,997] decided to investigate whether or not the physical appearance and nature of the medulla were perhaps different. The different types of medullated fibres were examined on a projection microscope and classified according to whether the medulla appeared "normal", latticed or a mixture of the two. It was found, that the medulla type so assessed (ie lattice or non-lattice) did not help to distinguish more reliably between kemp (ie "objectionable" medullated) and other medullated fibres as assessed visually. The question then arose as to whether or not differences in some other fibre characteristics were responsible for differences in appearance of medullated fibres having the same ratios. Longitudinal and cross-sections of the different types of medullated fibres were examined on a scanning electron microscope[812]. No feature of the fibres surface or medulla, which could explain why the different types of medullated fibres differed so markedly in their visual appearance, however, could be identified. Some examples of scanning electron microscope photographs are shown in Fig. 34[812]. These clearly illustrated the cellular appearance of the medulla, which was in no case found to be totally hollow or void of cell residues.

Knott[978] discussed the nature of the medulla in speciality animal fibres. Contrary to the cortex and cuticle, the medullar vacuole walls are very resistant to alkali and to other keratinolysed agents (Ref. [284] quoted in Ref. [978]).

11.6 Dyeing Behaviour

Hirst and King[3] found that the medulla substance in kemp dyed equally to the solid portion, the different appearance of dyed kemp fibres being solely due

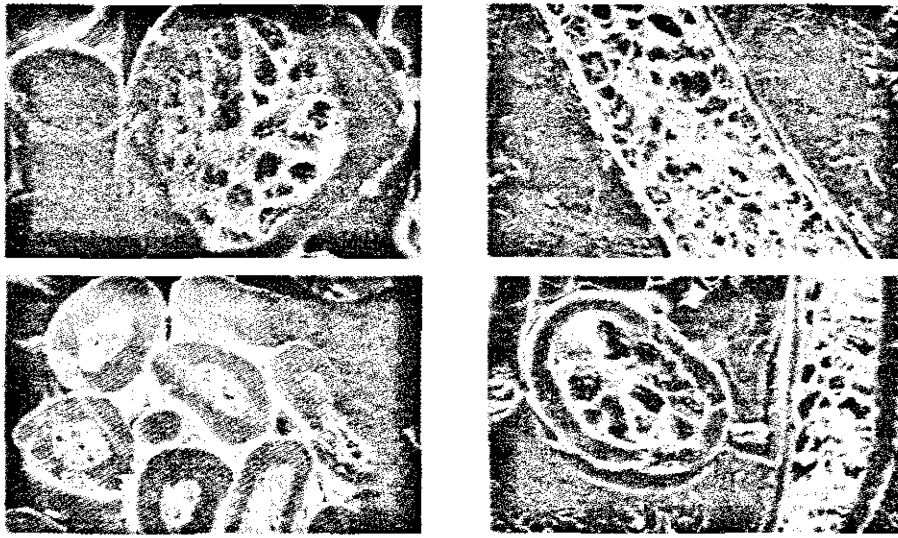


Fig. 34 Cross-sections and Longitudinal-Sections of Medullated Fibres Illustrating the Cellular Nature of the Medullae[771,812].

to the enclosed air (ie reflection of light). **Kriel** *et al*[155] found that the dye exhaustion curves (for the one dyestuff investigated) of kemp ($67.5\mu m$) and BSH mohair ($37.7\mu m$) coincided completely (ie their dyeing behaviour was the same) although the kemp did not have the same apparent depth of shade as the BSH or BSFK mohair, dyed with the same concentrations of dyestuff.

The flattish (oval) shape of kemp fibres can also affect their appearance, because of the associated differences in light reflection.

Swanepoel[191] summarised the current knowledge on the dyeing behaviour of kemp fibres in mohair, stating that the belief that kemp fibres do not dye at all was erroneous and that there appeared to be little difference in the dyeing behaviour of the keratin in mohair and kemp, with kemp fibres appearing to dye at the same rate as mohair. Observed differences between the appearance of dyed kemp and mohair fibres were largely ascribed to differences in the way light was reflected from within the fibre. He gave a detailed explanation of this effect. Since the difference in appearance of dyed kemp and mohair fibres is based on a difference in colour saturation, hues in which such differences are less easily detectable are most suitable for camouflaging kemp. Yellow is one of the best colours for camouflaging kemp. Green and red are less suitable than yellow but better than blue, while brown and black give a very high contrast between mohair and kemp. Contrast in the appearance of dyed kemp and mohair fibres can be reduced if pastel shades are used, differences increasing with increasing colour saturation[191].

Powell[618] discussed the properties and dyeing of the medulla of kemp fibres and also stated that the apparent differences in optical properties of kempy fibres were due to the different optical properties of the hollow network of cell walls (aerian vesicles) in the medulla, their light transmission properties approaching those of the solid fibre wall as they become filled with water or oil. Water entered the medulla from the circumference within about 10 minutes *whereas oil entered from the ends, or damaged places, by capillary action and* usually did not fill the entire medulla. He found that the aerian vesticles do absorb dyestuff, even being a darker shade than the cortex/cuticle portions of the fibre (possibly due to the high number of surfaces present in the aerian vesticles). The "white" appearance of dyed kemp fibres was therefore largely due to the light reflection and absorption characteristics of the aerian vesticles (because of the high number of surfaces available) and the casing surrounding them, rather than to the differences in dye uptake. He suggested that filling the medulla of kemp fibres by means of a translucent medium, which will not be lost during laundering and use, could eliminate, or at least reduce, the difference in appearance of kemp fibres.

Further studies[3,771,792,812,813] have been undertaken to compare the dyeing behaviour of medullated fibres, more particularly kemp and medullated fibres. Most results suggested that the solid material of the kemp (ie their walls) and the normal mohair fibres in many cases dyed to approximately the same colour (shade) as illustrated in Fig. 35. This work supported previous findings that the different appearance of kemp in a dyed sample is largely an optical effect due to the reduced light path through the dye in the fibre wall and refraction and reflection of the light at and within the medulla. It also appeared that kemp fibres can be more or less apparent (ie visually different), depending upon the colour and depth of shade to which the material is dyed.

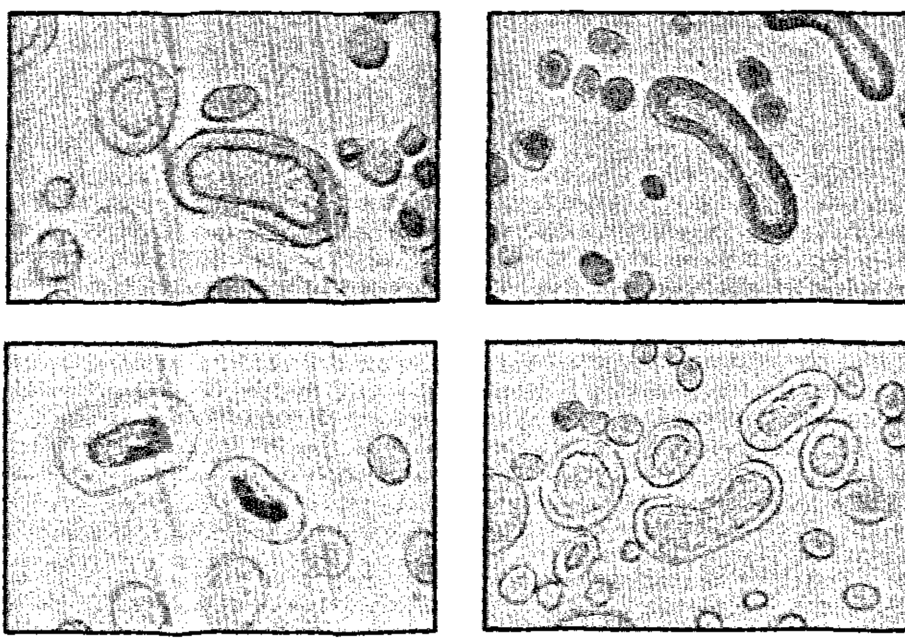


Fig. 35 Examples of Dyed Mohair, Unmedullated and Medullated[812].

Later studies by **Trollip** *et al*[792,876], indicated that the take-up of premetalised dyes containing chromium may be different for mohair and kemp, possibly due to differences in surface area per unit mass, rather than to differences in the cortex of the two types of fibres which contained similar levels of sulphur. They found that the medulla of the kemp contained a significantly higher concentration of dye than the cortex, which they ascribed to the fact that the medulla comprised of inter-cellular material having a relatively low level of sulphur.

11.7 Measurement of Kemp and Medullation

11.7.1 General

Clearly, a knowledge of the degree of medullation, more particularly kemp (also termed "objectionable" medullated fibres), in a sample is desirable, and various methods exist for measuring the degree of medullation, including manual separation (in air or in a suitable liquid), microscopic, flotation, gravimetric/chemical and refraction. Most of the abovementioned methods are rather time consuming, however, and also require a rather skilled and experienced operator [606]. The absence of a clearly defined basis (ie measureable or objective criteria) for distinguishing between kemp (ie visually "objectionable") and other medullated (ie visually acceptable) fibres, complicates the objective measurement of kemp fibre and so, too the lack of agreement between different operators as to what constitutes a kemp fibre. According to the ASTM D2968-83[585] (or ASTM D2968-89)[1092] standard test method, for medullated (Med) and kemp fibres in animal fibres by microprojection, for example, a kemp fibre is defined as a medullated fibre in which the medulla is 60% or more of the diameter of the fibre. Kemp has also been defined as those medullated fibres which have a medulla to diameter ratio exceeding 0.65 (65%)[535,732], with medullated fibres having a medulla to fibre diameter ratio less than this, frequently not a problem to the textile processor. It has been shown, however, that neither of these two criteria allows one to consistently distinguish between "objectionable" medullated fibres (ie kemp) and other medullated fibres. **Hunter** *et al*[1093] found that different laboratories all classified fibres with an average medulla to diameter ratio of about 0.5 (the individual values varying from about 0.2 to 0.8) as "objectionable" (both for undyed and dyed samples), with the different laboratories differing in the average diameters of the fibres they classified as "objectionable".

Photo-electric methods based upon differences in the light refraction of the fibre cortex and medulla, are generally the most rapid, simplest and most suitable for routine analysis of medullation. Theoretically, the photo-electric measure of medullation is proportional to the total area medullation of all the fibres in the sample. Values so obtained, however, are not always simply related to the degree of medullation. Fibre colour and pigmentation could also affect the photo-electric values. Furthermore, the occurrence of vacuoles [19] (small voids), which seems to be a characteristic of mohair rather than of wool[111] could also affect medullation values obtained photo-electrically, the occurrence of vacuoles apparently increasing with increasing mean fibre diameter. Photo-electric techniques also cannot discriminate between kemp and Med fibres. Nevertheless, if it is true that the large and heavily medullated fibres have a predominant effect on photo-electric values[606], photo-electric methods could be suitable for estimating the degree of kemp in mohair. Should the ratio of kemp to total medullation (ie area medullation) vary from one mohair to another[309], however, such estimates of kempiness may only be approximate.

Knott[978] and **Sternotte and Knott**[860] discussed the measurement of medullation in fine animal fibres, the medullary cells in wool and mohair behaving like small dispersing lenses having relatively large curvatures.

11.7.2 Medullameter Test

Smuts and co-workers[606,802] investigated and explored ways of finding a rapid and reliable method of screening mohair samples for degree of medullation and the possibility of using the method to provide a measure of kemp levels[606].

A Medullameter, based on a WRONZ design[606], was constructed at SAWTRI (now Textek). This is a photo-electric device designed to measure the amount of light scattered by the medullated fibres present in a sample which is immersed in a liquid (eg benzyl alcohol and aniseed oil) of the same (or similar) refractive index as the fibres (see Table 66 [606]), the amount of light scattering theoretically being linearly proportional to the percentage area medullation. A quick and easy method was devised to check and calibrate the instrument and to ensure reproducible results. Provided certain precautions are taken, accurate estimates of degree of medullation in terms of the Medullameter reading can be obtained fairly quickly and with relative ease. About six to eight measurements per hour are possible[606]. Sample preparation (ie cleaning of greasy mohair and sampling) was important and needed special attention and a simple scouring technique, avoiding the use of alcohol (since it caused the fibres to appear milky when immersed in the benzyl alcohol) was recommended. The

TABLE 66[606]
REFRACTIVE INDICES OF REVELANT FIBRES AND LIQUIDS

	REFRACTIVE INDEX*
Wool[29]	$\mu_s^{\parallel}$: 1,553 to 1,555
	$\mu_s^{\perp}$: 1,542 to 1,546
Mohair[30]	$\mu_s^{\parallel}$: 1,5579 to 1,5638
	$\mu_s^{\perp}$: 1,5474 to 1,5546
Benzyl Alcohol	1,5404 at 20°C
	1,5384 at 25°C
Ortho-dichlorobenzene	1,5515 at 20°C
	1,5491 at 25°C

* — $\mu_S^{\parallel}$ and $\mu_S^{\perp}$ are the average refractive indices for light vibrating parallel and perpendicular to the fibre axis, respectively.

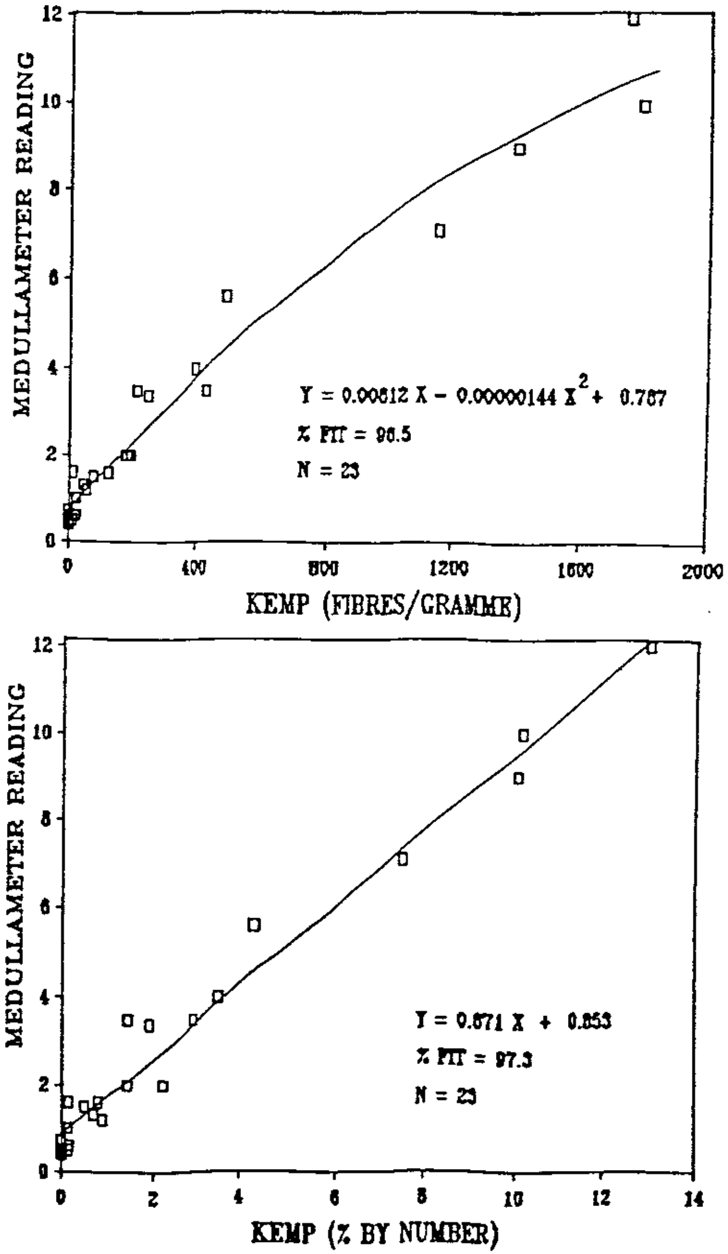


Fig. 36 Medullameter Reading vs Visual Kemp[997].

Medullameter reading was shown to be related to various other measures of medullation, in particular to percentage area medullation, but should rather be regarded as a unique measure of the degree of medullation of a sample[606].

Sternotte *et al*[897] reported on the measurement of medullation by means of the multi-angular light scattering technique, using an instrument they developed which enabled the scattered light to be measured at several angular positions. They also studied the effect of pigmentation and de-pigmentation on the results obtained, as well as the effects of oxidising agents, formaldehyde and iron concentration.

A good correlation was found between the number of fibres having a medulla diameter greater than 40μm and those having a medulla diameter to fibre diameter ratio greater than 0.6[606].

Hunter *et al*[997] found a fairly good correlation between the Medullameter values and the subjectively determined degree of kemp (ie "objectionable" fibres counted visually). It was concluded that, as a rapid screening test, aimed at estimating the degree of medullation and perhaps also of kempiness, the Medullameter would probably be adequate[606,997] (see Fig. 36), particularly also in view of the large differences between the kemp ("objectionable" fibre) levels recorded by different laboratories for the same samples.

A numerical classification for the degree of medullation in mohair (Fig. 37), ranging from 1 (virtually free of kemp) to 6 which represents very heavily medullated (kempy) mohair[802,997], has been proposed. Category 1 should be acceptable for even the most critical end-uses, Category 2 would be acceptable for some critical end-uses but not others, while Category 3 and higher will rarely be acceptable for high quality end-uses[802,997].

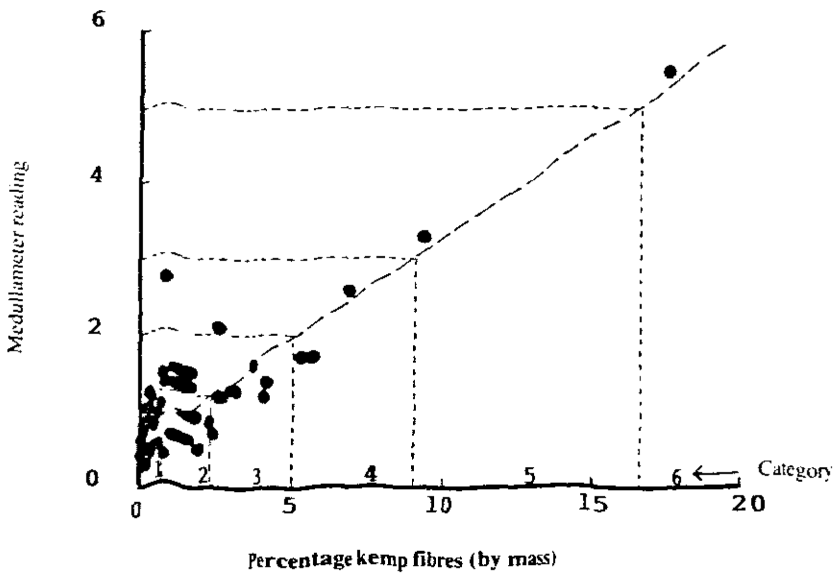


Fig. 37 Medullameter Readings vs Percentage Visible Kemp (by Mass)[802].

11.7.3 **Coarse Edge**

During certain studies it was noted[802] that kemp fibres were generally coarser than the parent population of mohair fibres and the possibility of using the FFDA (or FDA) determined "coarse fibre diameter edge" as a measure of kemp was investigated further. Preliminary results, presented at the IMA Conference held in Cape Town, June, 1988[874], showed that this approach could have potential and this was supported by the results of further work[854]. This approach was pursued and it was found that visible kemp (counted subjectively) tended to be correlated ($r = 0.85$; $n = 23$) with the FDA percentage of fibres coarser than about 2 x mean diameter. It emerged that the correlation could be improved to well over 0.9 if kurtosis, skewness and diameter were used together with the percentage coarse fibres (> 2 x diameter) in a multiple regression equation, the goodness of fit being illustrated in Fig. 38[997]. The coarse fibres and kurtosis contributed most by far to the percentage fit. Nevertheless, for the same range of samples, the Medullameter results were even more highly correlated with the subjective level of kemp than the FFDA results. Further work was required to explore the potential of both methods.

Hunter *et al*[1053] concluded that the FDA, fibre diameter distribution, including the coarse edge, and the Medullameter both provided a fairly good estimate of visually assessed kemp levels.

In a recent study by **Hunter** *et al*[1093] it was shown that kemp (ie visually "objectionable" fibres) tended to be coarser than the population (Fig. 39), confirming earlier studies.

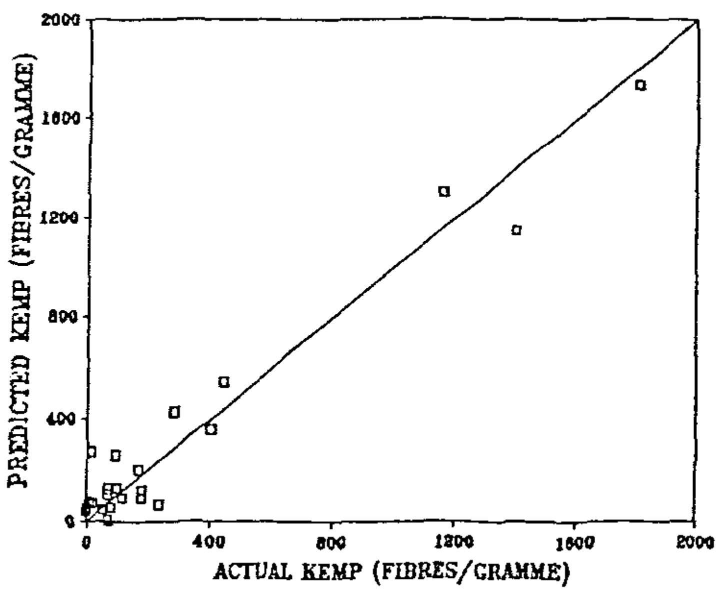


Fig. 38 Predicted vs Actual Kemp[997].

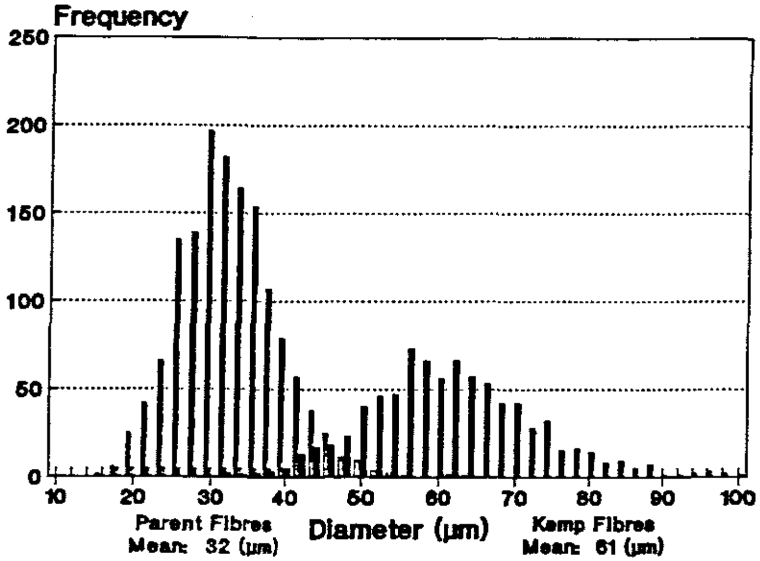


Fig. 39 Combined Mean Diameter Distribution[1093].

11.7.4 Other Tests

Many years ago, a method claimed to facilitate the visual counting of kemp in mohair was devised at SAWTRI[96]. It involved a quick (10s at the boil) slightly acid dyeing technique, in which even coarse mohair fibres dye well whereas kemp and heterotype fibres take up little dye. The fibres are then *sorted under a magnification of 2.25 times*[96]. ***Turpie and Steenkamp***[877] *inves*tigated the use of a cold water staining test to facilitate subjective assessments of kemp fibres in mohair, viewing the samples under filtered light. **Hunter and Dorfling**[1060] (unpublished report to the IMA, 1992) found, however, that dyeing or staining did not appear to improve the very large inter-laboratory variability in subjective kemp counting and concluded that the classification of a fibre as kemp (ie as "objectionable") was always highly subjective and varied greatly from laboratory to laboratory.

Gee[493] used three passages of each of two 20g samples of mohair through a Shirley Analyser to estimate the percentage kemp in the sample, the percentage fibres in the reject can being used as a measure of the kemp content of the samples. **Roberts and Teasdale**[826] mentioned the application of image analysis for the measurement of mohair diameter and the presence of kemp. Image analysis has also been used elsewhere to measure medullation and kemp in mohair[847,1060] while **Bassett**[732,733] used the projection microscope to estimate kemp. **Hutchings and Ryder** (quoted in Ref. [1069]) described the use of a Summagraphics Bit-pad One, in conjunction with a computer, for measuring fibre diameter and medullation. **Blakeman** *et al*[837] described a computer supported sonic digitizer technique for scanning mohair medullation, using the projection microscope. They also found medulla diameter to be approximately linearly related to the fibre diameter.

Boguslavsky *et al*[1074,1094] developed a novel method of obtaining a measure of total medullation which involved immersing the mohair sample in a liquid of the same refractive index as the mohair (eg benzyl alcohol) and then measuring the sample by NIR, after the necessary calibration and validation. This method appeared to be more accurate than other methods.

11.8 International Kemp Round Trials

When **Hunter** *et al*[997,1053] reviewed the work done at the CSIR on the measurement of kemp and medullation in mohair, they also reported on the first International Kemp Round Trials involving laboratories in different countries. They reported that substantial differences existed in the absolute values of kemp as assessed subjectively by the different laboratories, the difference being as high as a factor of 10 in the case of the kemp fibres per gram. The results obtained by the various laboratories, however, were fairly highly correlated, indicating that although the absolute counts often differed greatly, as already mentioned, the various laboratories tended to rank the different samples in a similar order as far as kempiness was concerned. From their studies, the authors concluded that an objective test method for kemp was an absolute necessity. They noted a high correlation between the coarse fibre edge (as measured by an FDA) and subjectively assessed kemp, as well as between the degree of medullation (measured by means of a Medullameter) and subjectively measured kemp.

From the results of the Second International Kemp Round Trials (**Hunter** *et al*[1093], unpublished report to the IMA) involving both dyed and undyed tops, it was concluded that dyeing did not improve interlaboratory variability to any significant extent, once again confirming the need for an objective test for kempy type fibres (ie "objectionable" medullated fibres).

11.9 Ways of Reducing Kemp Levels and Appearance

11.9.1 General

Hirst and King[3] tried ways of filling up the medulla air spaces with material of similar translucency as the mohair, but failed, although volatile liquids such as alcohol and benzene penetrated quite easily.

Powell[618] investigated ways of dyeing which would result in kemp and normal mohair fibres having an identical appearance after dyeing. **Powell**[618] concluded that the aerian vesticle portions in the medulla of medullated fibres do in fact absorb dyestuff and that the "lighter (undyed) appearance of dyed kemp fibres was due to the fact that the aerian vesticles reflect and/or absorb light at a greater rate than the cuticle/cortex of a normal fibre because of the high number of surfaces available. He concluded that if an agent could be found to allow dye liquor or penetration of the cuticle/cortex and the aerian vesticles, the colour character of the medullated fibres could be greatly enhanced[618].

Wyatt *et al*[664], investigated methods for covering, converting or eliminating kemp fibres from mohair and wool fabrics. Flotation of kemp in a mass of fibres, in a liquid of appropriate density, was not straight forward because the wet fibres tended to cling together, preventing the lighter fibres from floating to the surface of the liquid[664]. A fabric singeing process (Remaflam) for burning off surface kemp fibres was suggested.

Various workers from the Textile Research Center at Texas Tech. University investigated ways of chemically treating mohair fabrics so that the kemp type fibres are less visible [618,693].

Smuts *et al*[698] and **Hunter** *et al*[764], found that, within the fairly wide ranges they covered (0.5 to 6%), the degree of medullation had a relatively small effect on airflow measured fibre diameter and the airflow results could therefore be considered reliable. **Turpie**[756] and **Hunter and co-workers**[788,813,1053] discussed work done at SAWTRI on the importance, characteristics and measurement of medullation and kemp in mohair. **Smuts and Hunter**[859] reported on the levels of medullation in Cape mohair. They measured some 152 samples on the Medullameter. Their work confirmed that the level of medullation in Cape mohair was generally very low. There was also a poor relationship between the degree of medullation and fibre diameter.

11.9.2 Mechanical Removal of Kemp

Kruger and Albertyn[127] reported that mohair fibres had almost twice the relative density (1.29) of the kemp fibres (0.61) and that suitable air currents, directed at a disentangled mass of fibres, should separate the kemp from the mohair. They found that kemp levels decreased from greasy mohair to top and that most of the fibres mixed with the ejected burr at the card were kemp and that strippings from the card clothing also contained a high percentage of kemp[127]. They found that the mohair fibre length was not altered much by carding, with shorter kemp fibres being preferentially removed. They concluded that mohair rather than kemp, would break preferentially during carding. The kemp fibre length in the card sliver was higher than that in the scoured mohair[127]. They further concluded[142] that selective kemp removal by the card clothing took place mainly because of the greater centrifugal force acting on the mohair fibres of higher density which move to the outer layers on the card rollers, causing a relative migration of kemp towards the card clothing. In their experiment they found that carding reduced kemp from 2.18 to 1.78% (by mass), ie by about 20%. The selective kemp collecting power of the strippers was higher than that of the workers, with the breast-to-swift angle-stripper also showing a very high rate of kemp collection. They suggested that fettling should be carried out after 9 to 11 hours running, in order to obtain effective kemp removal. There appeared to be a linear relationship between roller surface speed and rate of kemp collecting. A migration of kemp in the direction of the centre of the rollers took place during carding. The shorter kemp fibres were removed by the rollers (as fettlings). Kemp was removed through selective collection by the card clothing on all rollers as well as through ejection together with burr. **Kruger**[206] subsequently also found that the selective collection of kemp fibres by the card clothing increased with increasing roller speeds. Opening and then drying, after scouring, aids more effective carding[671].

Kruger and Albertyn[127] reported that kemp decreased from 4% (by number) in scoured BSFH and BSK mohair to 1% in the top, and from 5 to 3% for CSH and BSH mohair. They gave a figure for the reduction in kemp during processing.

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*See also **"MECHANICAL PROCESSING INTO YARN"**.

As already pointed out, during the carding process the centrifugal forces cause migration of the kemp fibres (which are lighter and coarser than the mohair fibres) towards the inside of the clothing of all fast-moving rollers[196] and the kemp can largely be removed by fettling. The fibres delivered from the carding machine in the form of a sliver would consequently contain less kemp. At the working point, between the swift and the doffer, the material is turned over, so that the kemp fibres, which earlier had been on the inside of the web now occupy the outside portion of the web on the doffer. Some of these kemp fibres are only very loosely attached to the web, and if these are allowed to drop off the doffer, a reduction in the percentage kemp of the resultant card sliver is obtained.

Turpie[205] described modifications to a small carding machine, originally designed for carding very short fibres such as noil and wastes, to enable mohair to be carded successfully in small lots. It was observed that, when processing a very kempy mohair lot, the kemp fibres predominated on the outside layer of the web on the doffer, being only loosely attached to the other fibres in the web. Underneath the carding machine, immediately below the doffing point between the swift and the doffer, an accumulation of fibres containing a high percentage of kemp fibres was observed, the kemp content there being 38% compared to 7% in the scoured mohair. Therefore, the control of loose fibre droppings at the contact points between certain rollers can effect additional removal of kemp during carding[205].

The most effective method of removing a fair proportion of kemp is considered to be the combing process[196]. In this connection it was noted that of the two commonly used methods of combing available then, namely Noble combing and rectilinear (French) combing, the former was superior in terms of the selective removal of kemp[196,671]. The rectilinear comb removed fibres below a pre-determined length irrespective of whether the fibres were kemp or mohair. The Noble comb, on the other hand, produced a noil in which the mean fibre length of the kemp fibre was greater than that of the mohair fibres. In both cases, quite a substantial amount of kemp was removed and discarded together with the noil, so that the kemp content of the top was reduced appreciably. In earlier times, two combings were used to remove as much kemp as possible[8], a recombing operation on a Lister Comb having been employed to reduce kemp even further[800]. **Kruger**[143,156] studied the Noble combing of mohair and found that the smallest amount of kemp went forward into the top at a dabbing depth of about 1.3cm to 1.4cm. Breakage of the mohair fibres was higher than that of the kemp fibres which was nearly zero. The average length of the kemp fibres in the noil was somewhat greater than that of the mohair fibres in the noil[143,156]. This was attributed to the restraint of the less pliant kemp fibres by the dense pins in the small circles of the Noble comb[143,156]. The kemp content of the top showed little dependence upon production rate, with the ratios of kemp present in the top and noil also very similar, except at the highest production rate, in which a relatively greater amount of kemp was still left in the top. The kemp content of the top appeared to be independent of comb temperature, whereas fibre breakage increased with a decrease in comb temperature. Fibre breakage during Noble combing was less than 5% and mainly confined to the mohair fibres (as opposed to kemp)[143,156].

In studies on the rectilinear combing of mohair, **Kruger**[206] showed that the mohair fibres in the top were significantly longer than the kemp fibres left in the top, while the lengths of the two types of fibres in the noil were about the

Various workers from the Textile Research Center at Texas Tech. University investigated ways of chemically treating mohair fabrics so that the kemp type fibres are less visible [618,693].

Smuts *et al*[698] and **Hunter** *et al*[764], found that, within the fairly wide ranges they covered (0.5 to 6%), the degree of medullation had a relatively small effect on airflow measured fibre diameter and the airflow results could therefore be considered reliable. **Turpie**[756] and **Hunter and co-workers**[788,813,1053] discussed work done at SAWTRI on the importance, characteristics and measurement of medullation and kemp in mohair. **Smuts and Hunter**[859] reported on the levels of medullation in Cape mohair. They measured some 152 samples on the Medullameter. Their work confirmed that the level of medullation in Cape mohair was generally very low. There was also a poor relationship between the degree of medullation and fibre diameter.

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*See also **"MECHANICAL PROCESSING INTO YARN"**.

As already pointed out, during the carding process the centrifugal forces cause migration of the kemp fibres (which are lighter and coarser than the mohair fibres) towards the inside of the clothing of all fast-moving rollers(196) and the kemp can largely be removed by fettling. The fibres delivered from the carding machine in the form of a sliver would consequently contain less kemp. At the working point, between the swift and the doffer, the material is turned over, so that the kemp fibres, which earlier had been on the inside of the web now occupy the outside portion of the web on the doffer. Some of these kemp fibres are only very loosely attached to the web, and if these are allowed to drop off the doffer, a reduction in the percentage kemp of the resultant card sliver is obtained.

Turpie(205) described modifications to a small carding machine, originally designed for carding very short fibres such as noil and wastes, to enable mohair to be carded successfully in small lots. It was observed that, when processing a very kempy mohair lot, the kemp fibres predominated on the outside layer of the web on the doffer, being only loosely attached to the other fibres in the web. Underneath the carding machine, immediately below the doffing point between the swift and the doffer, an accumulation of fibres containing a high percentage of kemp fibres was observed, the kemp content there being 38% compared to 7% in the scoured mohair. Therefore, the control of loose fibre droppings at the contact points between certain rollers can effect additional removal of kemp during carding(205).

The most effective method of removing a fair proportion of kemp is considered to be the combing process(196). In this connection it was noted that of the two commonly used methods of combing available then, namely Noble combing and rectilinear (French) combing, the former was superior in terms of the selective removal of kemp(196,671). The rectilinear comb removed fibres below a pre-determined length irrespective of whether the fibres were kemp or mohair. The Noble comb, on the other hand, produced a noil in which the mean fibre length of the kemp fibre was greater than that of the mohair fibres. In both cases, quite a substantial amount of kemp was removed and discarded together with the noil, so that the kemp content of the top was reduced appreciably. In earlier times, two combings were used to remove as much kemp as possible(8), a recombing operation on a Lister Comb having been employed to reduce kemp even further(800). **Kruger**(143,156) studied the Noble combing of mohair and found that the smallest amount of kemp went forward into the top at a dabbing depth of about 1.3cm to 1.4cm. Breakage of the mohair fibres was higher than that of the kemp fibres which was nearly zero. The average length of the kemp fibres in the noil was somewhat greater than that of the mohair fibres in the noil(143,156). This was attributed to the restraint of the less pliant kemp fibres by the dense pins in the small circles of the Noble comb(143,156). The kemp content of the top showed little dependence upon production rate, with the ratios of kemp present in the top and noil also very similar, except at the highest production rate, in which a relatively greater amount of kemp was still left in the top. The kemp content of the top appeared to be independent of comb temperature, whereas fibre breakage increased with a decrease in comb temperature. Fibre breakage during Noble combing was less than 5% and mainly confined to the mohair fibres (as opposed to kemp)(143,156).

In studies on the rectilinear combing of mohair, **Kruger**(206) showed that the mohair fibres in the top were significantly longer than the kemp fibres left in the top, while the lengths of the two types of fibres in the noil were about the same. The kemp contents of the different components were not significantly affected by different comb settings, although there was a tendency to remove more kemp at larger gauge settings. The percentage kemp in the noil was much lower for rectilinear combing than for Noble combing[206], with the Noble combed top containing less kemp than the rectilinear combed top[206]. It was reported[143,156] that Noble Combing reduced the kemp content from about 2.3% in the gilled mohair sliver to about 1% in the top, the short kemp fibres being mainly removed as noil. It was concluded that selective removal of kemp was possible, using the techniques of centrifugal force and of Noble combing, but that a more detailed study was necessary to be able to improve the efficiency of the process leading towards the ultimate goal of a kemp-free top[196].

Townend *et al*[921] reviewed published work on the mechanical removal of kemp, including combing, modified gill box (stretch breaking) and carding. They also investigated the use of the card to separate coarse and fine Llama fibres.

Spencer[233] stated that a kemp count maximum of 0.3% should be aimed for in mohair tops, although in certain shades even this low figure was still not acceptable. **Kruger**[235] reviewed methods of separating fibres of different diameter (eg kemp and mohair). Selective collection of the thicker kemp fibres takes place in the small circle of the Noble comb[235], with changes in pin density and temperature improving the collection of kemp. **Turpie**[268] investigated the reduction in kemp in a wool top by Noble combing, finding that wide settings of the drawing off rollers together with the use of lower pin densities on the large circle were to be recommended.

Van Zyl and Kruger[213] investigated the removal of kemp fibres, mechanically weakened by passing them through pressurised fluted rollers. Although fibres were broken and/or weakened by passing them through the prescribed fluted rollers, there were no differences between the weakening or breaking of the mohair and kemp fibres, hence the technique appeared to have little potential for preferentially weakening and/or breaking the kemp fibres.

Srivastava[673] **and Onions** *et al*[301] proposed a stretch-breaking process on a modified gill-box (fallers removed) of gilled mohair sliver to preferentially break kemp and thereby facilitate its removal during subsequent combing. The stretch breaking process enabled the kemp in the top to be reduced from 3.4 to 2.2%[673].

Brief reference has been made[940] to a machine ("dekemper") which can remove kemp from mohair, reducing kemp levels from 4% or more to less than 1% with a capacity of 50 tons per year. It has also been reported[1020] that a dekemping machine was developed by the Wool Research Organisation of New Zealand (WRONZ), this being funded by way of a 1% fibre levy.

McGregor[894] reported that scouring and topmaking reduced kemp levels and he[784] illustrated the effect of goat age (very small) and scouring and topmaking on kemp levels.

Lupton *et al*[882] investigated the effects of standard scouring and worsted procedures on kemp content and found a poor correlation ($r^2 = 0.2$) between the kemp and medullated levels measured in the scoured mohair and those measured in the top. The average medullation level in the 29 lots of mohair investigated was 1.53% while that in the top was 1.35%, the corresponding levels of kemp were 0.54 and 0.35%, respectively.

FIBRE CHEMICAL, MORPHOLOGICAL AND RELATED STRUCTURE AND PROPERTIES

12.1 General

The reader is referred to recent excellent reviews of this subject by **Zahn[994,1054] and Spei and Holzem[1048]. Zahn** *et al*[502] earlier reviewed the structure (biological composite) of wool, with reference also to mohair.

All animal fibres, except silk, contain the same chemical substance, a protein called keratin[401]. Keratin can be regarded as a long fibrous composite, comprising crystalline, relatively water impenetrable microfibrils (lying parallel to the fibre axis) embedded in an amorphous, water penetrable matrix[931]. Wool and mohair fall into the class of protein materials known as keratins, characterised by their long filament-like molecules and insolubility in dilute acids and alkalis. They generally have high sulphur contents relative to other proteins[56]. All mammalian keratin fibres contain three main protein fractions[335], termed low-sulphur, high-sulphur and high tyrosine proteins, with the low-sulphur proteins generally representing the largest proportion. All animal fibres contain approximately 3 to 4% sulphur, largely as cystine. The mohair fibre generally consists of a cortex (cortical cells), the solid and main part (bulk) of the fibre, which is predominantly ortho-cortex (cortical cells), and epidermis (cuticle cells) of numerous overlapping scales (arranged somewhat like the tiles on a roof) each having its free end (or edge) directed towards the fibre tip[38]. Sometimes there is also a medulla present which is a central core (or

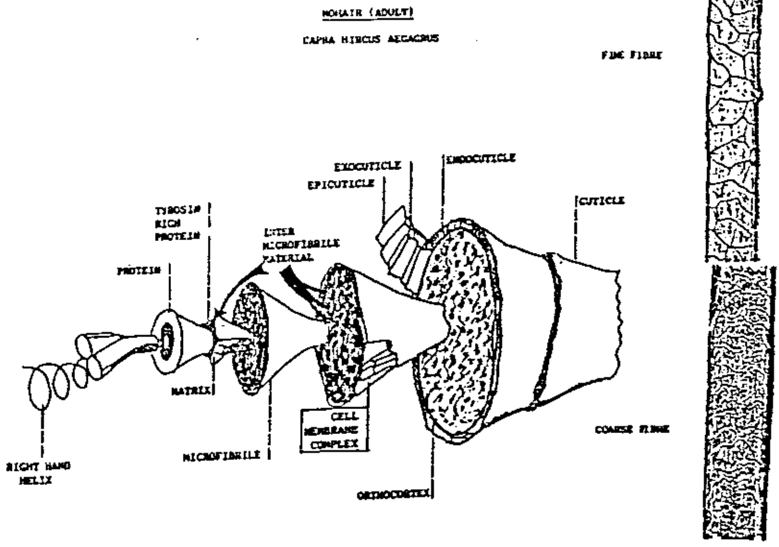


Fig. 40 Structure of a Mohair (Adult) Fibre[840,858].

canal) which is either continuous or fragmented (broken) and which consist of cell residues. The cuticle scales form a protective covering for the cortex and consist of three layers (epicuticle, exocuticle and endocuticle see Fig. 40). Each cuticle scale is enveloped by a thin semi-permeable[360,740] membrane called the epicuticle (which comprises protein and lipid). **Smith**[840,858] illustrated the structure of a mohair fibre (Fig. 40).

Chemically, mohair is very similar to wool but because it is predominantly *ortho-cortex, which is chemically less resistant than the para-cortex*[42], *it is* generally more sensitive to various chemicals than wool and more attention should therefore be given to the chemicals and conditions used during scouring, dyeing, carbonizing and finishing[34, 202]. **Ward** *et al*[44] produced the following table (Table 67) for the chemical composition of mohair and other fibres.

Tucker *et al*[992,1004] reviewed the chemistry of speciality animal fibres, stating that the fine speciality animal fibres, such as mohair, consist mainly of protein, water and internal and external lipids, and comprises long spindle-shaped cortical cells surrounded by a flattened sheath of cuticle cells held

TABLE 67[44]
COMPARATIVE ANALYSES OF WOOL, MOHAIR AND FEATHERS

	Wool (This Research)*	Wool (Graham et al. [16])	Wool (Lindley [21]†)	Wool (Simmonds [30])	Wool (Speakman [32]‡)	Mohair (This Research)	Feather (This Research)	Feather (Graham et al. [16])
				Grams from 100 g of Dry Keratin				
Constituent								
Total nitrogen	16.82	16.2	16.9	16.62	(17.23)‡	17.02	16.2	15.0
Ammonia (amide) nitrogen	1.10			1.42	1.37	1.21	1.09	
Amino nitrogen	0.33				(0.33)‡	0.35	0.25	
Sulfur	3.70		3.76	3.68	(3.65)‡	3.19	2.70	
Amino acid								
Alanine	3.85		3.4	3.71	4.4	4.26	5.4§	
Arginine	9.15	10.6	10.5	10.49	10.4	8.94	6.88	7.5
Aspartic acid	6.40	7.2		6.69	7.3	7.32	5.82	7.0
Cystine	*11.0*	*13.7*	*11.6*	11.30	13.1		6.8§	8.2
Glutamic acid	13.1†	15.6		14.98	16.0	14.2	9.02	9.7
Glycine	5.30			5.16	6.5	4.77	7.2	
Histidine	0.96	1.1		0.90	0.7	0.90	0.33	0.4
Hydroxylysine					0.2			
Isoleucine	3.80	4.5	10.6	3.07	11.6	3.90	5.3	6.0
Leucine	7.72	8.1		7.63		8.14	7.44	8.0
Lysine	3.08	3.3		2.82	3.3	3.07	1.00	1.3
Methionine	0.54	0.6		0.69	0.7	0.52	0.38	0.5
Phenylalanine	3.40	4.0	3.8	3.43	4.0	3.66	4.65	5.2
Proline	6.38	8.1	5.3	7.28	7.2	5.64	10.0	8.8
Serine	7.16		16.7†	9.04	9.5	6.05	14	
Threonine	6.55	6.7		6.55	6.6	5.62	4.8	4.4
Tryptophan				2.10	1.8			
Tyrosine	4.00	5.6	5.7	6.38	6.1	2.39	2.00	2.2
Valine	5.90	5.7	5.1	4.96	5.5	6.12	8.8	8.3
				Percentage Accounted for				
Recoveries								
Total weight	84.1	82.3	62.6	93.5‖	98.4	73.3	84.7	67
Total nitrogen	87.8	79.1	62.6	98.5‖		78.2	91	67
Amino nitrogen	89					92	38	
Sulfur	82.5		82.4	86.0			69	

* Average values are given for the contract (WC) wools cited in Table III.

† Calculated from results given. The value for serine plus threonine assumes equal weights of each, with allowance for 0.2% of hydroxylysine.

‡ The highest values are used for comparison. The total nitrogen, amino nitrogen, and sulfur given at the head of this column are those computed from the amino acid and ammonia nitrogen contents.

§ The alanine and cystine contents reported here for feathers are from weighted averages of analyses of feather fractions.

‖ One of the two unidentified substances found by Simmonds is allowed for in computing recovery of total weight and nitrogen.

together by the Cell Membrane Complex (CMC), referred to as the intercellular region, also referred to as intercellular cement, surrounding individual cortical cells)[1034] which is composed of lipids, nonkeratinous proteins and resistant membranes[740]. Cuticle cells are separated from the underlying cortical cells by the CMC[1034]. Together with proteins, the cell membrane lipids (ie internal lipids) are the main components of the cell membrane complex (CMC)[846,992], the latter forming a net-work throughout the whole fibre, thus contributing to cell cohesion (it surrounds the cuticle and cortical cells and holds them together)[1069]. The cell membrane complex, has a dramatic influence on fibre and fabric properties (**Leeder**[787] quoted [992]). **Tucker** *et al*[992] has reviewed work done on the composition of internal lipids.

Spei and Holzem[1048] reviewed the characterisation of fibre keratins, including mohair, by X-ray, microscope and thermo-analysis and presented the following summary:

"The three main morphological components of fibres, such as mohair, are the cuticle, cortex and membrane complex, with each consisting of further subcomponents[1048]. The cortex consists of individual cortex cells, which are in turn built up from macrofibrils (+ intermacrofibrillar matrix (cement), microfibrils, protofibrils and α-helices[1048].

The microfibril matrix complex largely determines the mechanical properties of fibre keratins and also contributes towards determining other physical properties. The microfibril matrix complex consists of partly helical, low-sulphur microfibrils embedded in a non-helical sulphur-rich matrix. It has recently become possible to determine the helix content of elongated and heat damaged fibre keratin samples rapidly and accurately by thermo-analysis (DSC). X-ray small-angle studies on chemically modified, extended fibre keratins have shown that at least two ordered regions exist along the fibre axis, and that the matrix, which was previously regarded as amorphous, must have a certain structure. The axial 198 Å reflex (1st order interference), already predicted in 1943, was demonstrated unambiguously in the X-ray small-angle diagrams of some solvent-treated and chemically modified mohair[1048].

Many physical properties of wool and hair are determined by the composite structure of the microfibril-matrix complex which normally consists of low-sulphur helical microfibrils embedded in a high-sulphur[659] nonhelical matrix[721]".

Zahn[994,1054] reviewed the structure of mohair, stating that the strength and resistance to wear of mohair are considered to be a consequence of the regular cortical layer built up from spindle-shaped cells[994]. The cortex of mohair comprises of microfibrils which are up to 0.2μm wide, the macrofibrils consisting of bundles of microfibrils which are in hexagonal packing. The microfibrils or keratin intermediate filaments (KIF) represent about 60 to 70% of the fibre mass. The sub-bundles of the KIF are 8 keratins of 40 to 70 kilodaltons. Each has a central alpha-helical rod domain of 311-314 amino-acids. The fundamental building blocks of the KIF are four-chained coiled-coil units consisting of a pair of two-chain coiled-coil molecules. Eight keratins constitute the KIF in cortical cells of both mohair and merino wool fibres[994] as illustrated by **Wortmann**[923] (quoted by **Zahn**[994,1054]) by gel-electro-phoretical separation of S-carboxymethylated keratins isolated from mohair fibres.

Zahn[994,1054] summarised the work done to date on mohair chemical structure as follows:

1) The resistance to wear of mohair is related to the regular structure of the macrofibrils in the cortex.
2) Eight keratins constitute the Keratin Intermediate Filaments (KIF) in cortical cells not only of Merino wool but also of mohair.
3) Mohair has the highest helix content as found by differential scanning calorimetry (DSC).
4) Lysine residues in the KIF of mohair have an axial periodicity of 39 Å in agreement with our present knowledge of the position of lysine in keratins.
5) X-ray studies on mohair gave early evidence for microfibrillar swelling.
6) The presence of a structural regularity at 198 Å has been identified by X-ray work on mohair.
7) Stretching mohair fibres under specified conditions revealed the phenomenon of bimodal elongation of filaments.
8) By combination of these data, a structural model for wool and mohair is proposed: In engineering terms the "fibre/matrix" composite is provided mainly by the KIF. The 50% non-helical sections are the main components of the "matrix".

Various other articles[221,419,639] also deal with topics related to those covered in this chapter, **Miró and Erra**[221], for example, relating the action of sodium hydroxide on wool and mohair to their morphological structures.

12.2 Nature of Mohair Cortex

Between the epidermis and the medulla of the mohair fibre lies the bulk of the fibre known as the cortex, which is built up from spindle-shaped cells[179] (quoted in Ref.[994]).

Hearle and Peters[106] reproduced the following schematic representation[67] (Fig. 41) of the relationships between the morphological structure of

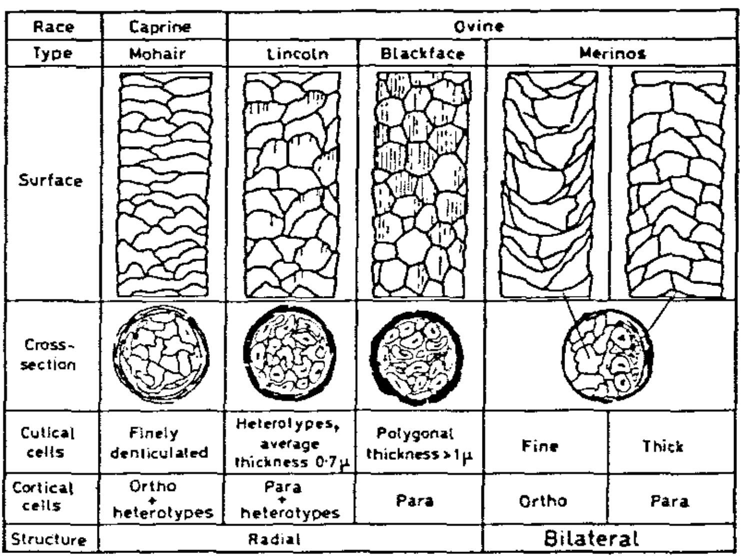


Fig. 41 Schematic Representation of the Relationships between the Morphological Structure of the Cortical Cells and those of the Cuticle[67].

cortical cells and those of the cuticle. Cortical cells of wool are approximately 110μm long and 5.5μm wide[1039], **Satlow** *et al*[128] reporting a value of 8 to 9μm for the width of the cortical cells of mohair. The cortical layer is built up of the spindle-like cells (filaments), clearly visible as strong striations throughout the length of the fibre[38,202]. In some instances there exists between the cortical cells, air-filled cigar-shaped pockets or vacuoles (streaks or cavities)[38,111] of various lengths[38,202], which appear as black "spots" in the fibre when viewed microscopically, and are similar in dimensions to the cortical cells[309]. The percentage of hairs containing such vacuoles varies within wide limits[202]. **Perkin and Appleyard**[111] also reported on natural occurring abnormalities in mohair, such as streaks or vacuoles which appear black when the fibre is examined microscopically. Such vacuoles are more common in mohair than in wool. When cross-sections of mohair fibres are mounted in O-chlorophenol, each such mark is clearly seen as a black area within a cortical cell, they occur in processed as well as unprocessed fibre and are therefore not caused by any mechanical action.

The cortical cells of keratin fibres, such as mohair, consist of filaments (aligned) of relatively low cystine (sulphur) content and high α- helix content (low-sulphur proteins)[117,247], surrounded by a non-filamentous matrix containing two protein types, one cystine rich (high-sulphur proteins) and the other rich in glycine and tyrosine (high-tyrosine proteins)[284] and Ref[592] (as quoted in[992]). There are important differences in composition between keratin fibres which are mainly caused by differences in the amount and type of constituent high sulphur proteins[121], which could hold the key to the differences in physical properties of keratins[164].

Although the constituent proteins of merino wool and mohair appear to contain some remarkable similarities, the overall chemical, physical and morphological properties of these fibre types differ in many respects. There also appears to be evidence that there are differences between Kid mohair and Adult mohair[155].

Broadly speaking, two types of cortical cells generally occur, namely para and ortho, which differ somewhat in chemical and physical properties.

Mohair (particularly Kid), is predominantly ortho-cortex, but also contains para-cortex, the types of cortical cells in mohair having been investigated by various workers[40,41,43,48,49,50,61,62,67,80,85,90,98,103,123,124,174, 182,199,201,272,320,368,863, 899,1028]. The cystine (sulphur) content of the para-cortex is about twice that of the ortho-cortex[85], with the latter less stable than the former[38].

Dusenbury and Menkart[41] found that Kid mohair dyed to deeper shades than wool and had higher solubility in alkali after acid treatment suggesting that mohair was composed mainly, if not entirely, of ortho-cortical cells. **Ward and Bartulovich**[48] **and others**[98] found evidence of the presence of both ortho- and para-cortical cells in mohair, these being uniformly distributed in the fibre. **Ward and Bartulovich**[48] described a method whereby the two different types of cortical (spindle) cells can be separated by a density gradient method, with the lighter of the two fractions predominating in Adult mohair. The mohair had about 3.2% sulphur, with the lighter cortical fraction having about 3.8% and the heavier about 4.3% sulphur.

Fraser and Macrae[50], using methylene blue dyeing to differentiate the cells, found that mohair consists of both ortho- and para-cells (radially differentiated ortho- para-distributions, randomly intermixed in the case of adult mohair) supporting the findings of **Ward and Bartulovich**[48] of two types of cortical cells. In one case it was concluded that, in the case of adult mohair ortho- and *para-cortical cells were randomly intermixed*[49], *whereas elsewhere it was con*cluded that in adult mohair the para-cortex appears to encircle the ortho-cortex[174]. The appearance of a mohair fibre, broken by twisting[237] (Fig. 42) indicated that the fibre consisted of two different types of cortical material, the one being situated in the fibre centre and the other enveloping it like a sheath[237]. **Menkart and Coe**[61] suggested that the cuticle was responsible for the deeply stained ring obtained within methylene blue. **Kassenbeck**[67], concluded that mohair consists of ortho-cells and also heterotype of cortical cells, with the structure being radial. **Tucker** *et al*[899] confirmed that mohair did not have a bilateral structure, with the ortho- and para-components having a random distribution.

Fig. 42 Scanning Electron Photomicrograph of Mohair Fractured by Twisting[237].

Thorsen[62] investigated the cortical components and other aspects of wool and mohair. He found that mohair bound very little nickel, possibly due to its low tyrosine content (2%), with the ortho-cortex more reactive to many reagents[62]. Mohair had a lower nickel uptake and a higher solubility in monothioglycol-urea than wool of similar diameter. Staining tests indicated that the adult mohair had more ortho-cortex than would be expected for a wool of similar fibre diameter.

Dusenbury[85] used urea bisulphite solubility to characterise the cortical structures of mohair and other keratin fibres. Their values (Table 68) supported earlier findings by **Dusenbury and Menkart**[41], **Menkart and Coe**[61] and **Dusenbury and Jeffries**[40] that Kid mohair was chiefly ortho-cortex. **Dusenbury**[85] observed cystine values for Kid mohair about 1% higher than that reported by him previously[40,41] and stated that this together with the urea-bisulphite data were not inconsistent with views expressed in the literature[49,61] that some para-cortical material exists in mohair.

TABLE 68[85]
EFFECTS OF TIME OF STORAGE ON UREA-BISULPHITE SOLUBILITIES OF VARIOUS KERATIN FIBRES

Fibre Type	Urea–Bisulphite Solubility (%) after	
	0 hr	8 hr
Human Hair	10·0	9·4
WC-4 Wool	44·7	40·5
IWS Wool B	57·2	53·6
Kid Mohair	74·6	75·2
Pooled 95% Confidence Limit	± 2·0₉	± 2·2₄

Brown and Onions[93] (also quoted by **Gupta and George**[447]) concluded that the small changes in the crimp (curvature) of adult mohair fibres with moisture content were consistent with the structure of its cortex in which a periphery of para-cortical cells surrounded an intimate mixture of ortho- and para-cells.

Perkin and Appleyard[182] used fluorescent stains to differentiate ortho- from para-cells in mohair and other animal fibres. **Miró and Erra**[199] and **Kondo** *et al*[272] also investigated the chemical and morphological properties and structure of wool and mohair.

Dobb[217] and **Dobb and Sikorski**[271] undertook electron microscopy and diffraction (low angle) studies, and suggested a system of cell classification based upon structural parameters rather than morphological features. **Dobb**[217] found two distinct types of diffraction patterns from different cells in mohair, these revealing differences in micro-fibrillar distribution, very similar to those recorded in merino wool. Bragg spacing for mohair indicated the presence of both ortho- and para-type cells[271].

Miró and Garcia-Dominguez[320] investigated the action of ammonium and sodium hydroxide on mohair and other keratin fibres in relation to their morphological structure, the results being consistent with merino wool consisting of both ortho- and para-structures and mohair consisting predominantly of an ortho-structure. In mohair, sodium hydroxide as well as ammonium hydroxide acted preferentially on the proteins isolated as α-keratose[320].

Kulkarni[368] reported on a comparative study by electron microscope examination, of the morphological structures of three different keratin fibres viz merino wool, Kid mohair and human hair. He concluded that the morphological structures of the ortho-segments of wool and Kid mohair were different, that of Kid mohair showing prominent occlusions of the intermacrofibrillar material and the nuclear remnants which were essentially absent in the ortho-cortex of wool but were present in the para-cortex of wool and human hair[368].

12.3 Crystallinity

Mohair is reportedly[1069] more crystalline than wool. **Burley** *et al*[47] used the hydrogen-deuterium exchange reaction to determine the crystalline/amorphous ratio of keratin fibres such as mohair. They presented the following table[47] (Table 69), illustrating the fractions of mohair and wool fibres which were accessible to deuterium oxide (heavy water) and also the crystalline/amorphous ratios of the different fibres. Using relative density measurements, **Fraser and Macrae**[52] found that the relative non-crystalline content of Kid mohair was 86 compared to 81 for merino wool (cow's horn taken as 100).

Nicholls[29] estimated that the fraction accessible to water was 0.60% for mohair, 0.63% for merino wool and 0.70% for Lincoln. **Nicholls and Speakman**[46] presented the following two tables (Tables 70 and 71) for the

TABLE 69[47]

Keratin	Fraction Accessible	Crystalline/Amorphous Ratio
Lincoln wool	$0{\cdot}87_3$	0·145
Romney wool	$0{\cdot}84_2$	0·188
Merino wool	$0{\cdot}83_6$	0·196
Mohair	$0{\cdot}82_4$	0·214

***To Deuterium oxide.**

TABLE 70[46]

Relative Humidity (%)	Water Adsorbed (% on Dry Weight) by				
	Lincoln Wool	Romney Wool	Merino Wool	Mohair	Methylated Lincoln Wool
9·6	3·91	3·81	3·68	3·65	3·65
25·4	7·12	6·95	6·92	6·80	6·21
39·4	9·69	9·62	9·58	9·35	8·36
53·8	12·68	12·37	12·34	12·00	11·20
69·0	16·26	15·62	15·50	15·15	14·42
84·7	21·33	20·70	20·63	20·26	19·33
98·0	31·5	30·6	31·0	29·3	31·0

TABLE 71[46]

Adsorbent	M	Fraction Accessible (R/M)	Crystalline/ Amorphous Ratio
Lincoln wool	175	0·70	0·43
Romney wool	191	0·64	0·56
Merino wool	194	0·63	0·59
Mohair	203	0·60	0·67
Methylated Lincoln wool...	194	0·63	0·59

moisture absorption of mohair and wool and for M (the molecular weight of the unit capable of one mole of water), R/M (the fraction accessible to water molecules) and the crystalline/amorphous ratios, crystalline being the ordered material and the amorphous, the disordered material[46]. Of the fibres examined, mohair was the most crystalline. In contrast to the widely held views that mohair was more accessible to aqueous reagents than wool, **Speakman and coworkers** found that the fractions accessible to the saturated vapours of water and deuterium oxide[47] were actually less in mohair than in either merino or Lincoln wool.

The sorption stoichiometry method *gives crystalline fraction values only* about half those given by the sorption isotherm method as illustrated in the following Table 72[52]) but agrees well with those obtained by the deuterium exchange (degree of accessibility) method. A question mark was placed on the interpretation of the deuterium exchange process. The microfibrils are regarded as the crystalline components of α-keratins.Contrary to earlier beliefs, water does penetrate the crystalline regions, indicating that the sorption and exchange methods underestimate the crystallinity[52].

TABLE 72[52]
ESTIMATES OF THE FRACTION OF CRYSTALLINE MATERIAL(fc) IN KERATINS

Material	Crystalline fraction	Method	Authors
Oxford Down wool	0.44	Sorption isotherm	Hailwood & Horrobin [15]
Romney wool	0.36	Sorption isotherm	Nicholls & Speakman [25]
	0.16	Deuterium exchange	Burley, Nicholls & Speakman [7]
Lincoln wool	0.30	Sorption isotherm	[25]
	0.13	Deuterium exchange	[7]
Merino wool	0.48	Sorption isotherm	[15]
	0.37	Sorption isotherm	[25]
	0.16	Deuterium exchange	[7]
Wool	0.15 to 0.18	Sorption stoichiometry	Valentine [33]
Hair	0.43	Sorption isotherm	[15]
Mohair	0.40	Sorption isotherm	[25]
	0.18	Deuterium exchange	[7]

Fraser and Macrae[52] gave the following values (Tables 73 and 74) for the specific gravity (relative density) of different keratins.

TABLE 73[52]
THE DENSITIES OF CERTAIN NATIVE KERATINS MEASURED BY THE FLOTATION METHOD IN MIXTURES OF o-DICHLOROBENZENE WITH CHLORO BENZENE OR BROMOBENZENE

Material	Density at 25° C. g.cm.$^{-3}$	Suspension temperature, ° C.	Mean residue weight, $\overline{M}$	Avg. volume per residue, Å^3
African porcupine quill (tip)	1.320	30	110*	138
African porcupine quill (cortex)	1.304	40	—	—
Echidna quill (tip)	1.335	29	110*	137
Feather rachis (goose)	1.269	46	101**	132
Horn (cow)	1.283	36	—	—
Horn (ram)	1.287	31	—	—
Hoof (cow)	1.288	47	—	—
Human hair (infant)	1.317	32	109‡	137
Mohair (Turkish, kid)	1.297	40	109†	140
Lincoln wool	1.299	37	—	—
Corriedale 56's wool	1.302	40	109	139
Merino 64's wool	1.302	41	112	143

* Assumed.
** Turkey feather rachis.
† Texas kid mohair.
‡ Adult hair.

TABLE 74[52]
PREVIOUS VALUES

Material	Density at 25° C. g.cm.$^{-3}$	Solvent	Method	Reference
Australian 80's wool	1.299	Benzene	Displacement	[7]
Lincoln 32–36's wool	1.290	Benzene	Displacement	[7]
Wool, 60's top	*1.300*	*Benzene*	*Displacement*	*[7]*
Wool, 60's top	1.302	Toluene	Displacement	[7]
Wool, 60's top	1.305	CCl_4	Displacement	[7]
Merino 60's wool	1.309	Benzene	Displacement	[16]
Corriedale wool	1.307	Benzene	Displacement	[16]
Mohair	1.304	Benzene	Displacement	[16]
Wool (fabric)	1.317	Xylene/ CCl_4	Gradient column	[17]
Wool (unspecified)	1.30	Xylene/ CCl_4	Gradient column	[12]
Porcupine quill	1.32	—	—	[11]
Keratins	1.29–1.305	—	—	[9]

According to studies by **Speakman** *et al*[11] on the variation of the density of wool and mohair with temperature, the coefficient of thermal expansion of keratins, such as mohair, is about 0.00016°C^{-1}[52]. Based upon the assumption that the density (dc) of the crystalline fraction is 1.39, **Fraser and Macrae**[52] arrived at the following values (Table 75) for the relative non-crystalline content of mohair and other keratins).

TABLE 75[52]
THE RELATIVE CONTENTS OF NON-CRYSTALLINE MATERIAL IN CERTAIN α-KERATINS ASSUMING dc = 1.39

Material	Density, g.cm.$^{-3}$	Relative noncrystalline content
Echidna quill tip	1.335	50
Porcupine quill tip	1.320	64
Human hair (infant)	1.317	67
Merino wool	1.302	81
Mohair (kid)	1.297	86
Hoof (cow)	1.288	95
Horn (cow)	1.283	100

12.4 Small (Low) Angle X-Ray and Related Studies of Mohair*

Spei and Holzem[1048] have recently provided an authoritative review of this subject and **Zahn**[994,1054] also covered it in his review of mohair keratin research. Various researchers, particularly **Spei and co-workers**[185,224,257,274,282,297,298,333,340,362,363,379,380,399,501,659] have undertaken extensive small angle X-ray diffraction studies of the structure of chemically treated and extended α-keratins, such as mohair.

Heideman and Halboth[240] (quoted by **Zahn**[994,1054]) reported on the fibrillar swelling of α-keratin (mohair) in different solvents, by using X-ray techniques. In short-chain n-alkanols and dimethylformamide the 9.2 Å reflection increased by more than twice that in water, this being related to a weakening of the hydrophobic effects. The lateral spacings of the protofilaments (protofibrils) and micro-fibrils increased in water-swollen mohair to the same extent, (17%), protofilament swelling was excluded, only microfibrillar swelling occurring. According to **Zahn**[994,1054], these results may be interpreted by the fact that water penetrates the KIF and is located on the surface and between the protofilament as the tetrameric structural units which results in the swelling of the KIF. The microfibrils (KIF) are only 50% crystalline and contain 50% nonhelical regions, the latter being part of the "matrix" in the two-phase model. The two-phase model regards the structure as consisting of microfibrils containing the organised alpha-helical structure, which is labile and weakened in water, according to **Feughelmann**[559] (quoted by **Zahn**[994,1054]). The rest of the structure includes the 50% nonhelical regions in the microfibrils (KIF)[600].

*Studies on thermally treated keratins are covered in the following section.

Heideman and Halboth[176] studied the distribution of amino-acid residues within the micro-fibril by X-ray diffraction patterns. Lysine residues appeared to have an axial periodicity of 39 Å, and to be distributed on the periphery of the protofilaments. They[240] subsequently reported on the fibrillar swelling of α-keratin (mohair) in different solvents, as assessed by X-ray techniques. They attempted to explain the differences in swelling in the different solvents, the non-linear increase of swellling in different water-propanol mixtures being ascribed to the leakage of hydrophobic bonding between non-polar side chains of the keratin[240]. The lateral spacing of the photofibrils and microfibrils also increased (17%) in water swollen mohair.

A meridional reflection at about 200 Å was identified by **Spei**[274,297,298] **and co-workers**[185] *in the X-ray patterns of some solvent treated and chemically* modified mohair. After extension of mohair fibres in 2,2,2-trifluoro-ethanol, some meridional spacings were considerably increased[256,297]. On the basis of X-ray studies, **Spei** *et al*[185] observed a structural regularity (periodicity) at 198 Å in treated mohair, although only the 66 Å reflection was considered a true meridional reflection. **Fraser and Macrae**[249,310] (quoted by **Zahn**[994,1054]), however, found a fibre axis repeat of 470 Å, the α-keratin structure having a helical symmetry in which the repeating keratin subunits are arranged at intervals of 470 Å on a helical pitch of 220 Å, with the 198 Å reflection the axial projection of the lattice vector (see also Ref.[908]).

On the basis of earlier studies[333,224,225,298,333,364,515,844,850], low angle X-ray diffraction of chemically modified and extended α-keratins, **Spei**[297,380] concluded that, not all low-angle meridional reflections can be regarded as higher orders of a 198 Å periodicity and that along the fibre axis at least two ordered regions existed. He explained the results on the basis of two helical components and one non-helical component, with the microfibrils made up mostly of the less stable helical component and less of the non-helical component. The matrix on the other hand consisted of the non-helical component and the more stable helical component. The 66 Å reflection was interpreted[224,297,333] to be a periodicity of the less stable helical components of the microfibrils and the 28 Å reflection a periodicity of the more stable helical component in the matrix (ie a matrix repeat). The 25 Å reflection (8 order) was regarded as a periodicity of the non-helical component of the matrix[298]. **Spei**[380] concluded that his investigations supported the idea of an ordered matrix in α-keratin.

Spei and Zahn[490] undertook X-ray small-angle studies on fibre keratins with varying matrix content, including mohair, after they had been swollen in water. They found that, human hair with the most matrix showed the least swelling which was in contrast to the hypothesis that the matrix was mainly *involved in swelling.*

Assuming an intermicrofibrillar distance of 74.5 Å, **Spei and Zahn**[490] showed that mohair contains about 42% by volume of matrix, porcupine quills 37% and human hair 54%. In order to gain further information about the microfibril-matrix composite, **Spei** *et al*[501] undertook X-ray studies of thermally treated keratins (mohair, porcupine quill, horse tail hair and human hair).

Zahn *et al*[502] concluded that their X-ray investigations had shown positively that the intermicrofibrillar matrix displayed a considerable degree of order, two meridonal reflections at 28 Å and 25 Å being indexed as matrix repeats. In water, the X-ray swelling of the matrix rich human hair was much lower than that of the matrix poorer mohair fibres and porcupine quill samples. The opposite swelling behaviour should have been observed if the hypothesis of preferential matrix swelling was correct[502]. An alternative explanation for this inverse correlation between swelling and matrix content had been offered[496].

Spei[565] undertook further low-angle X-ray diffraction studies of the microfibril-matrix-complex of α-keratins, eg mohair, human hair and porcupine quill, having different proportions of matrix. He found that fluorinated alcohols, trifluoroethanol and hexafluoroisopropanol, react equally well with matrix proteins as with micro-fibrillar proteins[565].

Spei[659] used low-angle X-ray analysis of the water swelling of mohair and porcupine quills. Using X-ray investigations of various swollen α-keratins (eg mohair and wool) **Spei**[610,721] showed there was not only a matrix swelling but also a considerable microfibrillar swelling.

Work by **Spei and co-workers**[224,225,298,364,515,632,644,650], involving studies of the influence of detergents on the low-angle X-ray diffraction patterns of α-keratins (mohair) confirmed the presence of two ordered regions along the fibre axis, the 28 Å meridional reflection being indexed as a matrix repeat and the 39 Å as a microfibrillar repeat. The deposition of anionic detergents (n-alkylsulphates) occurred in two stages: First the matrix was penetrated and then, at higher detergent concentrations and lower pH-values, the microfibrillar regions were penetrated.

12.5 Thermal and Thermo-Analytical Studies

Various workers[107,161] investigated differential thermal analysis as a possible method for interpreting the thermal characteristics of untreated and chemically modified mohair and wool. Broad endotherms, corresponding to peak temperatures of 213° to 224°C and 225° to 235°C, were accompanied by a foul, sulphurous or characteristic odour of burning wool, with the fibre liquefying at 5° to 10°C above the higher of the two temperatures[107,161] as quoted by **Zahn**[994].

Felix *et al*[107] found the "Differential Thermal Analysis Curves" of wool and mohair to be similar. The endotherm at 130° to 145°C, was ascribed to *vaporization of bound water.* **Weclawowicz**[226] *reported on the effect of high* temperatures (200°C in air for periods ranging from 30s to 6hr) on the physical and chemical properties of mohair and other protein fibres.

Crighton and Hole[377] investigated the use of thermal degradation characteristics (thermo-gravimetry) as a method for differentiating between different keratin fibres. Investigations by thermo-gravimetry (TG) between 200° and 400°C yielded curves which, although they showed recognisable differences, were not suitable for characterisation purposes. The derivative thermo-gravimetric (DTG) curve enabled recognition of reproducible differences between the fibre types examined, including mohair, wool and cashmere.

Spei[515] reported on the influence of heat (170° to 230°C) on the microfibril/matrix complex of wool and mohair and also investigated the influence of fluorinated solvents on the matrix proteins. The action of heat and liquid ammonia on the morphology of mohair and other keratin fibres was studied by means of thermo-mechanical analysis, stereoscan microscopy and differential scanning calorimitry[492].

Hagege and Connet[519] correlated various "thermal events" as studied by Differential Scanning Calorimetry (DSC), with length variations as followed by Thermo-mechanical Analysis (TMA) and with morphological features as revealed by scanning electron microscopy, when keratin fibres are heated. Good agreement was found between the three methods employed. They concluded as follows[519]:

"Supercontraction" near 220°C was associated with the "wrinkling" of the scales and corresponded to the Tg of the orientated "γ-phase" of keratin. Post-elongation near 260°C was associated with the restoration of the original external morphology of the scales and corresponded to the "melting" of the crystalline structure in the cortex. Volatilisation of the keratinic substance proceeded from inside towards the outside of the fibre. The degradation of the exocuticular component (at 10°C/min heating rate) began above 350°C and proceeded very progressively. The liquid-ammonia pre-treatment mainly resulted in a lowering of the Tg of the "dry" keratin and in spreading the "Tg-zone" down to room temperature".

Föhles *et al*[518] found that, according to amino-acid analyses of thermally treated mohair, there were considerable losses in lysine, aspartic acid and cystine, with the losses in amino-acids with hydrophobic side-chains being low. Their results supported the hypothesis that the 28 and 25Å reflections were matrix repeats and the 39Å reflection a micro-fibrillar repeat.

Müller-Schulte[530] showed that the structural features and decomposition reactions of untreated and chemically treated mohair can be described on the basis of differential scanning calorimetry (DSC) measurements made in conjunction with small-angle X-ray data.

Crighton and Hole[715] studied wool, mohair and other keratin fibres in aqueous media by high pressure differential thermal analysis (DTA)[715].

Spei[706] **and co-workers**[501] undertook low-angle X-ray, and amino-acid analysis of dry heated fibre keratins (170°-230°C) and low-angle X-ray investigations and DSC-investigations of wet heated (in water) fibre keratins (120°-140°C). **Spei**[706] showed that previously postulated helix melting points were not true melting points but irreversible decomposition points. DSC-investigations of isolated microfibrillar proteins and matrix proteins in the disulphide form supported this hypothesis. It was also showed that the intramolecular disulphide bonds displayed a greater thermal stability than the intermolecular ones[706]. **Spei**[721,754] **and Spei and Holzem**[946] carried out a number of studies on the thermal characteristics and degradation of keratin fibres, such as mohair, using X-ray and DSC techniques which provided information on the swelling and thermal stability of keratin fibres[754]. In the DSC-curves of α-keratins, two endothermic peaks had been interpreted contradictorily in terms of helix melting points and cystine decomposition points. Investigations[721,754,827,946] showed that the first (lower) endothermic peak (within the 230 to 250° range) was a microfibrillar peak (ie helix peak but not a helix melting peak) and the second (higher) peak a matrix peak (ie a cystine decomposition peak)[721]. Thermal degradation (ie decrease in the relative helix content) depended both upon the time and temperature of the heat treatment[721,754,946,1048]. **Spei and Holzem**[721,754,946] compared the degree of degradation of various fibre keratins and fibre keratin model substances after annealing at 200°C. They found that the thermal decomposition point of the annealed and immediately cooled samples depended upon the cystine contents, it being 235° to 240°C for undergraded wools, mohair, horsehair and human hair and 220°C for S-carboxylmethylated mohair (SCM ; 50% degree of reduction)[946,1048]. Fig. 43[1048] shows the effect of heating time (200°C) in the relative α-helix content of different fibres.

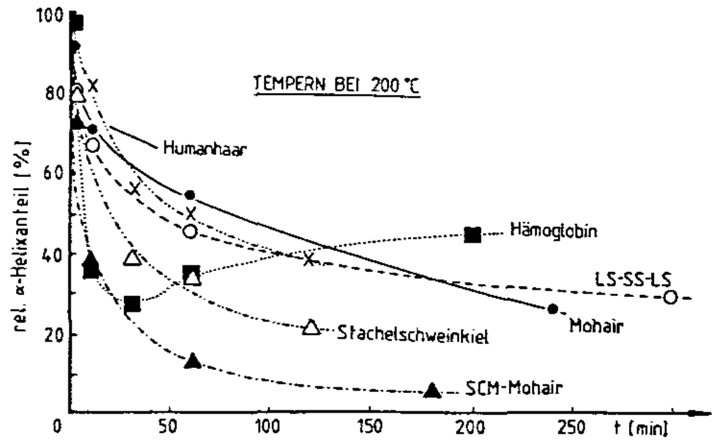


Fig. 43 Relative Helix Content of Six Different Materials as a Function of Temperature[1048].

The area under the endothermic "helix" peak (curve) which occurs in the thermograms of fibre keratins in the temperature range 230° to 240°C (238°C for mohair) is a measure of the relative helix content of the sample[687,791,827,910,918,1025,1048]. The peak area decreases continuously with increasing fibre extension and thermal degradation[919], mohair having a relatively high helix content of 35%[81] (Table 76[1048]).

Haemoglobin has half the relative helix content, but twice the absolute helix content, of mohair[79,917,1048].

Spei and Holzem[918] investigated the α- β-transition of different keratin fibres, including mohair, by DSC (thermo-analytical) and X-ray techniques and compared the results with theoretical values. They considered that for stretched and annealed fibre keratins, the α- β-transition is governed by a molecular mechanism up to elongation values of 60 to 80%, with previously crys-

TABLE 76[1048]
ABSOLUTE AND RELATIVE HELIX CONTENT OF DIFFERENT FIBRE KERATINS

Test	Absolute Helix Content (%) [81]	Calculated Relative Helix Content (%)	Measured Relative (DSC) Helix Content (%)
Mohair	35	35/35 ≈ 100	100
Lincoln Wool	30	30/35 ≈ 86	85 (83-87)
Human Hair	21	21/35 ≈ 60	60 (55-65)
Horse Hair	25	25/35 ≈ 71	60 (55-65)

talline α-helices being converted into drawn b-concertina structures. It could not be ruled out, however, that the molecular α- β-transition is superimposed by a non-molecular α- β-transition whereby previously amorphous keratin is converted into stretched β- structures by elongation crystallisation. During TLC studies on stretched mohair, **Spei**(1037) found that the relative helix content decreased linearly with increasing extension, the α- β-transition was therefore also linear, indicating that a regular extension of the helical and non-helical micro-fibrillar parts results throughout the whole elongation range.

Spei and Holzem(915) showed that weathering damage to mohair and other keratin fibres could be determined by thermo-analytical (DSC) techniques.

Deutz *et al*(1017,1028,1029) used high pressure differential calorimetry (HP - DSC) to investigate the thermal behaviour of, and to characterise, keratin fibres, such as mohair, their morphological structure and chemical composition. The thermally induced changes in keratin fibres, in the presence of water between 130° and 150°C, were due to a transition from the native α-helix into a random structure, the HP - DSC detecting these transitions in the form of endo-thermal peaks. A characteristic correlation between the melting point of the α-helix and the cystine content of the keratin fibres was observed. They concluded that the first endothermic peak originated from the unfolding of the keratins in the ortho-cortex, with the second endothermic peak being due to the keratins in the para-cortex because of their higher cystine content. They also investigated the dependence of the "melting temperature" on cystine content.

12.6 Amino-Acid Composition

To obtain a pure protein for amino-acid sequence studies, reduction followed by S-carboxymethylation (SCM) rather than oxidation, was generally used to solubilise the proteins(516).

Chemically, mohair fibres do not differ greatly from wool, the amino-acid composition of Kid mohair being found to be largely similar to that of merino and Lincoln wool(117). **Ward** *et al*(44) found the amino acid values for wool and mohair not to differ all that notably, except possibly in the cases of tyrosine, aspartic acid, serine and threonine. The most interesting apparent chemical differences were in the relatively low sulphur (and therefore cystine) contents and the relatively high values for aspartic acid(44). **Simmonds**(63) found mohair to be more reactive than wool or human hair and found that the levels of only certain amino-acids differed between the limited wool and mohair samples studied. Mohair appeared to have a greater proportion of the acidic and basic amino acids than human hair, explaining its greater affinity for both acidic and basic dyes.

Various investigations into the high-sulphur proteins of both oxidised and reduced mohair have been conducted(130,186,204,254,270). Amino-acid analyses have been carried out on mohair by for example, **Swart and co-workers**(130,198,251,258, 361) **and Gillespie**(120). **Swart** *et al*(130) compared the soluble proteins of oxidised mohair and reduced mohair with those of wool. They found that the amino-acid composition of wool and mohair as well as the α-, β- and γ-keratose isolated from the two fibre types were very similar, with the high-sulphur proteins revealing marked differences. They also showed that oxidised mohair contained more α- and less β-keratose than wool. The physical properties of mohair and wool γ-keratins sub-fractions were similar, although amino-acids analysis revealed interesting differences for the sub-fractions. Chromatographic separation, on DEAE-cellulose, indicated that the high sulphur protein fraction (SCMKB) of wool contained protein compounds which could not be accounted for in similar fraction of mohair.

Swart *et al*[130] presented the following table (Table 77):

TABLE 77[130]*
KERATOSE CONTENTS IN MOHAIR AND WOOL

Keratose	Origin	Mohair %	Wool %
α-Keratose	KIF	58.1	53.4
β-Keratose	"Nonkeratins"	10.3	15.8
γ-Keratose	"Matrix" (IFAP)	30.0	30.7

*Given in Ref.[994].

Gillespie and Ingles[121] compared the high-sulphur proteins (SCMKB) from various α-keratins, including mohair (see Table 78).

Crewther *et al*[149] studied the amino-acid composition and optical rotation dispertion properties of the low-sulphur proteins (SCMKA) from a range of α-keratins, including mohair. The effect of different purification methods on the separation of SCMKB proteins has been studied[140], the chromatogram of mohair SCMKB being found to be different to that of the other animal fibres studied.

TABLE 78[121]
THE AMINO-ACID COMPOSITION OF HIGH-SULPHUR PROTEINS FROM WOOL AND MOHAIR

	Lincoln	Merino	Romney Marsh	Southdown	Soay	Dorset Horn		Mohair
Lys	1·27	0·95	0·67	0·68	0·83	0·75	Lys	0·62
His	2·60	1·83	1·61	1·53	2·00	1·68	His	1·43
Arg	18·1	18·3	15·6	16·4	14·0	19·8	Arg	16·7
SCMC	14·4	14·6	15·7	16·6	16·7	17·7	SCMC	14·8
Asp	2·22	2·29	2·42	2·05	1·41	2·05	Asp	2·01
Thre	7·59	7·90	7·12	7·68	7·50	7·55	Thre	7·38
Ser	9·00	9·80	7·80	8·70	8·75	8·76	Ser	8·65
Glu	5·27	6·50	5·51	5·63	5·50	5·50	Glu	5·82
Pro	8·82	9·60	10·2	9·72	9·33	10·4	Pro	9·55
Gly	4·41	5·30	4·30	4·44	4·08	4·38	Gly	4·78
Ala	2·25	2·26	2·15	2·05	1·83	2·05	Ala	2·35
Val	4·54	4·35	4·30	4·09	4·00	4·29	Val	4·03
Ileu	2·27	2·75	2·28	2·22	1·91	2·14	Ileu	2·31
Leu	2·81	2·98	3·09	2·73	2·08	2·80	Leu	2·84
Tyr	1·81	1·64	0·81	1·19	1·08	1·58	Tyr	1·01
Phe	1·36	1·45	1·61	1·36	0·91	1·40	Phe	1·60

Results expressed as grammes of amino acid nitrogren/100 g total nitrogen.
These proteins were hydrolysed under reflux and the SCMC content reported was obtained from the sum of half cystine and residual SCMC.

Heideman and co-workers[176,184] studied the distribution of lysine in the microfibrils of α-keratins, such as in mohair.

Swart[139] showed that the amino-acid composition of kemp was different from that of adult mohair, the former containing more β-keratose but less γ-keratose than the latter. **Swart** *et al*[169] subsequently compared the proteins of Adult mohair, Kid mohair and kemp fibres, the amino-acid composition of the fibres revealing differences. This was further supported by the different proportions of the α-, and β -keratoses of the fibres and the amino-acid composition of these keratoses. Four fractions of the γ-keratose of the three fibre types, which gave single peaks on electrophoresis and ultracentrifugation, were isolated by column electrophoresis. Comparisons of the properties of corresponding sub-fractions of the various fibres revealed similar physical properties, but differences in their amino-acid composition were obvious[169]. Adult mohair was found to contain 6% more cystine, 13% more glycine, 10% less phenylalanine and 17% less tyrosine than Kid mohair[169]. Kemp contained 17% more lysine, 13% more histidine, 13% more phenylalanine, 7% less serine, 7% less tyrosine and 18% less cystine than adult mohair[169]. Kemp contained considerably more β-keratose and less γ-keratose than the other two fibre types (Kid and Adult mohair). The amino-acid composition of kemp medullary cells was calculated and found to be in reasonable agreement with that reported for porcupine quill medulla. **Swart** *et al*[169] gave a table summarising the physical measurements on sub-fractions of γ-keratose found in Adult mohair, Kid mohair and kemp and also gave the amino-acid composition of the sub-fractions of γ-keratose from Adult mohair, Kid mohair and kemp (Table 79).

TABLE 79[169]
AMINO ACID-COMPOSITION OF THE SUB-FRACTIONS OF γ-KERATOSE FROM ADULT MOHAIR, KID MOHAIR AND KEMP

Amino acid	γ_1-keratose			γ_2-keratose			γ_3-keratose			γ_4-keratose		
	Adult mohair	Kid mohair	Kemp	Adult mohair	Kid mohair	Kemp	Adult mohair	Kid mohair	Kemp	Adult mohair	Kid mohair	Kemp
Alanine	1·82	2·06	2·03	2·31	2·45	2·32	1·95	2·04	2·00	2·75	2·92	3·04
Ammonia	10·45	10·16	9·08	8·24	9·14	9·11	6·84	7·01	7·05	7·23	7·49	7·39
Arginine	15·57	14·78	14·62	19·35	18·47	17·95	27·62	27·60	26·39	18·80	16·68	15·47
Aspartic acid	0·80	0·56	0·62	1·52	1·40	1·72	1·53	1·56	1·62	3·97	4·73	5·33
Cysteic acid	18·39	18·68	17·74	16·50	17·24	15·90	15·18	15·03	15·28	11·73	11·40	11·19
Glutamic acid	7·91	8·16	8·50	6·29	6·38	6·39	5·24	5·27	5·14	4·15	4·39	3·56
Glycine	5·02	5·43	5·71	3·89	4·15	4·01	3·32	3·36	3·44	4·36	4·41	4·54
Histidine	0·73	0·56	0·37	1·35	1·21	1·48	0·54	0·58	0·58	3·17	4·22	4·23
Isoleucine	2·72	3·08	3·18	2·40	2·55	2·47	1·48	1·45	1·49	2·36	2·43	2·78
Leucine	1·24	1·36	1·31	2·49	2·50	2·75	2·14	2·17	2·17	4·06	4·57	5·17
Lysine	0·45	0·44	0·22	0·56	0·73	0·64	0·35	0·32	0·42	1·14	1·34	1·49
Phenylalanine	0·63	0·74	0·83	1·06	0·89	1·15	1·40	1·53	1·60	2·17	2·47	2·70
Proline	8·54	8·78	8·43	10·07	9·95	10·21	10·05	9·71	10·01	9·93	9·92	10·13
Serine	11·98	11·26	12·07	9·99	9·81	10·25	7·50	7·94	7·08	9·13	9·17	8·22
Threonine	8·42	8·26	8·82	8·01	7·45	8·23	7·93	7·90	7·78	7·62	7·85	7·69
Tyrosine	1·08	1·13	1·11	0·87	0·64	0·77	0·62	0·65	0·58	0·96	1·08	1·01
Valine	2·94	3·11	2·90	4·17	4·19	3·95	4·91	4·19	4·92	4·83	5·01	4·61
TOTAL	98·09	98·53	97·60	99·07	99·15	99·30	98·60	99·03	97·55	98·41	100·08	98·55

A comparison of Adult mohair, Kid mohair and kemp gave the following results[130,186]:

TABLE 80[130,186]

PERCENTAGES OF KERATOSES IN FIBRES ON A NITROGEN BASIS

		Adult Mohair	Kid Mohair	Kemp
α-Keratose		58,1	62,9	59,5
β-Keratose		10,3	8,8	15,8
γ-Keratose		30,0	27,3	23,9
	TOTAL	98,4	99,0	99,2

Bradbury *et al*[178] (quoted by **Kidd**[418]) undertook chemical analyses of individual structural components of mohair.

The elucidation of the first complete amino-acid sequence of a keratin protein was achieved by **Haylett and Swart**[198]. One of the first and most extensive surveys on the high-sulphur proteins (SCMK-B) from reduced mohair was carried out by **Joubert**[254,270] who defined five major proteins by differences in their molecular weights (approximately 9 900, 12 200, 15 500, 19 000 and 22 500), electrophoretic mobilities and amino-acid compositions. A comparison of the amino-acid compositions of the corresponding molecular weight groups of the high-sulphur proteins of wool and mohair revealed obvious differences and analogies. It was concluded that wool and mohair SCMK-B contain closely related protein components. However, the degree of homology, substitutions of amino residues, and essential differences between similar proteins of wool and mohair could only be evaluated when the amino-acid sequences were compared. **Haylett** *et al*[252] showed that the high-sulphur proteins of reduced carboxy-methylated mohair and wool consist of four main groups with different molecular weights (23 000, 19 000, 16 000 and 11 000), with each group comprising a number of closely related components. The total SCMKB of mohair was separated, by chromatography on DEAE-cellulose into three fractions, M1, M2 and M3[358,361]. The 11 000 dalton group occurred in Fractions M1 and M2 and the 16 000 dalton group only in Fraction M2, while Fraction M3 contained the higher molecular weight groups. Chromatography on cellulose phosphate at pH 2.8 in 5M urea proved to be highly effective in separating the 11 000 and 16 000 dalton groups due mainly to the large differences as in their argenine groups[252,315,404]. The individual components in a group could be separated by using extended sodium chloride gradients, this method yielding two components from Fraction M1 (11 000 dalton) of mohair[361] and seven from Fraction M2 (three from the 11 000 dalton group and four from the 16 000 dalton group)[358,404]. **Swart** *et al*[404] presented amino-acid sequence data on the high-sulphur proteins from the 16 000 dalton groups of mohair and wool, a five amino-acid residue repeating unit in the 16 000 dalton group previously being demonstrated by **Joubert and Swart** (quoted in Ref. [404]). A higher degree of homology was confirmed between the proteins of different molecular weights and between merino wool, Lincoln wool and mohair. The most probable fifteen nucleotide base sequence for the five residual repeating amino-acid units in the 16 000 and 19 000 dalton groups of proteins were derived. The correspondence between these units was absolute proof of a common ancestor[404]. **Swart** *et al*[404] also discussed aspects of homology and phylogenetics. A comparison of the proteins derived from wool and mohair showed that these high-sulphur proteins provided a record of their genetic history and, if extended to other sources, these keratins could provide an excellent study on phylogenetic relationships. The fact that the high-sulphur proteins of mohair and wool belong to groups with distinctive physical properties, was discussed[404] for the 11 000, 16 000 and 19 000 dalton groups of proteins, in terms of molecular size (there being well defined molecular weight-groups without intermediate sizes), charge (the 11 000 and 19 000 dalton groups being slightly basic and the 16 000 dalton group strongly basic), sulphur distribution (proteins in the 11 000 dalton group could be divided into a sulphur-rich (7%) half and a sulphur deficient (3%) half[198], cysteinyl residues, however, being evenly distributed in the 16 000 and 19 000 dalton group proteins) and N-termini.

Joubert[358] described the fractionation of the 15 500 molecular weight group of the high-sulphur proteins of mohair into four fractions. The complete amino-acid sequences of two proteins present in one of these fractions were elucidated and compared to similar proteins obtained from wool. The S-carboxy-methyl derivatives (SCMKB) of the high-sulphur proteins of mohair were fractionated by a combination of chromatography on DEAE-cellulose and cellulose phosphate, and seven fractions from group M2 were obtained. The complete amino-acid sequences of proteins SCMKB-M.2.6 and a minor component SCMKB-M26A were elucidated. The amino acid sequences of mohair proteins SCMKB-M2.6 and SCMKB-M2.6A showed a high degree of homology with the amino acid sequences of wool proteins SCMKB-IIIA3 and SCMKB-IIIA3A[358]. **Parris and Swart**[361] isolated and determined the first complete amino-acid

TABLE 80a[147]
AMINO-ACID COMPOSITION OF ANIMAL FIBRES DERIVED FROM VARIOUS STRAINS OR BREEDS OF SHEEP AND OTHER SPECIES

	Merino 70's[a]		Merino 64's[a]		Corriedale 56's[a]		Lincoln[b]		Mohair[c]		Human hair[c]		Range of variation (% of lowest value)
Amino acid	I[d]	II[e]	I	II	I	II	I	II	I	II	I	II	
Alanine	3.51	415	3.51	417	4.37	524	4.16	493	3.80	452	2.93	345	49
Ammonia	7.92	937	7.46	887	9.27	1112	7.89	936	6.68	793	6.76	797	20
Arginine	19.35	575	20.32	602	18.21	546	20.00	592	16.52	490	16.15	476	41
Aspartic acid	4.68	555	4.24	503	4.86	584	4.96	588	4.58	544	3.52	415	39
Half-cystine	6.50	768	7.93	943	6.80	817	7.18	852	6.81	808	12.07	1422	86
Glutamic acid	8.54	1011	8.58	1020	9.69	1160	8.79	1040	8.89	1055	7.58	885	28
Glycine	6.60	781	5.80	688	6.40	769	4.80	568	5.43	645	4.34	512	52
Histidine	1.48	59	1.46	58	1.59	63	1.65	65	1.76	70	1.58	62	21
Isoleucine	2.13	252	1.97	234	2.38	286	2.48	294	2.29	272	1.80	212	38
Leucine	5.37	635	4.90	583	5.51	659	5.93	703	5.66	672	3.94	464	51
Lysine	3.19	189	3.25	193	3.72	224	4.46	264	3.75	223	3.02	178	48
Methionine	0.37	44	0.31	37	0.37	44	0.37	44	—	—	—	—	—
Phenylalanine	2.28	270	1.75	208	2.35	284	1.88	234	2.06	245	1.21	143	94
Proline	5.12	605	5.33	633	5.52	662	4.50	533	4.68	557	6.39	753	42
Serine	8.63	1020	7.25	860	7.71	925	6.33	750	6.28	745	7.22	851	37
Threonine	4.12	487	4.61	547	4.84	582	4.23	501	4.06	482	4.58	542	19
Tryptophan	1.38	163	1.73	205	1.80	214	—	—	—	—	—	—	—
Tyrosine	3.09	366	2.97	353	3.11	373	2.00	237	1.64	194	1.07	126	191
Valine	3.56	422	3.57	423	4.50	540	4.29	508	5.59	663	4.16	490	57
Nitrogen (%)	16.57		16.62		16.80		16.58		16.60		16.50		

[a] From Simmonds (1955).
[b] From Thompson and O'Donnell (unpublished data, 1962).
[c] From Simmonds (1958b).
[d] Throughout this table the values designated in column I are given as as % total N.
[e] Throughout this table the values designated in column II are given as μmole per gram.

sequence of a high sulphur mohair protein, SCMKB-M1.2. The protein was closely homologous to wool protein SCMKB-IIIB2. Protein M1.2 was the first mohair protein of which the complete amino-acid sequence was determined[361], the calculated molecular weight of the protein being 11 206.

Crewther *et al*[147] gave a comparative table (Table 80a) for the amino acid composition of various animal fibres and human hair.

Corbett[384] compiled the following table (Table 81) from various sources.

TABLE 81[384]
AMINO-ACID ANALYSIS OF HAIR AND WOOL*

	Wool			Human Hair		
	Merino 64s	Lincoln	Mohair	Caucasian	Negro	Cuticle
Glycine	688–734	590	645	437–539	541	836
Alanine	417–483	601	452	345–471	509	500
Valine	423–498	570	663	405–538	568	644
Leucine	538–627	740	672	442–554	570	404
Isoleucine	234–282	333	272	174–250	277	186
Serine	860–970	541	745	851–1087	672	1628
Threonine	546–552	483	482	452–664	615	415
Tyrosine	314–353	266	194	126–194	202	134
Phenylalanine	208–242	273	245	124–150	179	115
Aspartic acid	503–511	575	544	399–455	436	300
Glutamic acid	987–1028	828	1055	871–1053	915	848
Lysine	193–240	310	223	178–218	231	331
Arginine	563–602	662	490	466–534	482	289
Histidine	58–78	71	70	57–70	84	53
Half cystine	858–959	745	808	1308–1608	1370	1880
Cysteic acid	11	6	–	27–55	10	59
Methionine	37–54	–	–	13–54	–	39
Proline	582–633	490	557	588–753	662	900

*Values given in micromoles/g

Tucker *et al*[899] (quoted in Ref.[978]) gave a table for the amino-acid composition of various speciality animal fibres, including cashgora and cashmere.

12.7 Sulphur Content

Mohair has a sulphur content similar to that of high lustre wool of similar fineness[98]. **Mauersberger**[32] gave values of sulphur content (based on dry mass) for Turkey mohair of 3.4% for fine and 3.0% for coarse, respectively. **Harris**, quoted by **Von Bergen**[202], found that the sulphur content of Texas Kid mohair was 2.9% and Turkey mohair fleece 3.6%. It has been stated[17] that mohair has an average sulphur content of about 3.7%.

Dusenbury[85] also gave the following table (Table 82) for the cystine content of various keratin fibres, the cystine content of the para-cortex being about twice that of the ortho-cortex.

TABLE 82[85]
CYSTINE CONTENT OF VARIOUS KERATIN FIBRES

Fibre Type	Cystine Content (%)
Human Hair	18·8
IWS Wool C	11·3
Kid Mohair	10·4
B. A. Fleece Wool (40s—44s) ...	10·8
B. A. Fleece Wool (56s)	11·7
Lincoln Wool (40s)	12·8
White Cashmere	11·8
Dark Vicuna	13·6
Pooled 95% Confidence Limit ...	±0·3,

Satlow *et al*[128] found that alpaca contained more cystine than mohair and found that the cysteine content was less for mohair than for camel hair and alpaca. **Satlow**[168] also quoted values for the cysteic acid and tryptophane content of mohair.

Grünsteidl and Wilhelm[190] also investigated the amino-acid composition of mohair and other animal fibres. They gave the following table (Table 83) for the sulphur content of the various animal fibres:

TABLE 83[190]
SULPHUR CONTENT(%)*

Karakul	3.23
Mutton Sheep	3.45
Mountain Sheep	3.33
Camel	3.27
Mohair	3.31
Angora Rabbit	5.57

*Based upon dry mass.

They also published a table of the amino-acid content of the different animal fibres. **Gillespie and Broad**[286] found a linear relationship between ultra-high-sulphur protein content and sulphur content for wool and various hair fibres, including mohair. **Kassenbeck** *et al*[378] determined the sulphur-content along the cross-section of mohair and other keratin fibres. The sulphur content of the cuticle was significantly higher than that of the cortex, with that of the para-cortex higher than that of the ortho-cortex. They gave the following values (Table 84) for sulphur content:

TABLE 84[378]
SULPHUR CONTENT OF DIFFERENT ANIMAL FIBRES

Fibre	Sulphur Content (%)
Poodle Hair	4.2
Merino Wool - Ortho-Cortex	2.9
Merino Wool - Para-Cortex	4.3
Cape Mohair	2.8

Kidd[418] compiled the following tables (Table 85 and 86), from various sources, for the sulphur and cystine contents of various fibres.

Maasdorp[583] used a scanning electron microscope and energy dispersive X-ray system to determine the distribution of sulphur and chromium in mordant dyed keratin fibres (mohair, Lincoln wool and merino wool). The chromium in the keratin fibres was found to be evenly distributed and not affected by fibre type, chroming temperature or a steaming process, although less chromium was deposited in dyed fibres at a low chroming temperature (25°C). The sulphur in the keratin fibres was similarly located and confirmed that merino wool has a bilateral cortical segmentation (ortho-cortex and para-cortex) while the Lincoln wool and mohair examined, seemed to consist mostly of ortho-cortical materials[583]. **Trollip** *et al*[792] showed that the sulphur concentration of the mohair cortex was similar to that of the kemp although the medulla of kemp had a relatively low sulphur content.

TABLE 85[418]
SULPHUR CONTENT OF VARIOUS FIBRES

Fiber	Sulfur content (%)
Bristle (Gortorg)	3.7
Whalebone or baleen	3.6
	3.0
Cow's horn	3.4
	4.1
Rhino horn	1.9
Porcupine quill	1.35–2.5
descaled tip	2.7
Rabbit hair	
—	4.2
—	5.2
Russian	3.84
Agouti	4.30
Black	4.14
Racoon fur	5.78
	5.6
Dog hair	5.1
Dog wool, white	5.07
Muskrat fiber	4.68
Goat hair, Tunisian	3.5
Guinea pig hair	4.3
Alpaca	
—	4.17
white	3.93
brown	4.35
black	3.90
—	3.85
Mohair	
—	3.22
Turkish	
fine	3.36
coarse	3.03
Texas, kid	2.92
Turkish fleece	3.58
Vicuña	4.10
Camel hair	3.41
Cashmere	3.39
Human hair	
—	5.0
—	5.1
—	4.9
—	4.7
—	5.0
—	3.9
black	4.9
Horsetail hair	3.1–3.9
	3.6

TABLE 86[418]
CYSTINE CONTENT OF VARIOUS FIBRES

Fiber	Cystine content (%)
Rabbit hair	
shaft	11.8
tip	8.8
Alpaca	
Suri, white	
shaft	15.1
tip	13.8
Huacayo, white	
shaft	14.4
tip	11.1
—	12.0–13.0
—	12.2–12.9
Cashmere	
white	11.8
—	11.5–12.0
—	11.6–12.0
Camel hair	10.8
	10.3–11.1
Mohair	
kid	10.4
—	10.4–10.9
—	10.2–10.9
Vicuña, dark	13.6
Rabbit hair	
Angora	13.1–13.8
blown	11.2–11.7
Hare hair, blown	13.9–14.2
Goat hair	
clipped	9.8–11.2
clipped	9.4–12.0
lime-soaked	2.2–9.6
Human hair	
—	17.6±0.9
Italian female	14.5
African Negro male	15.5
Cattle body hair (British breeds)	10.8–12.6

12.8 Certain Chemical Related Properties and Treatment Effects

By and large, the chemical and related properties and the effects of chemical treatments are generally similar for wool and mohair and much of the findings relating to wool are therefore also applicable to mohair.

12.8.1 Sensitivity to Acids and Bases and Urea-Bisulphite and Alkaline Solubilities

Urea-bisulphite solubility and alkali solubility tests are two of the chemical methods which have been developed to rapidly measure the degree of chemical damage to wool and mohair. Mohair is generally considered[35,98,128] to be more sensitive to alkali than wool, although **Bamford**[56] found wool more sensitive to alkali than mohair. According to alkali solubility tests, treatment in boiling sulphuric acid modified mohair more than human hair[41]. Low values (15%) of urea-bisulphite solubility have been associated with human hair, which is essentially a para-cortex fibre, intermediate values (45 to 55%) with a crimped wool fibre (ortho- para-fibre with bilateral symmetry), and high values (75%) with Kid mohair which is chiefly ortho-cortex[86].

Dusenbury[85] found that heating kid mohair at 105°C for 4hr reduced its urea-bisulphite solubility and that the effect was not reversible by subsequent treatment with LiCl solution.

Satlow *et al*[128] compared the urea-bisulphite and alkali-solubilities of different animal fibres, as well as their cystine and cysteine contents. Tables of values as well as graphs were given. They compared the behaviour of the various fibre types after different chemical treatments. They reported that mohair was more sensitive to alkali and acid than Buenois Aires (BA) wool.

Kriel[126] investigated the modification of wool and mohair by alkali treatment, using urea-bisulphite solubility as a basis of assessment and found a 38μm mohair more resistant to alkali than a 21μm merino wool. Observed differences between the wool and mohair were considered to be due to differences in fibre diameter and the protective action of the oxidized grease on mohair[126], which was higher for the mohair. **Miró and Erra**[199] investigated the effect of sodium hydroxide on the chemical properties of mohair and wool. **Kidd**[418] compiled the following table (Table 87) for the solubility of various animal fibres, the previous history of the fibre laying an important role in its solubility.

Kidd[418] reproduced the following table (Table 88) from Ref.[78].

TABLE 87[418]
SOLUBILITIES OF VARIOUS FIBRES

Fiber	Alkali solubility[a] (%)	Urea-bisulfite solubility[b] (%)	4.5 N HCl solubility[c] (%)
Cashmere			
—	13–17	38–45	—
white	12–18	43–47	12–23
—		31	
Alpaca	9–16	47–60	—
Suri	7–13	47–58	7–10
shaft	—	39	—
tips		25	
Huacayo			
shaft	—	73	—
tips		54	
Camel hair	14–15	29–52	—
	10–17	37–52	11–20
Vicuña, dark		46	
Mohair			
—	11–15	55–65	—
—	9–27	44–69	4–13
—	—	70	—
kid		75	
Rabbit hair			
Angora	7–12	60–69	5–11
blown	9–15	52–60	10–14
Hare hair, blown	7–11	60–65	7–10
Goat hair			
shorn	13–17	43–44	9–11
shorn	10–20	29–56	8–15
Cattle hair, clipped	6–7	0.7–1.2	12
Calf hair, clipped	6–8	2–10	9–14
Human hair			
Caucasian	5.0	27	
Negro	4.1	37	
—		12	
Lincoln wool for comparison	10	53	

[a] Method of Harris and Smith.[284]
[b] Method of Lees and Elsworth.[358]
[c] Method of Zahn and Würz.[288]

TABLE 88[78]*
CONTRACTION OR SET OF FIBRES TREATED IN BOILING WATER AT 40% EXTENSION

Fiber	Treatment period			
	2 min	30 min	60 min	120 min
Lincoln wool	−27.9	−6.3	8.4	14.9
Mohair	−26.9	12.9	17.5	26.6
Alpaca	−5.9	−0.2	8.6	16.2
Human hair	−7.9	−2.2	5.6	14.5
Cattle tail hair	−18.9	2.2	10.7	20.4

*From Kidd[418].

12.8.2 Supercontraction

Haly and Feughelman[55] studied the supercontraction of mohair, wool and human hair in bromine-free lithium bromide solutions, showing that it took place in two stages with the total contraction determined by the number of disulphide cross-linkages in the fibre. The degree of contraction appeared to be inversely related to the cystine content. **Haly and Griffith**[58] studied the supercontraction of mohair in Lithium Bromide solution.

Bell *et al*[60] investigated the measurement of damage in wool and mohair by a modification of the Krais-Markert-Viertel (KMV) test involving the supercontraction in solutions of caustic potash (KOH). They concluded that changes in recovery time rather than changes in super-contraction provided a better measure of fibre damage and could distinguish between acid and alkaline damage. Nevertheless, many other reagents affected the changes and the results of tests based on dimensional changes in caustic potash, as well as those obtained by the conventional KMV test, needed to be interpreted with great reserve.

Swanepoel[95] investigated the supercontraction of sound and weathered mohair in lithium bromide. **Haly and Swanepoel**[101] studied the supercontraction and elongation of modified keratin fibres, such as mohair, in LiBr solution. They found that irrespective of the residual cystine content (with disulphide loss of up to 53%), the maximum level of super-contraction was approximately the same as in normal wool.

12.8.3 Resistance to Micro-Organisms

As in the case of wool, mohair can be attacked by bacteria and mildew if stored under moist conditions, particularly under warm, dark conditions. The resistance of mohair and certain other fibres to microbiological agencies has been investigated by **Burgess**[12] (quoted in Ref.[98]). Mohair was found to be less resistant to trypsin (enzyme) than wool or human hair (**Burgess**[12] quoted in Ref.[98]), this also being indicative of susceptibility to microbiological attack.

According to **Onions**[98], mohair is more easily attacked by bacteria and mildew than wool.

12.8.4 Birefringence

Barakat and Hindeleh[109] reported on the interferomic determination of the refractive indices, for light vibrating parallel and perpendicular to the fibre axis, respectively, ($n_{\parallel}$ and $n_{\perp}$), and birefringence ($n_{\parallel} - n_{\perp}$) of mohair.

They obtained the following values for the fibre skin: (Corresponding values for wool, quoted from the literature, are given in parenthesis).

$n_{\parallel}$: 1.5474 to 1.5546 (1.542 - 1.547)
$n_{\perp}$: 1.5579 to 1.5638 (1.553 - 1.556)
Δn : 0.0082 to 0.0111 (0.009 - 0.012)

Fouda *et al*[954] gave the following tables (Table 89 and 90) for the refractive indices and birefringence of mohair fibres. They concluded that multiple-beam Fizean fringes were promising in the investigation of fibre properties. The refractive indices $n_s^{\parallel}$ and $n_s^{\perp}$ are for the mohair fibre skin, the birefringence Δn_s values, also being calculated[954].

TABLE 89[954]
THE VARIATION OF REFRACTIVE INDEX WITH DIFFERENT WAVELENGTHS

λ, nm	n_L	According to equation (2)						According to Equation 3		
		$n_s^{\parallel}$	$n_s^{\perp}$	Δn_s	$n_c^{\parallel}$	$n_c^{\perp}$	Δn_c	$n_e^{\parallel}$	$n_e^{\perp}$	Δn_e
436.0	1.5605	1.5654	1.5534	0.0121	1.5682	1.5504	0.0178	1.5658	1.5550	0.0106
546.1	1.5520	1.5574	1.5456	0.0118	1.5606	1.5429	0.0177	1.5573	1.5467	0.0106
578.0	1.5498	1.5554	1.5438	0.0116	1.5582	1.5409	0.0173	1.5559	1.5437	0.0122
589.3	1.5787	1.5544	1.5426	0.0118	1.5573	1.5406	0.0167	1.5549	1.5430	0.0119

TABLE 90[954]
BIREFRINGENCE OF MOHAIR FIBRES

Temperature, °C	$n_s^{\parallel}$ *	$n_s^{\perp}$ *	Δn_s
18.5	1.5573	1.5474	0.0099
17.5	1.5581	1.5471	0.0110

* Values have an accuracy of ±0.0005.

12.8.5 General

Fröhlich[197] gave some results for the physical and chemical properties of mohair, including regain, strength (wet and dry), extension (wet and dry), alkali solubility, ureabisulphite solubility and length and length variation. **Bamford**[56] reported that the titration curves for wool and mohair were almost identical, except for pH 0 to 1.5 and again in the iso-electric range.

Kassenbeck and Hagége[122] investigated the fixation of silver by mohair and other fibres. **Guthrie and Laurie**[180] showed that mohair keratin forms two types of complexes with copper (II) ions, the one being stable at pH < 9 and the other being stable at pH > 9.

Crewther[135] investigated the effects of reduction and alkylation on fibre stress-strain characteristics and concluded that the side-chain interactions between helical structures and matrix molecules containing many interchain disulphide bonds are chiefly responsible for stiffening the fibre in the Hookean region. He showed that when the strain at the end of the yield region was plotted against residual disulphide content, the various fibres fell on the same curve (Fig. 44[135]).

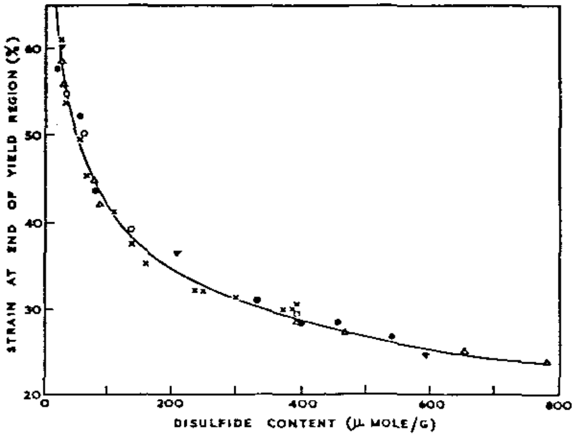


Fig. 44 Relationship between Disulphide Content of S-Methylated Animal Fibres and Strain at the Transition between Yield and Post-Yield Regions: X Lincoln; O Mohair; ● Horsehair; ◄ Lustre Mutant Merino; Δ Human Hair[135].

Appleyard[159], quoted by **Kidd**[418], studied the effect of o-chlorophenol on the cross-section of mohair and other animal fibres.

Atkinson and Speakman[113] investigated the action of mixed solvents on wool and mohair and produced a table illustrating the reduction in work due to the action of an aqueous solution of N-propanol. The behaviour of mohair and other fibres in organic solvents has been investigated[474]. **Ahmad**[216] quoted by **Kidd**[418] studied the adsorption of alcohols by wool and mohair, his results supporting individual experience. The treatment of mohair with tetranitromethone results in only partial conversion of the tyrosine residues into 3-nitro and 3.5 dinitrotyrosine residues[193].

Mohair swells about 12% in diameter in methanol, ethanol, n-propanol and dimethylformamide but contracts in isopropanol[240,359].

Robbins[906a] gave the following comparative table of cross-link density and diffusion rates (Table 91).

Pittman[255] found little difference in the wettability of single wool and mohair fibres. **Jurdana and Leaver**[1075] found that t-butanol did not penetrate the mohair cortex but did appear to penetrate the intercellular material between cuticle cells.

TABLE 91[906a]
CROSS-LINK DENSITY AND DIFFUSION RATES

Type of keratin fiber	% Cystine* calculated from % sulfur	Relative diffusion [89] coefficient at 60°C using orange II dye
Human hair	14.0	1.0
80's Merino wool	11.3	1.9
6's Mohair	9.2	3.4
56's Down wool	8.8	5.0

*Calculated from % sulfur, assuming all sulfur exists as cystinyl residues, and a residue of 178 daltons.

CHAPTER 13

SCOURING AND CARBONISING

13.1 Scouring

Scouring is a critical process for mohair and often it is at this stage that the ultimate state of the finished article is decided[233]. Mohair generally contains far less impurities than wool[110,145] (eg 4 to 6% of grease compared to about 15% for merino wool)[394] and scouring generally causes a loss in mass of between 15 and 20%[309]. Mohair is generally regarded as more sensitive to alkali than wool and less soda-ash should therefore be used during scouring[110,145]. **Stapleton**[1016], *in Australia, suggested the following three categories* for mohair yield:

Heavy Condition :- scoured yield of less than 85%.
Medium Condition :- scoured yield between 85 and 90%.
Light Condition :- scoured yield of greater than 90%.

Before scouring, individual mohair bales were (and still are) often sorted on screens for style and quality, often up to 8 different sorts being obtained from a single bale[102], efficient sorting playing an important role in the eventual quality of the yarn. The fibre can then be willeyed before it is scoured. Scouring conditions for mohair are generally gentler than for wool, the first bowl temperature, for example, being of the order of 50°C, dropping to about 40°C in the last bowl[102]. Alkali need not be used and the scouring rate is generally much lower than the capacity of the scouring train[102].

Slivers made from coarse mohair off-sorts can be used for wrapping the squeeze rollers of the scouring train[102]. After scouring (which normally takes place at between 45°C and 55°C)[533], the fibre can be dried to a moisture regain of about 20% for the longer lengths and about 25% for the shorter types, the higher regain helping to control fly during carding[102]. Care must also be taken during scouring not to impair the lustre of mohair, hence soda ash is often only used in the first bowl[133] or even omitted altogether. The scouring liquor temperatures and pH must be strictly controlled, a maximum scouring temperature of 55°C was suggested[233] and in a typical 3-bowl scouring set the pH of the first bowl could be 10.5, that of the second bowl 9.5 and that of the third bowl 8.5. Excess alkali in the fibre can lead to discolouration in dyeing[233]. **Spencer**[233] suggested that mohair should be scoured to a residual grease level of 0.6% and that l to l.2% of combing oil should be added to give a total fatty matter content of 1.6 to 1.8%, which was considered ideal. An opening/cleaning *operation prior to and after scouring (on a three bowl set), to open the fibre and* remove excess dirt (or stubborn matter), heavy seed etc, results in more effective carding[233,671]. A series of pilot-scale experiments on the scouring of mohair was carried out at SAWTRI in the 1960's[110,133,145]. **Kriel**[110,115], quoting unpublished work by **Veldsman**, stated that a higher consumption of detergent was required to remove 1g of grease from mohair than from wool, the generally lower level of grease (4 to 6%) in mohair as well as its more oxidised nature (because of greater weathering than in the case of wool) being relevant factors. **Kriel**[110,115] **and Kriel and Grové**[145] studied the effect of different backflow rates[110] and temperature[115] on mohair scouring efficiency, stating that for efficient scouring, the minimum temperature should not be lower that the melting point of the wax on the fibre while excessive temperatures could damage the mohair, particularly its lustre. For one of the detergents an optimum rate of backflow of 50% was found[110]. It appeared that as far as grease removal was concerned, temperature had similar effects in the first and second bowls[110,145]. A second bowl temperature of 50°C was judged better than one of 45°C, the third bowl temperature being kept constant at 45°C and that of the fourth bowl at 40°C. Increasing the first bowl temperature from 45° to 55°C increased the grease removal, the residual grease decreasing linearly from 0.9% to 0.2%[115,145]. **Grové and Albertyn**[133] concluded that it was unwise to exceed 55°C in either the first or second bowls when scouring mohair. The use of soda-ash in the first bowl should also be restricted to 2% (mass on mass of raw mohair)[133]. It has also been stated[309] that the scouring liquor should preferably not exceed 45°C and the drying temperature 55°C[309], a pH of 9 is considered suitable for mohair scouring.

Grové and Albertyn[116,134] modified the standard column-and-tray method used to determine residual grease on wool, so as to make it suitable for mohair, the modification mainly involves cutting (using cutting mill) the mohair into the shortest possible lengths and blending it with fat-free cotton-wool, thereby eliminating problems of channeling.

Turpie[375] investigated the unconventional scouring of mohair, which involved relatively high concentrations of grease in the first bowl of the scouring train, the grease removal in this bowl being found to depend upon the concentration of detergent rather than on the concentration of grease. A method of scouring mohair in a scouring bath, containing a nonionic surfactant, vegetable oil or animal fat (eg wool grease) in an aqueous emulsion was also described[324].

Turpie and Musmeci[394] undertook some laboratory experiments on the centrifugal treatment of mohair scouring liquors. They found that the grease recovery potential from such liquors was rather poor, with the choice of non-iogenic detergent having a noticeable effect on the results obtained. **Turpie and Mozes**[432] reported on the destabilisation of a mohair scouring effluent by means of sea water. Good grease removal from the sludge phase was obtained but not from the effluent phase (phases produced by centrifuging the liquor). Storage for several days at 65°C improved the flocculation[432]. The sodium chloride, magnesium chloride and magnesium sulphate components of the sea-water were mainly responsible for the destabilisation (grease removal)[431]. **Mozes and Turpie**[455] found that storage (at 65°C) improved the destabilisation, by sea-water, of centrifuged mohair scouring liquors and effluents. A preliminary study, based on industrial wool and mohair scouring liquor, suggested that grease removal after destabilisation with sea-water was correlated with the level of bacterial activity[464]. In other studies **Mozes**[462] **and Mozes and Turpie**[521] found that the use of the magnesium-rich waste residue from a common salt recovery plant (bitterns), as a flocculant, gave better grease removal (destabilisation) from wool and mohair scouring liquors and effluent than sea-water. It was concluded[521] that bitterns was a satisfactory flocculant for the treatment of wool and mohair scouring wastes. In a later study, **Mozes** *et al*[529] showed that magnesium chloride was a good substitute for bitterns as a flocculent for wool and mohair scouring wastes, 1% of magnesium chloride giving better results than 5% bitterns in a pilot scale trial involving a horizontal decanter centrifuge.

Mozes and Turpie[433] reported on the treatment of mohair scouring liquors using hollow fibre pilot scale ultrafiltration (membrane separation). The rejection factor for the membrane for grease was found to be independent of the liquor type but increased as the grease concentration of the feed increased until it reached a constant value of 99.5% at feed concentrations above 10%[433], the rejection factors for total solids decreasing as suint content increased. **Mozes**[477] reported on the treatment of wool and mohair aqueous scouring wastes, involving centrifuging, flocculation (eg sea-water and bitterns) and membrane separation (eg ultrafiltration or microfiltration).

Mozes and Turpie[487] reported on the particle size distribution of suspended solid dirt in a range of industrial raw wool, mohair and karakul aqueous scouring wastes. The log transform of the particle size followed an approximately normal distribution. The various distributions showed peaks between 5 and 20μm for liquors and secondary sludges and between 0.5 and 1μm for centrifuged effluents. About 95% of the dirt particles were larger than 1μm in the case of liquors and 0.5μm in the case of centrifuged effluents[487].

Mozes[578] reviewed literature published on the treatment and purification of wool and mohair scouring wastes, much of the information on wool also being applicable to mohair.

Turpie *et al*[962,1062,1067] reported on the membrane treatment of wool and mohair scouring effluents from an industrial operation.

13.2 Carbonising

According to **Pfeiffer** *et al*[889] vegetable matter (or "defect") in mohair can pose serious problems in the manufacture of textiles containing mohair, vegetable matter referring to burrs, seeds, twigs and other plant parts which become entrapped in the goat fleeces. Some vegetable matter is inevitable but excess amounts increase waste in the carding and combing processes. Some types of vegetable matter cannot be physically removed by carding and combing and may require carbonisation, a method using acid, normally sulphuric acid, to completely remove cellulosic contaminants. This process, which follows scouring, is expensive and results in decreased fibre lustre and strength. Hence, mohair buyers are prepared to pay more for mohair, free of vegetable matter contamination. **Pfeiffer** *et al*[889] found that spraying Angora goats with emulsions of oleic acid (referred to as "red oil") resulted in small reductions in vegetable matter content in the shorn fleeces. It has been stated[17] that the sulphuric acid content of mohair prior to baking should be less than 6% and that carbonising is normally resorted to when the vegetable matter exceeds 3%[533].

Generally, only about 2% of the Cape mohair clip is classified as carbonising[341]. Seasons of high rainfall, can however, result in abundant growth of grass and other vegetation and the presence of undesirable seeds in excessive quantity and therefore of considerably higher (up to 12%) of hair classified as carbonising types. The two varieties of seed which tend to be the most common and troublesome in South Africa are carrot and "klitsgras" seed. **Turpie and Godawa**[341] showed that a very seedy mohair (15% seed) could be effectively carded and combed, without prior carbonising (in both cases the fibres being opened before scouring), provided a rectilinear (French) comb was used. The uncarbonised mohair had a superior lustre and colour compared to that of the carbonised mohair. It was recommended that for improved carding efficiency and the production of still cleaner tops, either a willeying treatment (imposed between scouring and carding) or the use of a more sophisticated forepart to the carding machine (designed specifically for seed removal) or both, would be desirable commercially for the treatment of uncarbonised seedy mohair.

Turpie[805,814] proposed a mild carbonising process, followed by worsted processing, for achieving satisfactory vegetable matter removal while preserving, or even enhancing, other attributes, such as mean fibre length, yield and colour. With respect to mohair, which was heavily infested and matted with vegetable matter, light carbonising produced notable results, removing some 90% of the VM prior to carding with improvements of 10 mm in the mean fibre length of the top and 10% in the top and noil yield over the results of the control lot which, under normal circumstances, could not have been processed commercially on the equipment used. A major finding which emerged was that wool and mohair which were too faulty to be processed commercially on a worsted plant designed for a specific level of fault in the raw material, could be considered for processing on such equipment after a mild carbonising treatment which did not inflict serious damage to the fibres and did not lead to much loss in fibre mass. However, the cost of such treatment had to be considered in relation to the benefits which accrue[814].

CHAPTER 14

MECHANICAL PROCESSING INTO YARN

Mohair is not an easy fibre to process, particularly in drawing and spinning[88], and considerable secrecy exists even today concerning its processing, since firms which have built up this specialised knowledge do not share it because it provides them with a competitive edge. Mohair's low cohesion often necessitates that the fibres (slivers) be supported (by for example aprons) during processing. The efficient mechanical processing of mohair into quality yarn is widely accepted to be a highly specialised field, requiring considerable skill, experience and know-how. It has been stated[233] that mohair is a challenge to man's ingenuity to make a yarn that is weavable and acceptable to the customer, strict quality control being essential at every stage of processing[233]. Because of the specialist skills and expertise required to process mohair and the fact that they are generally kept a closely guarded secret, by the firms which have them, it has been stated that it is an area which the Third World could find difficult to penetrate[582].

Mohair can present problems during processing due to its lack of cohesion (smoothness)[196] and the generation of static electricity[36]. Mohair blends well with wool, the latter facilitating its processing[196]. The application of the correct types and levels of processing lubricants and additives and the selection of the most appropriate processing machinery and conditions (including atmospheric conditions) are all crucial in the efficient processing of mohair into a quality product.

Veldsman[201,516] **and Turpie**[705] reviewed work done on the mechanical processing of mohair while **Darwish**[355] investigated the factors which affect the spinning of mohair. Traditionally, mohair was processed on the Bradford Worsted system (drafting against twist) followed by flyer spinning[673], **Villers**[82] describing the traditional processing of mohair. In earlier times, some mohair qualities used to be double Noble Combed, some Noble and then Lister combed and some single combed. In the case of the longer mohair, Noble combing was followed by two further gillings and then Lister combing, the latter being considered unsurpassed for the final combing of mohair[102]. The Lister combed slivers would then be given two finisher gilling operations. In the case of the shorter hair, there would be preliminary opening of the scoured mohair, followed by carding, three gillings, Noble combing and finally, two finisher gillings. The drawing operation would involve open drawing sets and Raper autoleveller sets. The top would be allowed to relax for an extended period of time and so too would the roving. Spinning would be on flyer frames[102], yarns generally being coarser than 30 tex. The Noble comb was referred to as the most highly productive comb in the hair trade and superior to other machines in certain instances such as, for example, combing fibre containing kemp or similar defects, or raw materials where heavy noiling ceases to be a disadvantage[671]. The Bradford combers were referred to as the best hair combers at the time[671]. Flyer spinning was considered one of the best methods for spinning mohair[674] and fine yarns for light-weight mohair suitings were traditionally spun on the flyer system.

Today mohair is mainly processed on the French (Continental or dry-combed system of drafting and spinning)[196] involving French (rectilinear) combing. One company reportedly carried out an auto-levelling operation before and after the combing (rectilinear) stage[671].

It was widely held[220,253,498] that mohair should be "rested" (stored), for prolonged periods, between the various stages of its mechanical processing, from top to yarn, the top and roving generally being stored for periods of weeks. Some 70 years ago it was reported[1] that mohair roving was stored for three months in a dark, cold and fairly humid chamber so as to produce good spinning and yarn properties. To improve spinning and reduce waste it used to be customary to rest mohair tops for extended periods (eg six weeks) after combing (after topmaking)[220,253,281] and also after the drawing operation[36] (in roving form)[220]. The subsequent improvements in spinning performance and reduction in fly-waste were ascribed to the dissipation of static electricity[220].

Srivastava and co-workers[673] used a cheaper shortened system, including the Uniflex high draft spinning system (also **Onions** *et al*[301,352], and **Srivastava** *et al*[411]) to convert mohair into yarn. **Srivastava**[309] briefly reviewed various aspects relating to the mechanical processing of mohair and investigated the use of the Uniflex system for spinning mohair, deriving the optimum conditions for both fresh and stored (cellared) rovings. He found that the stored rovings produced superior yarns in all respects. The storage appeared to increase the roving strength and extension, with an ageing period of between 7 and 20 days appropriate.

Blackburn[422] **and Parkin and Blackburn**[498] also investigated the effect of roving storage on spinning and properties of mohair yarns. **Parkin and Blackburn**[498] investigated the effect of different periods of roving storage on Cap spinning performance and yarn properties. Storage was found to reduce static electricity on the rovings. The rovings were found to reach equilibrium regain after approximately one week of storage. Spinning end-breakages were found to decrease with increased periods of roving storage. Fly waste during spinning also decreased with roving storage, reaching a minimum after 22 weeks of storage. Yarn evenness and strength and elongation generally improved with increasing periods of roving storage, with yarn twist liveliness increasing with roving storage until it reached a maximum after about 18 weeks storage. Yarn hairiness first increased and then decreased with increasing roving storage time. **Parkin and Blackburn**[498] found that the spinning properties of the finer yarn 24.5 tex were more sensitive to roving storage than those of the coarser 32 tex yarn, and considered that little commercial benefit would accrue from extended roving storage except in the case of relatively fine yarns. They concluded[499], that although roving storage resulted in improved yarn properties, particularly in the finer count, the improvements were generally too small for storage to be of commercial benefit. They also concluded that measuring the cohesive properties of mohair rovings should provide a measure of spinning performance and yarn properties.

One firm used 25°C and 72%RH for its mohair spinning plant[75], which comprised Pin Drafter intersecting drawframes, dry-combing by a commercial topmaker and French combs (1 to 1.25% oil). The tops were conditioned (at 25°C and 72%RH) for up to six weeks or more. After drawing, the mohair was spun into 100 to 148 tex yarn. Spinning was on Super-Draft spinning frames[75]. **Villers**[82] suggested 50% RH and 21°C were satisfatory for processing mohair on the Bradford system. To avoid static, the moisture content of mohair should be above 12% for processing (**Von Bergen** quoted in Ref.[309]). **Cilliers**[189] suggested a regain of 16%. **Kruger and Albertyn**[127,142] investigated the processing (carding and combing) of mohair and stated that mohair can be opened more easily than wool so that the carding process used need not be as severe but that the carding process should be effective enough for the removal of impurities, such as kemp. Most of the fibres mixed with the ejected burr at the card were kemp and the strippings from the card clothing also contained a high percentage of kemp[127]. They found that the mohair fibre length was not altered much by carding, with shorter kemp fibres being preferentially removed (see also **KEMP AND MEDULLATED FIBRES** Section). They concluded that mohair, rather than kemp, would break perferentially during carding. The kemp fibre length in the card sliver was higher than that in the scoured mohair[127]. They further concluded[142] that selective kemp removal by the card clothing took place mainly because of the greater centrifugal force acting on the mohair fibres of higher density which move to the outer layers on the card rollers, causing a relative migration of kemp towards the card clothing. The strippers showed the highest selective kemp collecting power and the workers the lowest[142].

Kruger[143,156] studied the Noble combing of mohair and used the withdrawal force test to obtain a measure of the aligning power of the gill, the first two gillings having the greatest affect on fibre alignment. The dabbing depth during Noble combing, had a small affect on percentage noil, reaching a minimum at a dabbing depth of about 1cm. The smallest amount of kemp went forward into the top at a dabbing depth of about 1.3cm to 1.4cm. Dabbing depth did not appear to affect fibre breakage during combing. Breakage of the mohair fibres was higher than that of the kemp fibres which was nearly zero[143,156]. The average legth of the kemp fibres in the noil was somewhat greater than that of the mohair fibres in the noil. This was attributed to the restraint of the less piliant kemp fibres by the dense pins in the small circles of the Noble comb. It was concluded that dabbing depth was by no means critical, with an optimum at around 1.0 to 1.2cm[143,156]. The kemp content of the top showed little dependence upon production rate, with the ratios of kemp present in the top and noil, also very similar except at the highest production rate, in which a relatively greater amount of kemp was still left in the top. The kemp content of the top appeared to be independent of comb temperature, whereas fibre breakage increased with a decrease in comb temperature, the latter being ascribed to an increase in dabbing and withdrawal forces resulting from the increase in viscosity of the grease and oil on the fibres. Tear tended to improve with comb temperature, up to a temperature of about 80°C, after which it tended to decrease again. The best comb temperatures were considered to be around 70°C. Fibre breakage during Noble combing was less than 5% and mainly confined to the mohair fibres (as opposed to kemp)[143,156]. Cilliers[136] investigated fibre migration during the ring spinning of mohair and wool, in various intimate blends. He found that preferential migration occurred, and was to some extent dependent upon the yarn twist, at the lower twists more of the longer and coarser mohair fibres being present on the yarn surface[136].

Cilliers[137] also stated that the 'draft-against-twist' method, as employed on the Bradford system, was traditionally used for processing mohair. He investigated the processing of wool/mohair on the French (Continental or Dry-combed route) system, using blends of a fine (26.5μm) Kid mohair with a 64's quality wool (20.5μm). Three blends viz 60%, 40% and 20% mohair, respectively, were processed. The total fatty matter of the blends (column-and-tray method) varied between 0.82 and 1.03%. For the first three drawing passages an intersecting gill box was employed at the same faller pin density and front ratch setting as used during blending[137]. Raising the back roller, thereby eliminating back draft, was found to be preferable. The low cohesion of mohair necessitated special care during drawing, intimate blending, for example, being essential. Cans with false bottoms, fitted to easily compressible springs, helped to avoid sliver breakages. A deposit, origination from the skin of the goat and containing a small amount of fatty matter and some dust, was picked up by the velvet cleaners during gilling. The last drawing operation as performed on a high draft draw box using only one heavy sliver. Drawing ws found to improve once the pressure between the double aprons had been dereased somewhat by inserting brass spaces between the apron axes as prescribed by the manufacturers. The pressure between the back rollers was also increased[137]. Using a relatively fine roving, yarns as fine as 16 tex could be spun, provided the rubbing motion on the roving was sufficient during drawing. A single roving, rather than a double méche roving was used to avoid problems with "clicking". Spinning (16 to 30 tex yarns) was done on a double apron ring spinning frame with a ring diameter of 5.5cm, at 65% RH and 20°C, spinning speed ranging from 5 000 rev/min to 11 000 or 12 000 rev/min. The formation of yarn curls, a problem encountered when long fibres are spun, was also encountered. This was due to the longer fibres being stretched in the drawing zone and then regaining their original length as they emerged from the front rollers, causing the short fibres to curl around them. Increasing the spinning tension, either by using a heavier traveller or a higher spinning speed, avoided this problem[137]. (**Villers**[82] noted that drying in hank form after a wet process eliminated yarn "curls" or "crackers"). As expected, spinning end breakages increased as the yarn became finer, and as the mohair content increased. In all cases, a minimum tex twist factor of 21 (1.8 worsted) was required to give a reasonable spin. Higher mohair levels required a higher twist level to produce minimum end-breaks, and also a higher yarn lenear density, with the 60% mohair yarn requiring a tex twist factor of about 35 to produce a minimum number of end breakages. The spinning speed could be increased as the mohair content decreased, front roller lapping occuring sometimes when the spinnin tension was too low. Spinning waste was of the order of 1 to 3%[137].

Cilliers[189] investigated the processing of mohair on the Continental (French) system, including the effects of different additives and regains. The importance of fibre fineness in producing good spinning and quality yarns was emphasized. The low cohesion of mohair necessitated special care throughout the various mechanical processing stages eg not too hevy roving packages, strong (coarse) rovings, easily revolving packages etc. He found that a regain of about 16% was necessary for a reasonable spinning performance (Continental/French system), for mohair (37μm), spinning performance improving markedly when as little as 10% of a coarse wool (26 or 30μm) as added. Additives with antistatic properties, which increase inter-fibre friction and sliver cohesion, gave the best results. A measure of spinning performance could be obtained by measuring the withdrawal forces of the slivers[189].

Slinger and Robinson[183] also reported on problems with mohair lack of cohesion, and sprayed the mohair top during the first gilling with two appropriate commercial additives and water.

Turpie[205] described modifications to a small carding machine, originally designed for carding very short fibres, such as noil and wastes, to enable mohair to be carded successfully in small lots. It was observed that when processing a very kempy mohair lot the kemp fibres predominated on the outside layer of the web on the doffer, being only loosely attached to the other fibres in the web. Underneath the carding machine immediately below the doffing point between the swift and the doffer, an accumulation of fibres containing a high percentage of kemp fibres was observed, the kemp content, there being 38% compared to 7% in the scoured mohair. Therefore, the control of loose fibre droppings at the contact points between certain rollers can effect additional removal of kemp during carding[205].

Kruger[206] found that the selective collection of kemp fibres by the card clothing increased with increasing roller speeds. He studied the rectilinear (ie French) combing of mohair and showed that the percentage noil produced during combing was linearly related to the gauge setting of the comb. An increase in the gill feed at constant gauge caused a slight decrease in percentage noil. The mean fibre length in the top and the noil first decreased somewhat when the gauge setting was increased and subsequently increased for a further increase in gauge setting. Percentage fibre breakage increased significantly for an increase in gauge setting but dropped rapidly at the very wide setting of 32mm. The medium gill feed settings resulted in greater amounts of fibre breakage, the best combing performance being for large gill feed settings[206]. The mohair fibres in the top were significantly longer than the kemp fibres left in the top, while the lengths of the two types of fibres in the noil were about the same. The kemp contents of the different components were not significantly affected by different comb settings although there was a tendency to remove more kemp at larger gauge settings (most of the kemp appeared to be present in the leading end of the with-drawn fringe). The percentage kemp in the noil was much lower for rectilinear combing than for Noble combing, with the Noble combed top containing less kemp than the rectilinear combed top[206].

One article[192] discussed the spinnability of mohair in blends with wool, rayon and other man-made fibres, the necessary processing data also being given. Another provided[192] some details on the mechanical processing, including ring spinning (42 tex yarn), of mohair, detailing also some quality control measures and parameters.

Cilliers[212] investigated the spinning, into 68 tex yarn, of seven mohair lots (29 to 42μm) using the Bradford (cap, ring or flyer) system as well as a combined Bradford/French system. He showed that the finer mohair could be spun into finer, stronger and more even yarns, with longer fibres also producing stronger yarns. Cap spun yarns were more hairy, stronger and could be spun finer than ring or flyer yarns. Yarns of good regularity were spun from lower twist Bradford roving on any double apron French type ring spinner. Yarn hairiness was influenced by spinning speed, the spinning mode, fibre fineness and length, roving and yarn twist and the use of balloon separators. The affect of fibre length, within the limits studied (73 to 120mm), on spinning performance was much smaller than that of fibre diameter. The formation of "crackers" during spinning was observed for the longest mohair which also exhibited the greatest variation in fibre length, in spite of the fact that the ratches on all machines were increased to accommodate the long fibres. Yarn hairiness was found to increase with increasing spindle speed and fibre diameter and with decreasing fibre length and yarn twist. Traveller weight appeared to have little effect. Higher roving twist, the use of condensers behind the front roller nip (thereby reducing the width of the ribbon of fibres emerging from the front roller) and the removal of the separating guards between the spindles (particuarly with cap spinning) all tended to reduce yarn hairiness. Cap spun yarn was nore hairy than ring spun yarn, with the latter slightly more hairy than flyer ;pun yarn.

Cilliers and Turpie[196] summarised the processing of mohair as follows:

"In order to overcome the lack of fibre cohesion, special additives need to)e applied, usually in the form of a fine spray[196], thus improving the inter-fibre :ohesion. Special techniques to assist the passage of the carded web to the :omber and the slivers as they emerge from the cams during gilling are re-]uired so that the tension on the slivers is at a minimum. Carded mohair slivers ire generally not very entangled and usually only two gilling operations are 'equired before combing. At the first gilling it is generally necessary to spray on vater, anti-static lubricant, and if required, oil. It may also be necessary to nclude an additive to increase to increase fibre cohesion. In this way the slivers ire prepared for optimum combing performance. When it comes to drawing ind spinning, both the Bradford and Continental systems are used, the Brad- ord system operating on the draft-against-twist principle, (ie the slivers are wisted prior to drafting)[196]. This system has obvious advantages for mohair ;ince the twist in the sliver keeps the fibres together, thereby increasing the ;liver strength and controlling the drafting action. On this system, it is also :ustomary to spray the fibres with about 3% oil to increase inter-fibre cohesion ind further assist the drawing[196]. On the alternative Continental system twist- ess slivers are processed and cohesion is obtained by means of rubbing iprons, which only insert "false" twist into the slivers. These slivers are, there- ore, more open in construction and also weaker, with fibres protruding fro n he fibre stream. This is an obvious disadvantage since the cohesion betwe‹n he fibres is relatively low. The very nature of the Continental system prohibits he application of large amounts of additives with a high fatty matter content. Nevertheless, it is possible, when using the correct techniques on either sys- :em, to produce a satisfactory yarn. Once the mohair fibres have been convert- ed into a yarn, which contains "real" twist, subsequent conversion of the yarn nto fabric is relatively troublefree. It is interesting to note, however, that as 'egards the Continental system of drawing and spinning a small amount of vool blended in with the mohair significantly improves the spinnability; that is :o say, the number of ends breaking down per unit time is appreciably lower. This means that the overall production speed of the spinning frame can be ncreased and the production thereby increased, care being taken, however, not o exceed a certain upper limit beyond which the quality of the yarn would be mpaired due to the appearance of excessive hairiness[196]."

Carding can prove difficult if mohair is either over- or under-scoured[233]. The introduction of metallic card wires (clothing) was considered advantageous n that it allowed the card to be shortened and reduced the probability of over- :arding. Static control during carding can be achieved by efficient humidifica- ion and the application of anti-statics, but care must be exercised with the atter to prevent the fibre wrapping around the card rollers. Because of possible)roblems with lapping, carding can take place without the addition of a comb- ng oil, the oil being sprayed on after carding (spraying being recommended ıbove "dripping"). **Spencer**[233] stated that the top should be stored in bump orm as balling could prove problematic. He stated that his firm spun the mo- ıair yarn on the package that would be used in the shuttle as weft, and recom- nended a maximum regain of 17% when storing mohair, higher regains could ead to problems with mildew. Piecenings, during the finishing and drawing operations, could lead to yarn faults[233].

Spencer[233] stated that high speed spinning leads to yarn hairiness and that ratch setting was important, in both drawing and spinning, as mohair is susceptible to curl ("crackers") which can be introduced by under-ratching[233].

Quality control on mohair tops generally involves testing for evenness (irregularity), fineness (μm) and fibre length[281]. Mohair can be blended during the combing or drawing process, various types of mohair often being blended to produce the desired yarn but tops containing a blend of fine and coarse fibres or thick and thin places are rejected because of potential spinning problems[281].

Kul and Smith[273] investigated the effect of different lubricants (oils) on the properties and processing (Bradford system) of mohair slivers and on the yarn evenness and tensile properties. The drafting force (drag) of the mohair slivers was found to increase with oil content and also with the product of oil viscosity and speed, the greater the viscosity the greater the rate of increase. Surface tension, through its effect on inter-fibre adhesion, was judged to be the main force governing sliver cohesion, a high surface tension appearing to be desirable. In processing trials, involving the Bradford system, the best results were obtained with 3% of an oil with a viscosity near 100 centistokes (poise) and containing suspended silica. An antistatic spray was found to be essential[273]. The more viscous oils were found to give less fly during processing. The addition of silica to the lubricant changed the ratio of dynamic to static friction. The ratio of dynamic to static sliver drag appeared to be positively associated with irregularity produced during drafting.

Blends of mohair with polyester and rayon were shown, by **O'Connell** *et al*[300], to process readily on the worsted system. In the Bradford processing of mohair, 3 to 3.5% of oil may be added at the fourth open gill-box of the preparing set to prevent the fibres from becoming wild[352]. Because of low fibre cohesion, backwashing of mohair (which increases lustre[201]), could present problems although twist insertion helps[201].

Lupton and King[288,372,373] investigated the small-scale processing of mohair on Conventional worsted machinery (a modified American worsted system involving pin drafting and twisted roving), using 12 commercial processing additives (each at three levels) sprayed onto the scoured mohair. Fibre breakage during carding was negligible. Processing took place at 22°C and 80%RH. Most of the additives tested gave optimum carding performance at the lower level of add-on (0.5%), with the application of a colloidal silica producing excellent carding performance. They also investigated[349] the application of commercial water dispersable additives (by overspraying) to mohair prior to carding. Rovings prepared from the treated fibre had greatly increased cohesion.

Turpie *et al*[295] investigated the lubrication of mohair for processing on the Continental system. They found that it was important that the additive must improve cohesion and reduce static. Spinning performance was found to depend upon the sliver withdrawal force (see Fig. 45) rather than on the particular lubricant. Best spinning performance was obtained when the withdrawal force of the tops was adjusted to its optimum value (40 N/g) with additional additives. Yarn friction was primarily related to the ether extractable matter of yarns, with paraffin waxing of little use if the ether extractable matter content of the yarns was high[295].

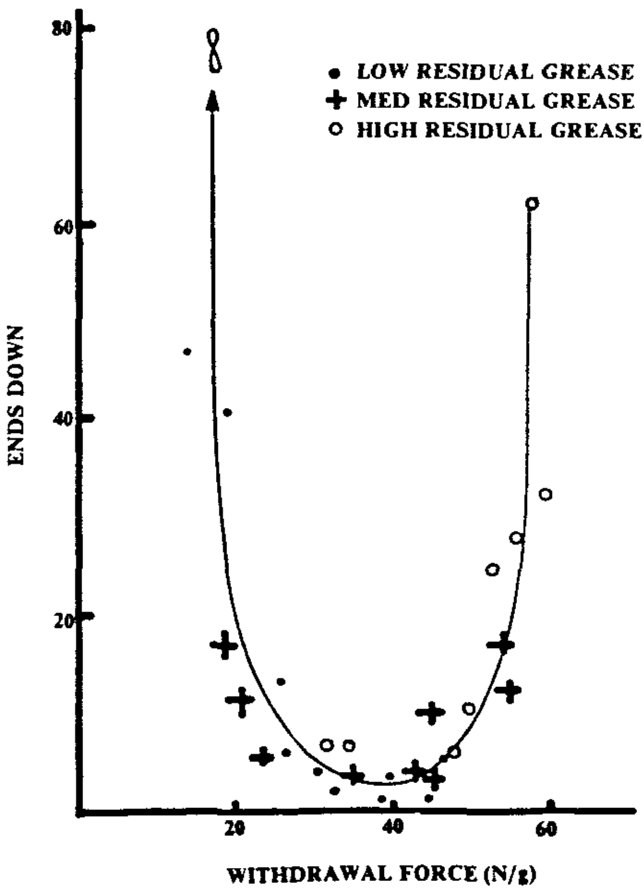


Fig. 45 Ends Down in the Spinning of BSH Mohair versus Withdrawal Force of the Mohair Tops[295,705].

They concluded as follows[295]: Topsol plus some antistatic performed well in carding and gilling but not so well in combing; more of the antistatic would have improved this performance. Topsol together with Alon or Leomin KP performed well throughout the topmaking processes, provided that a low grease level on the scoured mohair was maintained. When a strong antistatic was added to Topsol alone an excellent performance was obtained with BSFK mohair throughout the topmaking processes. Leomin KP together with an antistatic also performed well.

They arrived at the following general conclusions: Carding efficiency was improved when the fibres were well lubricated but a certain amount of cohesion was also necessary (Topsol or Leomin KP proved to be efficient). Too much cohesion (as with Alon) resulted in adverse fibre breakage. An antistatic also proved to be essential. In gilling, similar requirements prevailed, although static effects proved to be critical and too much lubricant caused lapping around rollers. In combing, static was once again important while lubrication together with a certain amount of cohesion was important. Very high fibre cohesion resulted in too much noil. Low to medium amounts of residual grease proved to be better for all these processes. Some additives resulted in rust formation on metal parts and it would therefore be necessary to use a rust inhibiter with these[295]. **Veldsman**[516] stated that at that time Duroil4027 was quite widely used at SAWTRI and the local industry.

Darwish[325] studied the Bradford system of drawing followed by cap spinning of 15 mohair lots which differed in fibre length, strength and diameter. He concluded that fibre diameter was far more important than length or strength in determining spinning performance (end breaks), limiting count and yarn properties, such as extension and irregularity. An increase in diameter generally caused a deterioration in all these characteristics, while an increase in fibre length (up to about 120mm) improved spinning performance and yarn properties. An increase in fibre strength also had a beneficial effect on spinning performance and yarn properties. Softly twisted and stored rovings reduced end breakage rates.

The most detailed processing studies on mohair were undertaken at SAWTRI during the 1980's, using the Continental System, with some lots also being processed on the Noble comb. The studies were aimed at elucidating, amongst other things, the effects of fibre diameter and length on processing behaviour and yarn and fabric properties.

In one of the first such studies at SAWTRI, **Turpie and Hunter**[439] investigated the ring spinning potential (processed on the Continental worsted system) and yarn properties of a range of mohair lots, using the mean spindle speed at break (MSS) and commercial spindle speed (CSS)tests. The hair (Kids, Young goats, Fine Adults, Locks and Average Adults) was scoured to 0.2% residual grease after which 0.5% of additive was applied, different additives being applied at the top stage. Spinning potential was mainly affected by fibre diameter, deteriorating with an increase in fibre diameter. Within the ranges covered, neither the type of supplementary additive nor the mean fibre length had a material effect on MSS. Better spinning performance was obtained when spinning with an uncollapsed balloon[439].

In a later study **Strydom**[552] studied the processing characteristics of 15 lots of mohair of "Good" to "Average" style, covering approximately the same range of mean fibre length and mean fibre diameter values as the South African clip. Processing was carried out on Continental worsted equipment, with certain batches also being combed on the Noble comb (Fig. 46).

Mohair base values were of the order of 66% to 75% and top and noil yields varied from 78% to 89%. Card losses, although generally low (3% to 7%) tended to be higher for the shorter grades and combing tear increased with increasing mean fibre diameter. The Noble comb removed 2% to 3% more noil than the French comb (Fig. 46) and produced tops 4 to 6mm longer with a lower CV of length. Finer mohair appeared to suffer more fibre breakage during processing and as a result exhibited poorer conversion ratios, see Fig. 47. Nevertheless, they tended to spin better than the coarser qualities, even for the same number of fibres in the yarn cross-section (see Fig. 48). Mean fibre length, mean fibre diameter and number of fibres in the yarn cross-section were found to explain some 85% of the observed variation in spinning potential test results, with the contribution of other variables such as CV of length and CV of diameter being non-significant.

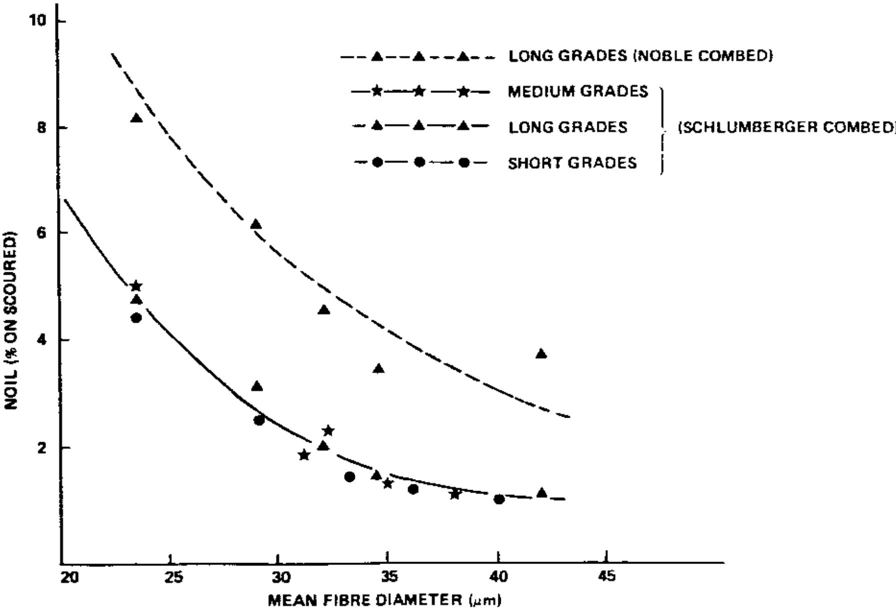


Fig. 46 The Effect of the Mean Fibre Diameter of the Raw Hair on Percentage Noil[552].

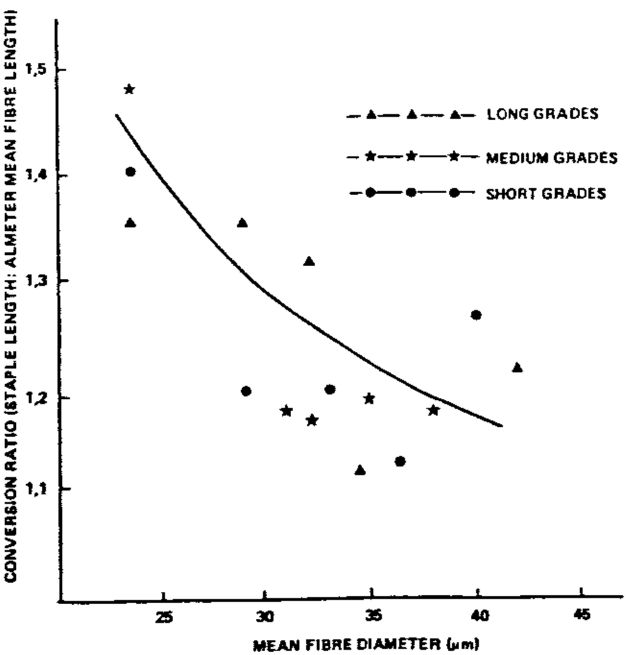


Fig. 47 The Effect of Mean Fibre Diameter on the Conversion Ratio (Schlumberger Combing)[552].

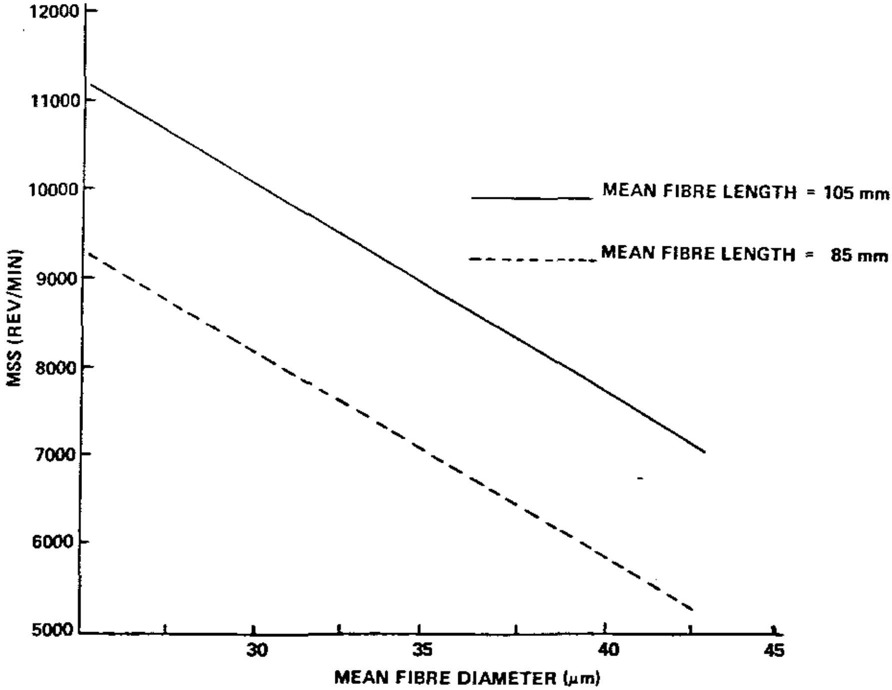


Fig. 48 Regression Curves Illustrating the Effect of Mean Fibre Diameter on MSS (No. of Fibres/Cross-Section = 40)[552].

Goen[581] reported on the processing of cut mohair top (38mm length), in blends with cotton, on a short staple (cotton) system. The fibres were blended in the opening room in blends of 10/90, 20/80, 30/70 and 40/60 mohair/cotton. Although the lower levels of mohair processed without much difficulty it became increasingly difficult to process the blends as the mohair content increased, it being very difficult to process the 40/60 mohair/cotton blend[581], more roving twist also being required. This caused snarling and the roving had to be steamed. Spinning also became increasingly difficult as the level of mohair increased (yarns ranging from 50 tex to 75 tex being spun).

Strydom[621] compared the processing behaviour of Summer and Winter Cape Mohair. Sixteen batches of "Good" to "Average" style mohair, varying in length and mean fibre diameter, were processed into tops on the Continental System to assess whether season as such affected the nature of the correlations between processing performance, the properties of the top and the physical properties of the raw hair. No such an effect could be detected, and once differences in mean staple length and mean fibre diameter had been allowed for (see Figs 49 to 51), no residual effect of season could be found in any of the relationships governing scoured yields, card wastes, comb noil, top and noil yields, mean fibre diameter in the top, top Hauteur or conversion ratio[621]. Season therefore only affected processing performance insofar as it affected staple length and mean fibre diameter.

In a follow-up study, **Strydom**[622] compared the processing behaviour of blends of mohair types differing in length.

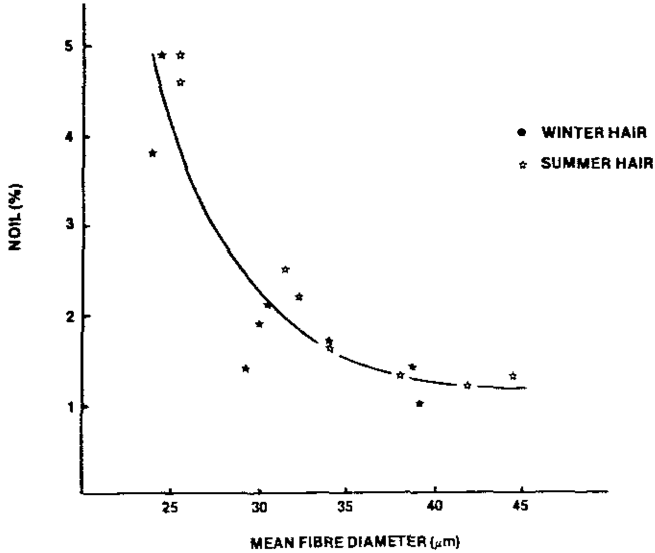


Fig. 49 The Relationship between Mean Fibre Diameter in the Grease and Percentage Noil[621]**.**

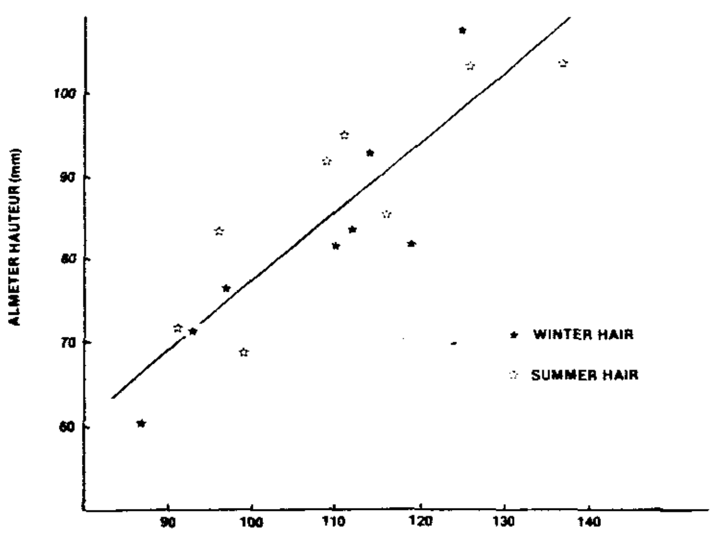


Fig. 50 The Relationship between Average Staple Length in the Grease and Almeter Hauteur Mean Fibre Length in the Top[621]**.**

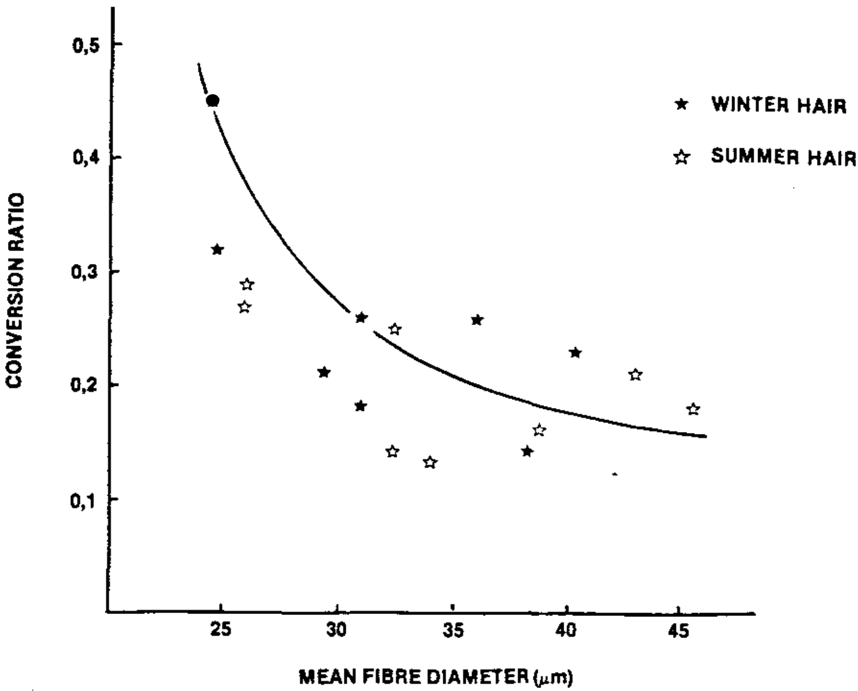


Fig. 51 The Relationship between Mean Fibre Diameter and Conversion Ratio (Expressed as Fractional Reduction in Mean Staple Length in Terms of Almeter Hauteur)[621].

Batches of good to super style mohair, of nominally the same fineness category (either Kids, Young goats or Adults), were blended in such a manner that the components in a given blend differed by either one or two primary length classes. For this purpose, producer-classed batches in the "B" (125-150mm), "C" (100-125mm) and "D" (75-100mm) length categories were selected and blended in pairs in a 1:1 ratio, and converted into tops on the Continental system. It was shown that scoured yields, comb noil and top and noil yields for the blends did not differ from the values predicted from the components. Similarly, mean fibre diameter, CV of diameter, Almeter Hauteur and CV of Hauteur behaved in accordance with the expected values. The absolute values of CV of Hauteur and short fibre, however, depended to a large extent on the relative difference in length of the blend components prior to blending[622].

In a final report on the studies on the processing of mohair on the Continental system, **Strydom and Gee**[722] concluded as follows:

Wave frequency (ie waviness or crimp) decreased with age, it being negatively correlated with fibre diameter and slightly positively correlated with grease content. The scouring yields they observed varied between 78 and 91%, while card losses varied from 3 to 12%. The following table summarises their results (Table 92).

TABLE 92[722]
MEANS AND RANGES FOR RAW MOHAIR CHARACTERISTICS AND PROCESSING DATA

INDEPENDENT VARIABLE (Greasy mohair data)	SYMBOL USED IN TEXT	KIDS			YOUNG GOATS			ADULTS		
		Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.
Mean Fibre Diameter (μm)	D	27,6	23,1	31,6	32,2	29,1	35,3	38,5	33,0	44,5
CV of Diameter (%)	CV_d	26,0	21,0	33,0	22,7	20,0	26,0	25,9	21,0	29,0
Mean Staple Length (mm)	SL	107	78	127	110	84	137	111	91	126
CV of Staple Length (%)	CV_{SL}	15,0	10,0	22,0	15,5	10,0	27,0	15,0	10,0	22,0
Mean Single Fibre Length (mm)	-	106	78	133	115	95	147	110	88	129
CV of Fibre Length (%)	-	37,0	29,0	44,5	32,6	26,2	36,3	25,9	28,5	42,4
Wave Frequency (cm^{-1})	WV	0,52	0,45	0,66	0,47	0,42	0,53	0,39	0,28	0,46
CV of Wave Frequency (%)	CV_{WV}	21,0	10,0	30,0	21,3	10,0	35,0	24,4	10,0	42,0
Grease Content (%)	GC	4,9	3,3	8,0	4,9	4,0	5,6	4,1	2,9	5,5
Suint Content (%)	SC	2,7	2,2	4,0	2,9	2,4	4,2	2,5	1,8	3,2
Mohair Base (%)	MB	70,9	64,3	75,1	70,0	65,7	74,1	73,1	66,5	77,3
VM Base (%)	VMB	0,30	0,1	0,7	0,20	0,04	0,4	0,3	0,1	1,5
DEPENDENT VARIABLE *(Processing factor)*										
Scoured Yield (%)		84,0	77,7	91,0	82,5	79,4	86,9	86,1	80,1	90,6
Card Rejects (%)		4,3	7,8	8,0	4,0	2,9	5,9	5,2	3,5	12,5
Comb Noil (%)		3,5	1,2	6,3	1,8	1,1	2,5	1,3	0,6	2,0
Top and Noil Yield (%)		81,6	72,8	89,2	80,5	78,1	85,9	83,0	76,4	87,9
Mean Fibre Diameter (μm)		28,5	24,0	33,8	32,8	29,3	36,2	38,9	31,5	45,6
CV of Diameter (%)		25,7	19,0	33,0	22,5	20,0	25,0	25,4	22,0	28,0
Hauteur (mm)		84	60	104	91	76	109	93	71	107
CV of Hauteur (%)		46,2	35,5	66,3	44,9	29,8	55,6	39,4	34,2	48,0
Short Fibre (% < 25 mm)		6,4	1,3	23,6	6,4	0,6	17,1	3,8	0,3	12,8
Long Fibre (L @ 5%)		137	112	165	143	112	169	141	114	158
Single Fibre Length (mm)		99	81	122	103	84	118	101	79	114
CV of Single Fibre Length (%)		35,6	22,0	43,0	35,3	30,0	49,0	35,3	28,0	42,0
Short Fibre (% < 25 mm)		3,6	1,2	7,3	3,3	1,1	5,9	3,6	1,1	7,3
Long Fibre (L @ 5%)		150	133	167	155	122	189	152	131	175

The fibre diameter means and CV's of the top were found to be closely related to those of the unprocessed hair. The top tended to be coarser than the raw hair from about 0.5μm at the fine end of the scale (ie Kids hair of about

25μm) to about 1.3μm at the coarser end of the scale (Adult hair of about 45μm). (**Keller and colleagues** for the USDA (quoted by **Strydom and Gee**[722]) found similar differences for Kid hair but only about half this difference for Adult hair[722]). Staple length on its own appeared to be not a very good predictor of Hauteur, but by including data on diameter (D), diameter variability (CVd) and wave frequency (WV), some 83% of the observed variation in Hauteur could be explained. Dry-combed top and noil yields varied from 73 to 89%, depending largely upon mohair base[722]. There were no systematic differences between the yields estimated from core test data and the actual yields obtained. Diameter played a very important role in determining noil, the latter decreasing almost linearly with an increase in mean fibre diameter (part of this could be due to the correlation between staple length and mean fibre diameter). Their results suggested that hair either more variable in length or diameter or both, tended to yield lower top and noil values. The small contribution of a term involving staple length and wave frequency (SL x WV) suggested that hair either longer or more curly, or both, tended to yield slightly better top and noil values.

Strydom and Gee[722] found that wave frequency affected the relationship between Almeter and single fibre length results. They found that coarser fibres had poorer spinning performance than finer fibres, even when the number of fibres in the yarn cross-section was constant. The following table (Table 93) summarises the results of their statistical analyses.

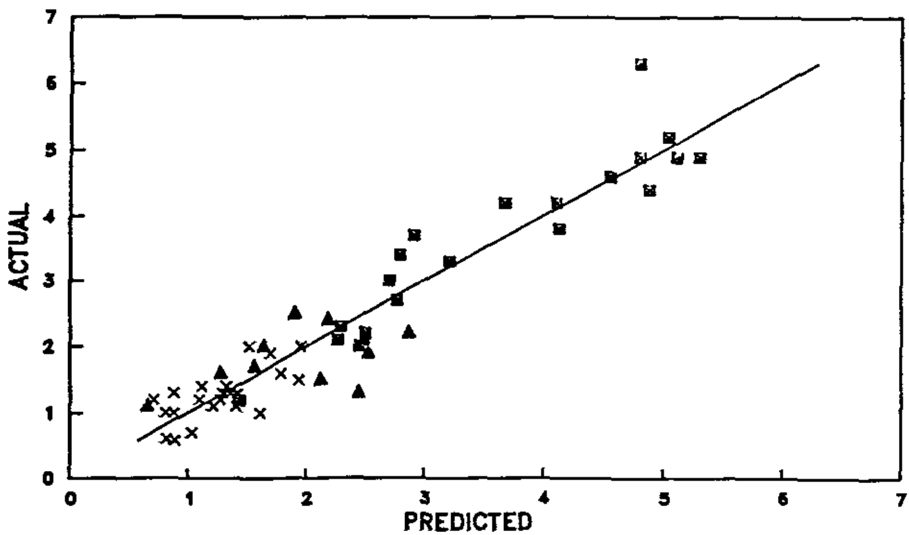
TABLE 93[722]
REGRESSION ANALYSIS: SPINNING PERFORMANCE AS MEASURED BY MSS TECHNIQUE

Basis of Analysis	r^2	Regression Equation
No of Fibres in Yarn Cross-Section (n)	0.642	$-3.0\ D^2 + 0.57\ (H \cdot n) + 1.3\ (HxCV_H) + 1.5\ CV_d^2 + 2546$
Yarn Linear Density (tex)	0.658	$-5.2\ D^2 + 0.63\ (H \cdot tex) + 1.1\ (HxCV_H) - 0.2\ (tex)^2 + 6481$

In both equations a term ($HxCV_H$) appears, which suggested that hair either longer, or more variable in length, or both had better spinning performance. The primary determining factors for MSS, however, remained the number of fibres in the yarn cross-section (n) and mean fibre length (H), with the effect of CV_H being of secondary importance in terms of its magnitude[722].

In parallel studies[750] on the Noble and rectilinear combs (comb settings being adjusted according to length in keeping with commercial practice), it was found that, as expected, more noil was produced on the Noble comb than on the rectilinear comb (Fig. 46). The noil ranged from as little as 1 to about 5% during rectilinear combing and from about 4 to 8% during Noble combing. An interesting fact emerged, namely that the amount of noil was dependent upon the diameter of the hair, but was independent of length. The increase in noil with decreasing fibre diameter was probably due to more breakage being suffered by the finer fibres during processing. The tops were generally nep-free and ranged in mean fibre length from 60 to 105mm. These lengths represented conversion ratios from the staple to the top ranging from about 1.1:1 to 1.4:1[750].

Recently **Hunter and Dorfling**[1060] investigated the effect of Angora goat age on mohair processing performance on the Continental (French) system. They showed that, provided corrections are introduced for differences in the measureable fibre properties, notably diameter and length, goat age has no effect on processing performance and top properties, such as % Noil and Hauteur (see Figs 52 and 53). What this essentially means is that provided the fibre charateristics, such as diameter and length, are constant, the age of the goat has no additional effect on mechanical processing performance up to and including spinning performance.

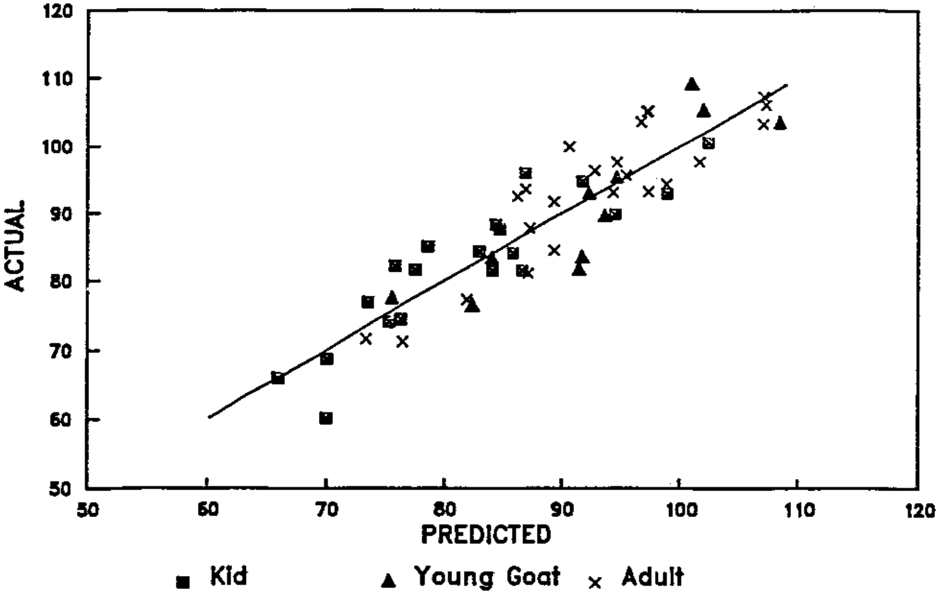


■ Kid ▲ Young Goat × Adult

Noil(%) = −0.7684 D + 0.02548 L + 0.008257 D^2 + 0.002560 Vd^2 + 14.15

%FIT = 90.3 N = 54

Fig. 52 Noil (%)[1060]



Hauteur = −1.239 Vd − 0.02385 D^2 + 0.02067 L.D + 71.31
%Fit = 81.5   N = 54

Fig. 53 Hauteur (mm)[1060].

Mohair yarns spun on the worsted system, have been reported (**Veldsman** quoted in Ref.[325]) as being rather lean, because of the straightening of the fibres.

Kowalewski[314] reported on the use of increased levels of mohair in blends processed on the **woollen** system, this leading to a lower shrinkage of finished fabrics.

The direct spinning of mohair blends sliver (semi-worsted and worsted) on a spinning frame with two drafting zones has been reported[517] and the semi-worsted production of 20/80 mohair/acrylic blend yarn has also been discussed[148].

Mazzucheti *et al*[548] described the "Carfil 2" woollen spinning frame and gave details for the spinning of mohair/wool blends, making comparisons with the mule.

Hollow spindle (ie wrap) spinning has found significant application in the spinning of mohair yarns for hand and machine knitting[851].

Turpie[750] summarised the work done at SAWTRI on the effects of mohair fibre properties, diameter in particular, on processing performance, including spinning.

Smith[858] discussed some of the processing requirements of the various speciality fibres.

In woollen spinning, mohair shorter than 75mm is generally used while on the Bradford (worsted) system the length is 90mm and longer, with a staple length of some 120mm often required for worsted processing[785]. In order to qualify for a Spinners type, which is the top end of the market, a minimum staple length of 125mm is reportedly required[1043].

Van Aardt[758] investigated the effects of storage time on the Almeter length results of mohair tops and concluded that the effect was small and of little consequence when the tops were stored in ball form. The CV of fibre length of mohair tops is reported to be typically 20 to 30%[98].

Moia[719] reported on a machine which was able to sort combed tops according to fibre length.

Millmore[1013] *discussed various functions and space requirements of a* manufacturer specialising in mohair and alpaca.

CHAPTER 15

ARTIFICIAL CRIMPING

Crimp plays a very important role in the cohesion and mechanical processing of staple fibres as well as in the aesthetic and physical properties (eg bulk, handle and comfort) of the yarns and fabrics. Mohair has little crimp (sometimes referred to as "waviness").

Cilliers[210] investigated artificial crimping as a means of improving sliver cohesion and the bulk of 75/25 mohair/wool. He compared the processing performance, on the French system, of artificially crimped and uncrimped (ie natural) blends of mohair and Corriedale wool. He concluded that the method of artificially crimping wool (developed by the IWS) could be applied to mohair, increasing yarn strength and diameter and irregularity, and fabric bulk, but decreasing spinning performance. **Keighley**[671], quoting **Brammah**, referred to a special crimping attachment to a rectilinear comb which allowed the comb to "bind" the fibres together to impart the necessary cohesion prior to first finishing, instead of inserting twist.

Goldberg[367] reviewed research done to increase the cohesion of mohair fibres and the utilisation of surfactants. One firm found a special "crimping" attachment on their French comb to be an advantage, in that it allowed the comber to "bind" the fibres together to provide the necessary cohesion prior to first finishing[671].

Veldsman[201] reported that the IWS artificial crimping process developed for wool improved the bulk of mohair worsted yarns and fabrics. **Umehara** *et al*[723] investigated the application of the IWS Supercrimping process for imparting crimp artificially to wool and mohair. The crimping process involved a draft relaxation followed by a stabilisation of the crimp by chemical modification. It was found that for fibres without a bilateral structure (eg lustre wool and mohair), crimp stability was not satisfactory but could be improved by prolonging the time of the bisulphite treatment.

CHAPTER 16

CORONA TREATMENT

Thorsen and Kodani[152] found that corona discharge treatment of mohair top increased its cohesion significantly. **Landwehr**[211] reported on the electrostatic properties of corona (glow discharge) treated wool and mohair and gave the following tribo-electric series (Fig. 54). He reported that corona treated mohair was easier to card than untreated mohair, possibly because it was tribo-electrically closer to the steel card wires than the untreated mohair. Changes in frictional properties could provide an alternative explanation. He[211] postulated that blending "positive" and "negative" mohair fibres (ie untreated and treated) *could improve drafting due to greater fibre cohesion.*

Thorsen and Landwehr[238] reported on a pilot-scale reactor for corona (accelerated by injecting air-chlorine mixtures) treating wool and mohair tops, the treatment reducing felting shrinkage and improving spinning performance. The latter was thought to be as a result of increased single fibre surface friction and fibre cohesiveness[152,238].

Thorsen and Landwehr[262] and **Thorsen**[259,264,290] reported on the increase in mohair friction, cohesiveness, tensile strength and processibility by *corona treatment and considered that the treatment had potential for improving* mohair processing performance, including carding, and yarn strength (by 31%). Corona treatment produced polar sites, probably sulphonic and carboxylic acid groups, on the fibre surface[259]. It increased wettability, friction, soil repellency and resistance to felting shrinkage and altered electrostatic behaviour. Fabric handle can be adversely effected by corona treatment, but this can be improved by the application of a suitable softener. The lustre of mohair was

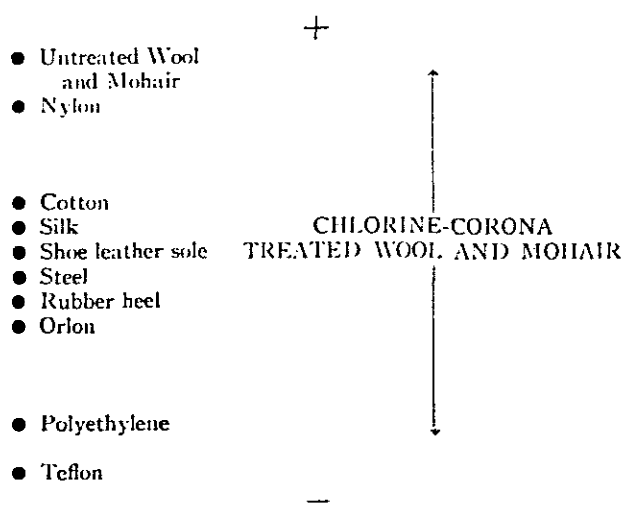


Fig. 54 Tribo-Electric Series of Selected Materials[211].

unaffected by the corona treatment[255,290]. The blending of short mohair, wool and cotton, (untreated and corona treated) and their processing on the short staple system, was reported on[338,348]. It was reported[401] that corona treated wool improved the strength and abrasion of mohair/wool/cotton fabrics.

Hird[461] studied the spinning behaviour of corona (ionic glow discharge) treated mohair, showing that the treatment had a significant effect upon both the static and dynamic frictional properties of the mohair fibres, both being increased. Spinning (apron drafting) performance was improved by the treatment and so too the yarn tensile properties.

CHAPTER 17

FANCY (NOVELTY) YARNS

Mohair is used to particular advantage in fancy or novelty yarns[196,220,281,304,442,527,631,934], such as loop, brushed, bouclé, knop, flame, snarl, slub, gimp etc, where its properties provide aesthetic appeal and comfort. Such yarns are used in blankets, stoles, shawls, scarves, knitwear (sweaters, cardigans, jerseys etc), travel rugs, curtaining, table coverings, upholstery, furnishings, pram covers, ladies dresswear, suitings, coatings etc. Traditionally, mohair yarns (particularly loop yarns) were raised after knitting by passing the fabric through a teazle machine. Loop yarns are often first converted into fabric and then brushed to give the desired light and fleecy (brushed) appearance[220]. Adult hair is often used to form the loops of bouclé yarn properly[631].

Villers[82] gave the following three examples of mohair loop yarn production:

1) R443 tex all-mohair.

1st Operation	
Two foundation threads:	31.6 tex mohair.
One effect thread:	136 tex mohair.
Delivery ratio:	1:2.6
Twist:	236 turns/m (left).
2nd Operation	
Fourth Component:	37 tex mohair.
Twist:	126 turns/m (right).

2) R590 tex mohair/wool.

1st Operation	
Two foundation threads:	45 tex wool; 472 turns/m Z twist.
One effect (loop) thread:	220 tex 177 turns/m Z
Delivery ratio:	1:2 (approx).
Twist:	472 turns/m S twist.
2nd Operation	
Fourth component:	44 tex wool 472. turns/m Z twist.
Twist:	157 turns/m Z twist.

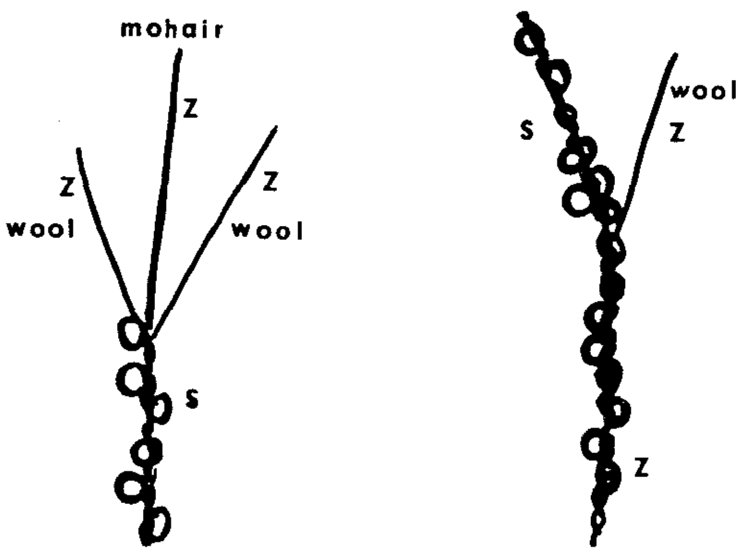
3) R633 tex (1.4's) mohair and cotton.

1st Operation	
Two foundation threads:	R88.6 tex/2 cotton.
One effect thread:	222 tex mohair.
Delivery thread:	1:2 approx
2nd Operation	
Fourth Component:	R74 tex/2 mohair.

Curl yarn is produced by twisting a number of yarns together setting the yarn (eg boiling at pH 6.7) and then untwisting and separating the individual yarns again.

Hunter[276] investigated the use of the knit-de-knit process to increase the bulk of mohair yarns. The production of sufficiently fine and even yarns and abrasion of the yarn during the knit-de-knit process could present problems, and so, too, the stability of the set kinks (crimps) in the yarn. **Grenner and Blankenburg**[266] investigated the chemical setting, and associated damage of mohair and wool "crinkled" yarns.

Traditional mohair blankets[350] are manufactured by weaving a fancy mohair loop yarn in both the warp and weft directions with a low number of ends and picks per centimetre. The loop yarn is made by two doubling processes, the first of which is known as the "folding" effect, and the second as the "running back" or "locking" effect. For example, two single or ply ends of about 44 tex worsted yarn can be folded with a mohair yarn of about 220 tex, the mohair *yarn being overfed to produce loops in the yarn. This is illustrated by Fig. 55.* The loops formed in this manner are unstable and therefore this loop yarn is subjected to a second doubling process known as "running back". Fig. 55 shows the second stage in the manufacture of loop yarns; the folded loop yarn is run back with another end of single 44 tex yarn and the loops of mohair are locked into position by this binder thread. The resultant fancy loop yarn has a linear density of about R450 tex with evenly spaced loops. There are variations of the above process, the most common being that ply yarns are used in the locking process.



First Process – Folding Effect

Second Process – "Running back" – Binding the Mohair loops to give a stable yarn

Fig. 55 The Production of Loop Yarns[350].

Loop yarns are often wound into hanks, dyed and brushed then used for weaving into rugs and shawls. They may also be woven directly into blankets after dyeing, and the woven fabric raised to give a pile effect. This type of woven blanket may be plain weave and constructed with only about four ends and picks per centimetre. When the blanket fabrics are raised, the rollers of the raising machine pluck the mohair loops, breaking them and drawing the fibres parallel to give a raised pile. The base of the fibres remain locked in the yarns in the fabric. The resultant fabric has a long pile of soft, silky fibres with the characteristic lustre of mohair, and the resultant mass per unit area of the blanket is in the region of $350 g/m^2$.

Shorthouse and Robinson[(658)] gave recommendations for the spinning of mohair brushed and loop yarns, using a novelty spinner. Yarn brushing and yarn and fabric properties, fibre loss during brushing and also the weaving of yarns were discussed.

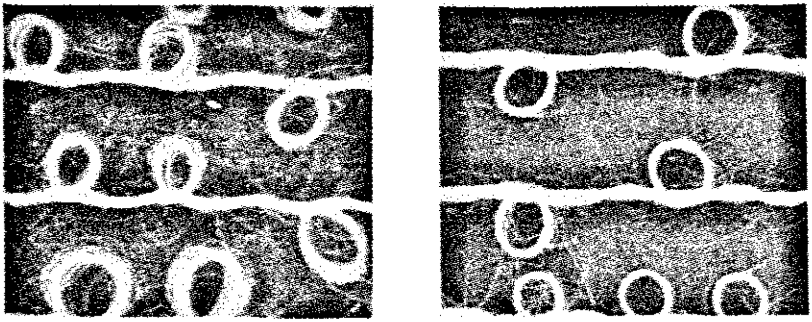
Shorthouse and Robinson[(658)] investigated the effect of mohair fibre diameter on the processing performance of loop and brushed yarn as well as the physical properties of the yarns and the fabrics produced from them. Eight lots of mohair were processed to obtain a yarn construction similar to a commercial loop yarn. The mohair was spun into 120 tex Z200 yarn. A 60/40 wool/nylon 40 tex Z400 yarn was used as the ground and wrapper components. The loop yarns were produced on a fancy twister operating at a spindle speed of 1 600 rev/min as follows:

First operation: Each of the 100% mohair yarns was combined with two of the wool/nylon (ground) yarns using a feed ratio of 2.37:1 and folded with S450 turns/m.

Second operation: The resultant unstable loop yarn from the first operation was then combined with a third wool/nylon yarn as wrapper using a folding twist of Z150 turns/m.

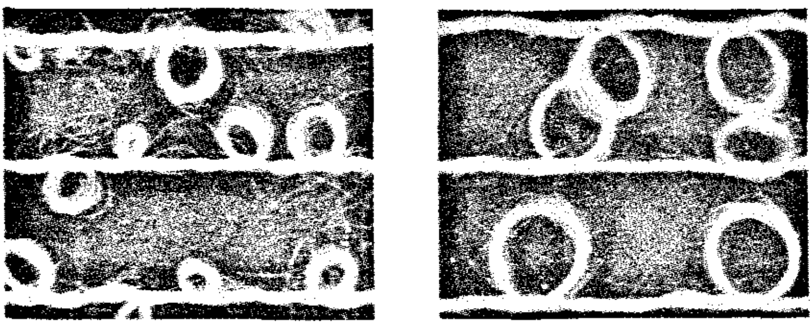
The yarns were brushed on a yarn brushing machine using either two, four or six wraps. Both the loop and brushed loop yarns were woven into a blanket construction having the mohair on the face of the fabric. The pile was raised after finishing. The loop and brushed loop yarns containing the coarser mohair exhibited the lowest number of faults (malformed loops). Fault rates were reduced by increasing the severity of brushing. Higher percentages of fibre loss were obtained as the fibre diameter increased and also as the number of wraps increased[(656)].

Shorthouse and Robinson[(772)] investigated the effect of twist, oil content and dyeing on mohair loop and brushed loop yarns (see Figs 56, 57 and 58[(772)]). Loop properties were influenced by the amount of twist in the singles mohair yarn. The loop frequency and size were related to the amount of folding twist. A high oil content reduced the number of malformed loops. Loop yarns were hank-dyed without problems but components of brushed loop yarns should preferably be dyed prior to fancy doubling. Singles and folding twist levels required to produce the best loop and brushed loop yarns, were determined. An optimum twist of about 200 turns/m was found for the 120 tex mohair yarn, this yarn being folded with two 60/40 wool/nylon (40 tex Z 400) yarns as ground, using a feed ratio of 2.37:1 and S 450 turns/m. The unstable loop yarn so produced was combined with a third wool/nylon loop yarn (wrapper) using a folding twist of Z150 turns/m.



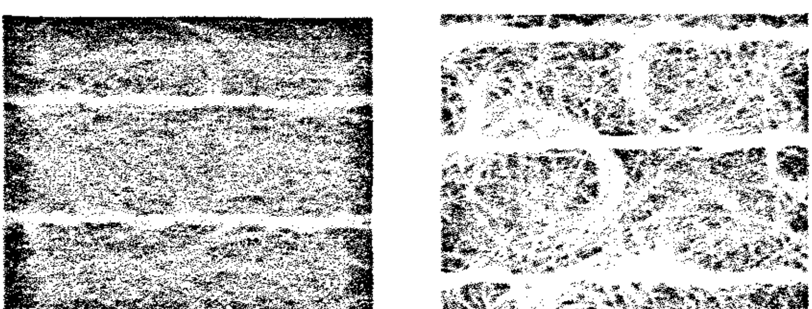
120 tex Z200 | 120 tex Z400

Fig. 56 Effect of Singles Mohair Twist Levels on Loop Appearance[772].



S500/Z200 | S400/Z100

Fig. 57 Effect of Folding Twist Levels on Loop Appearance [772].



Undyed loop yarn (brushed) | Hank-dyed loop yarn (brushed)

Fig. 58 Effect of Hank-Dyeing the Loop Yarn[772].

Metchette[564] discussed the spinning and dyeing of fancy yarns.

REPCO-WRAPPED CORE-SPUN YARNS

Various researchers at SAWTRI carried out considerable work on the spinning of mohair yarns[443] including slub yarns[397], on the Repco self-twist spinner, without[395] and with nylon filaments[424]. It was concluded that the best results were obtained when two multi-filament yarns (usually 17 or 22 dtex nylon) were introduced, the one to act as a core and the other as wrapper. Yarns so spun (and generally uptwisted after spinning - STT) were designated as Repco-Wrapped Core-Spun (RWCS) yarns. Two strands of mohair and one nylon filament core were drafted and self-twisted with a filament binder yarn to form an RWCS yarn[424] (see Fig. 59). Different variations were developed. The yarns were converted into lightweight fabrics, generally with highly acceptable properties. Much of the work was summarised by **Robinson and Turpie**[446]. The advantages attributed to RWCS yarn were stated[446] to be:

1) Much finer yarns (down to 16 tex) could be spun.
2) Higher spinning (up to 220 m/min) and better spinning efficiencies could be achieved.
3) Reduced yarn hairiness.
4) Better yarn performance during preparation and weaving.
5) Lighter weight (150 to 160 g/m^2) fabrics of a finer construction could be woven and knitted.
6) Improvements in certain fabric physical properties.

The spinning of RWCS yarns is illustrated in the following Fig. 59.

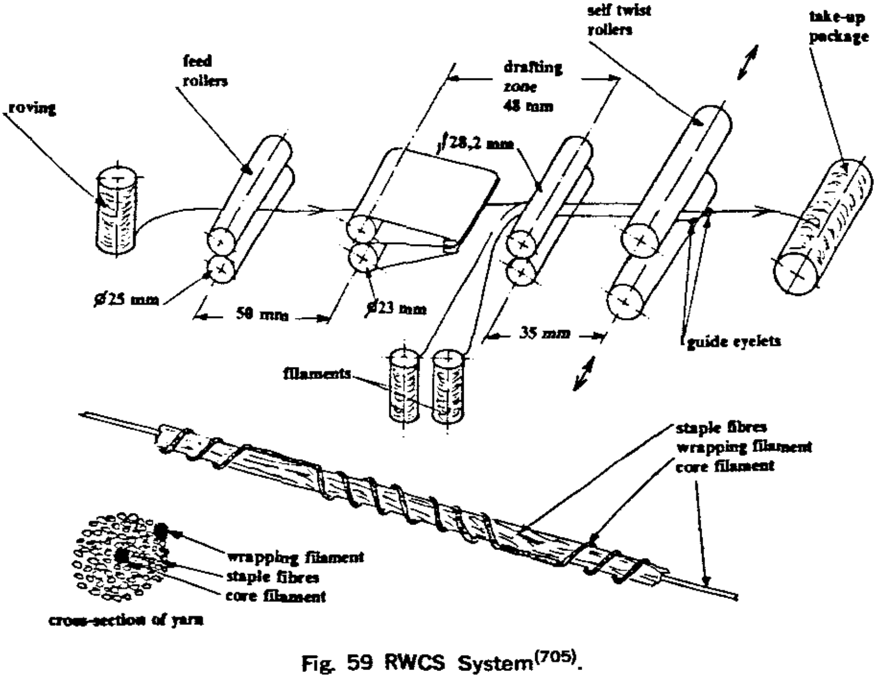


Fig. 59 RWCS System[705].

A core-spun self-twist mohair-based slub yarn, comprising a mohair base and a rayon slub, was successfully spun on a Repco-Spinner, the rayon slub being produced from a woollen slubbing introduced into the drafting zone[397].

Robinson *et al*[424] reported on the spinning of relatively fine RWCS (STT) yarn and the production of relatively light weight (160g/m²) mohair suiting fabrics. The yarns performed well during weaving. Yarns with as few as 18 mohair fibres per yarn cross-section were spun[424]. **Turpie** *et al*[488] gave typical values for the irregularity and breaking strength of RWCS mohair yarns, containing mohair ranging in fibre diameter from 25 to 40μm. The yarns contained a core and wrapper of 22 dtex nylon multi-filament (7 filaments each). Multiple regression analysis of the data showed that yarn thick places and breaking strength were affected by fibre diameter, fibre length and yarn linear density (tex), yarn thin places, neps and irregularity by fibre diameter and yarn linear density and yarn hairiness and tenacity by yarn linear density. Graphs of typical values were given, two of which are re-produced here (Figs 60 and 61).

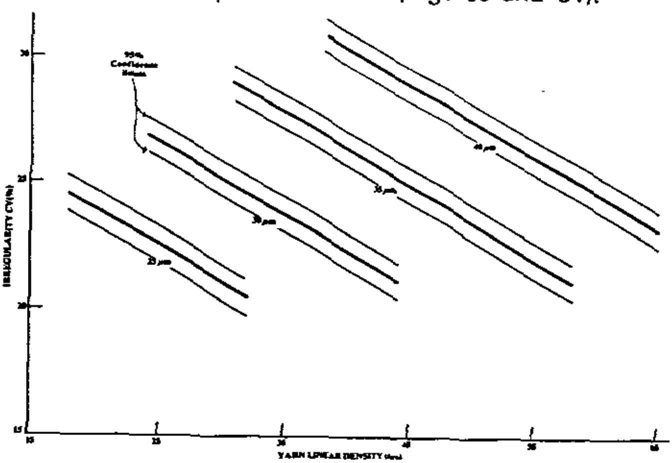


Fig. 60 Irregularity (CV) of RWCS Mohair Yarns, for Various Mean Fibre Diameters of Top[488].

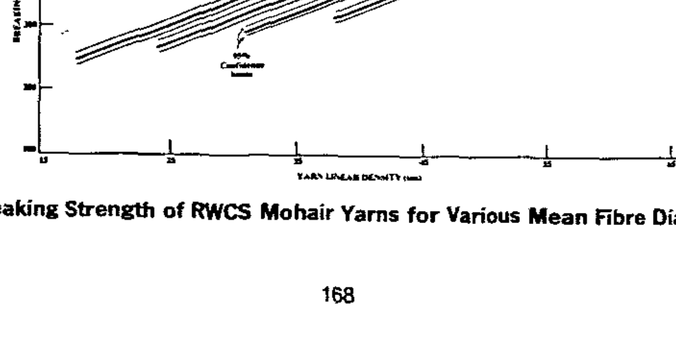


Fig. 61 Breaking Strength of RWCS Mohair Yarns for Various Mean Fibre Diameters of Top[488].

By combining RWCS mohair weft yarns with sized singles yarns it was possible to weave fancy weaves eg Chevron stripes, 2/2 twills and herringbone and Glen Urguhart Check patterns[539]. Good fabric stability was still achieved because of the fine yarns and higher setts employed. The fabrics were singed and pressed to give a clean surface and had exceptionally good crease recovery properties and a high lustre. The mass of the fabrics was 180g/m^2 or lower[539].

CHAPTER 19

DREF FRICTION SPINNING

Robinson *et al*[555] used the novel feature of the DREF II open-end friction spinning machine, which enables the radial positions of the fibres in the yarn cross-section to be predetermined, to show how a speciality fibre, such as camel hair or mohair (eg noils), can be made to predominate on the yarn surface whilst a cheaper fibre makes up the body of the yarn. In this manner the yarn, and subsequent fabric, has the aesthetic qualities of the speciality fibre in spite of the fact that the latter only makes up a small proportion of the whole.

YARN PROPERTIES

20.1 General

Tipton[33] reported on the dynamic tensile mechanical properties of mohair/wool worsted yarns and other yarns. **Cilliers**[137] investigated the spinning and properties of mohair/wool yarns and found that the yarn strength increased with increasing yarn linear density, twist factor and wool content, with the yarns spun at the higher speeds weaker than those spun at lower speeds. Nevertheless, for all the blends, the yarn strength compared favourably with those of commercial yarns tested. Similar trends were observed for yarn extension at break. Yarn evenness was somewhat below average, being the lowest with 60% mohair[137]. **Patni** *et al*[437] investigated the yarn properties of Kid mohair, Adult mohair and mohair/wool blends, showing that the Kid mohair yarns were generally superior to the Adult mohair (the fibres also had a greater tenacity of 15.8 vs 13.6 gf/tex).

Hunter *et al*[480] carried out a limited trial to determine the effect of mohair fibre diameter on yarn properties and found that in general an increase in mohair fibre diameter caused a deterioration in yarn physical properties. In a later study **Hunter** *et al*[520] found that fibre diameter had a greater affect on yarn properties than fibre length, with an increase in diameter generally, having an adverse effect on yarn properties.

Gürcan *et al*[543] compared the properties of mohair yarns (22 to 44 tex) spun on the French and English systems, respectively, and concluded that the yarns spun on the French system were at least as good as, if not better than, the yarns spun on the English System.

In a wide ranging study, involving the processing of some 50 mohair lots on the Continental worsted system followed by ring spinning, **Hunter** *et al*[716] investigated the effect of fibre properties, notably diameter and length, on yarn and fabric (knitted and woven) properties. They derived multiple regression equations by means of which the yarn and fabric properties could be predicted from fibre diameter, fibre length and yarn linear density and twist. Within the ranges covered, the effect of fibre diameter on yarn properties was far greater than that of fibre length, while the effects of variability (CV) of fibre diameter and fibre length and short fibre content were relatively small. Virtually all the yarn properties deteriorated with an increase in mean fibre diameter (or with a decrease in the number of fibres in the yarn cross-section), while an increase in mean fibre length generally had a beneficial effect[716]. Figure 62 illustrates some of the main trends

Yüksel[926] investigated the application of an improved Martindale yarn irregularity formula by **Grisham** to mohair yarn irregularity. His results favoured the former. Some properties of mohair/wool (in blends of 80/20, 60/40 and 40/60) and mohair/silk (50/50) blend yarns have been reported[726]. The strengths of the mohair/wool blend single yarns were of the order of 3.7 cN/tex and that of the mohair/silk about 5.6 cN/tex.

20.2 Friction

It is widely accepted that the friction of a yarn is very important in their efficient machine knitting and in maintaining course length and garment size uniformity, consistent yarn friction being of particular importance. **Hunter and**

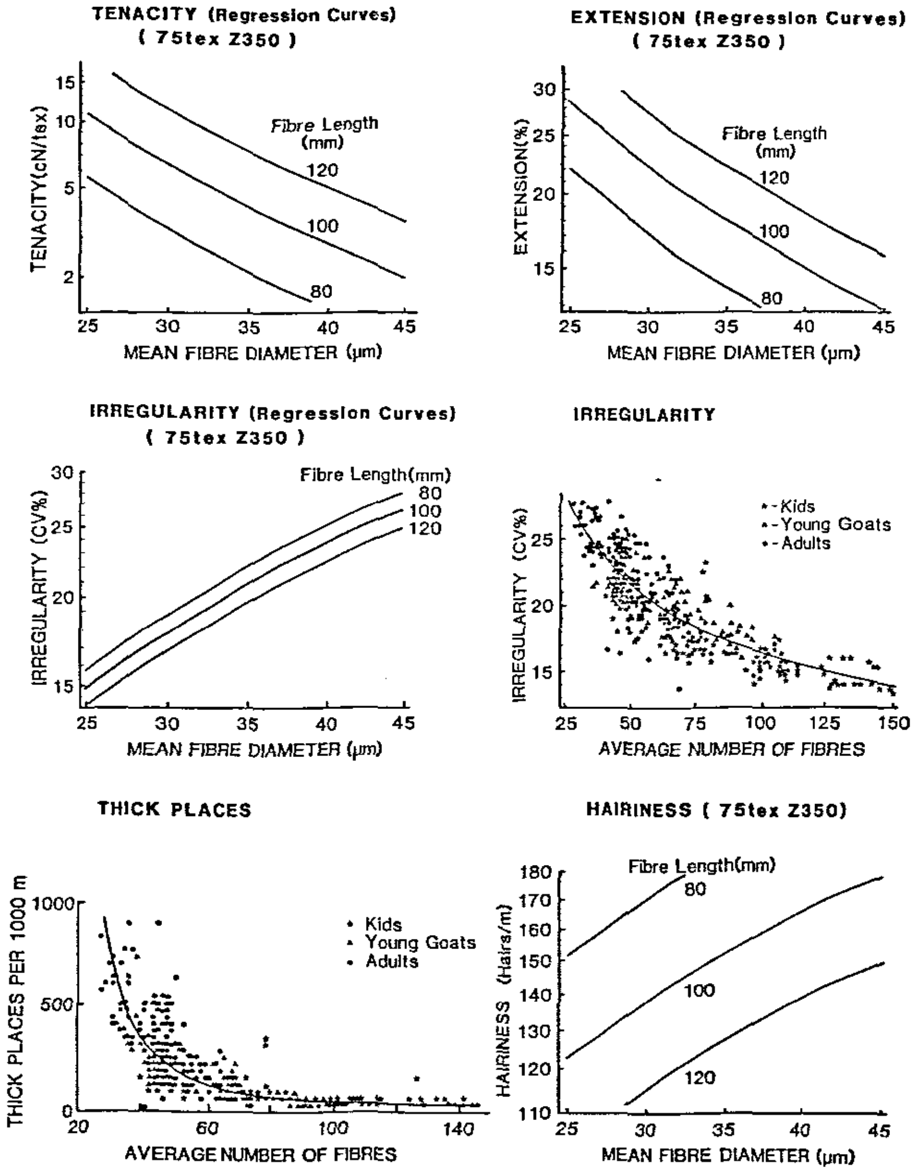


Fig. 62 The Effect of Mohair Fibre Properties on Yarn Properties[716].

Kruger[287] investigated the effect of different levels of paraffin wax on the friction of mohair/wool yarns of different blends. They found that the friction of waxed mohair/wool yarns increased with increasing mohair content. This was ascribed to the extractable matter on the mohair rather than to the mohair fibre itself, since solvent extraction or scouring of the yarns prior to waxing eliminated the effect (see Fig. 63). The minimum friction of the waxed yarn was correlated with the original either extractable matter content of the yarns. Optimum friction was found to occur at a wax application of around 0.5μg/cm. Generally, the wax with the highest melting point (63°C) gave lightly better all-round performance than the other two waxes studied[287].

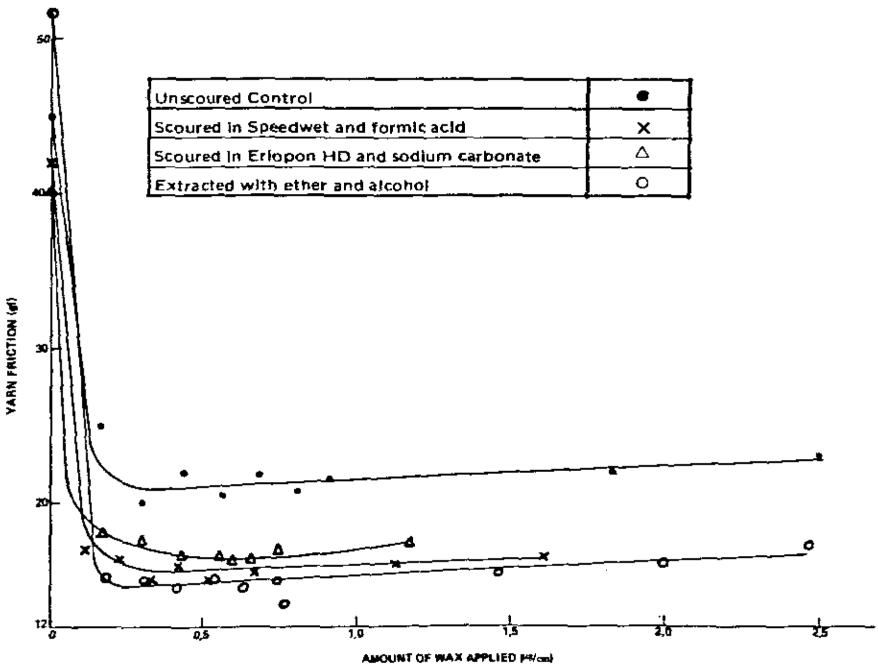


Fig. 63 Yarn Friction vs Amount of Wax Applied (100% Mohair Yarn; Melting Point of Wax 63°C)[287].

20.3 *Bending Stiffness*

An important property of textiles is their low bending stiffness (flexural rigidity) which makes them suitable for many end-uses, in particular apparel. Understanding the role of the many factors involved in determining flexural rigidity, or bending stiffness, is essential for a better understanding of the broader issue of fabric drape and handle which play such an important role in determining the suitability of a fabric for a particular end use. It is generally accepted that fibre stiffness plays a dominant role in yarn and fabric stiffness and handle (softness), with fibre stiffness largely a function of fibre diameter, increasing with the fourth power of diameter.

Yarn flexural rigidity, is important because of its large effect on the bending properties and behaviour of a fabric. Yarn stiffness affects the drape coefficient and, because it is related to fabric flexural rigidity, it also affects the handle of a fabric, handle being closely related to fabric flexural rigidity. It is also of some importance during fabric forming processes (eg knitting).

Van Rensburg *et al*[611] investigated the effect of wool and mohair fibre properties on yarn flexural rigidity. Mean fibre diameter had the overwhelming effect on yarn flexural rigidity and accounted for more than 90% of the variation in it. At the same mean fibre diameter, the flexural rigidities of the wool and mohair yarns were similar (see Fig. 64)[611]. Yarns with a higher twist were marginally stiffer than yarns with a lower twist. A good relationship was found between yarn stiffness and fabric stiffness for 1 x 1 rib fabrics although, at the same yarn stiffness, the wool fabrics tended to be stiffer than the mohair fabrics, possibly, because of higher inter-fibre and inter-yarn frictional and cohesive forces, due to differences in fibre crimp and friction.

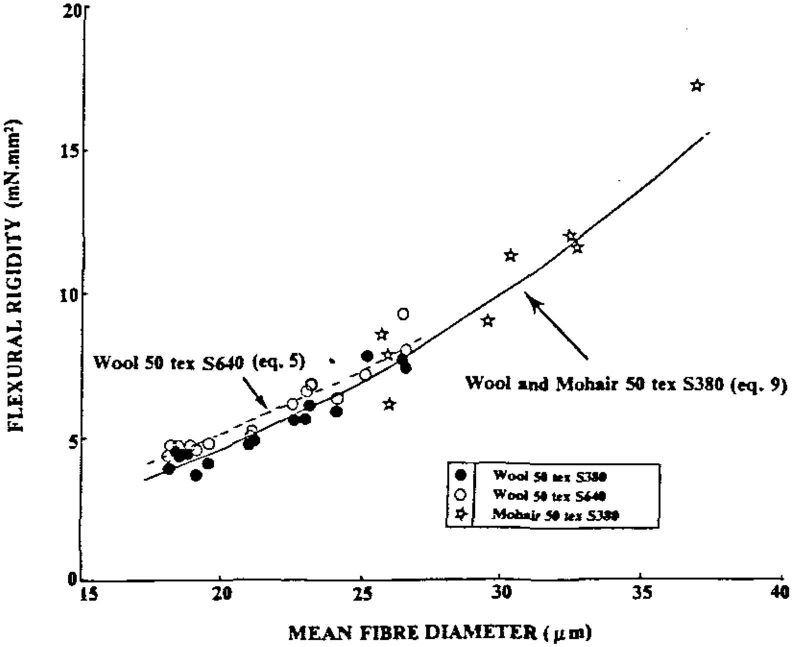


Fig. 64 The Relationship between Yarn Flexural Rigidity (G) and Fibre Diameter for Wool and Mohair[611]**.**

20.4 Diameter and Hairiness

The hairiness of mohair yarns is an interesting property. For some end-uses, such as hand-knitted women's cardigans, shawls and blankets, hairiness is an asset, enhancing the appearance of the fabric. For this purpose, brushing of mohair yarns and fabrics is commonplace in the industry. In other end uses[750], however, such as men's worsted suits, hairiness is a disadvantage, and has to be minimised. Mohair is inclined to produce a hairy yarn, and if hairiness is to be minimised, various precautions are necessary during processing and yarn winding etc.

Yarn diameter (thickness) is important from the point of view of the cover and bulk which it provides. Although yarn diameter is largely a function of the yarn linear density (tex or count) and twist, other factors, such as the manufacturing system (ie worsted, semi-worsted or woollen) and the fibre properties, such as diameter, length and crimpiness, also influence it.

Cilliers[137] observed that, for wool/mohair yarns, hairiness increased with increasing mohair content. **Barmby and Townend** [170,171] investigated the effects of spindle speed (flyer and ring frames) on the lustre and hairiness of 45 tex mohair yarn. A dolly roller twister fitted with leather covered dollies, was used to study the effect of doubling on yarn hairiness, this system minimizing the disturbance of the surface hairs[170]. They found that more yarn faults were produced at higher spindle speeds, with the first winding operation having a considerable effect on the number of faults. The second winding operation appeared to remove some of the faults caused by the first winding operation, probably related to the direction of the protruding hairs. The yarns spun on the flyer frame tended to have fewer faults than those spun on the ring-frame. The surface hair ends were found to be trailing when the yarn left the front rollers of the spinning frame and therefore leading when the yarn was withdrawn from the spinning tubes during the first winding operation. The first winding operation increased the yarn hairiness, the effect being smaller for the yarns spun at the higher spindle speeds. The second winding operation reduced hairiness. An increase in spindle speed was associated with an increase in hairiness for both the unwound and once wound yarns[170]. In the case of the doubled yarn, the unwound yarn was judged to be the most hairy, with higher spindle speeds being associated with greater yarn hairiness. They found considerable disagreement between subjective and objective assessments of yarn hairiness[171]. Winding the yarn twice, rather than once, appeared desirable. The photo-electric hairiness test indicated that the twice wound yarn was the most hairy whereas the subjective test indicated the once wound yarn was the most hairy. None of the parameters studied appeared to affect the lustre of the yarns as assessed in the woven fabrics. They claimed that the best mohair fabric was made from unwound weft[171].

Cilliers[189] found that ring-spun mohair yarn hairiness increased with spinning speed. An increase in inter-fibre friction, as measured by a withdrawal force tester, led to an increase in yarn strength.

Rewinding a mohair yarn causes the hairs on the yarn surface to lie in a different direction which could lead to bars in the fabric[233]. The yarn should be cleared in the singles form, as two-ply knots are difficult to mend[233].

Townend[302] reported that, for mohair flyer-spun yarn (Bradford system), there were about three times as many leading fibre ends as trailing ends on the yarn as it was spun, with the protruding fibres (ie hairs) mainly caused by thicker and stiffer fibres. The ASD drafting system on a Uniflex spinner produced less hairy yarns than the conventional carrier and tumbler system. Higher yarn twist led to slightly lower hairiness. Roving storage (for one month) was found to significantly reduce yarn hairiness, there also appearing to be an optimum roving twist as far as hairiness was concerned.

According to **Onions** *et al*[352], yarn hairiness, although desirable in certain applications, can create problems during twisting, winding, weaving, knitting and finishing. On mohair flyer-spinning, most of the hairs on the yarn were already present before the yarn had passed the flyer top. Hairiness was increased by using a higher draft (on conventional carrier-and-tumbler drafting equipment). Some oil was advantageous but not beyond 4%, when 0.5% anti-static agent was applied, the amount of oil could be reduced to 2%. Hairiness was critically affected by fibre fineness, coarser fibres leading to much greater hairiness, fibre length not being as critical, although longer fibres tended to produce less hairy yarns. The number of gillings as well as roving and yarn twist levels did not appear to have a major affect on yarn hairiness[352]. The ribbon width and the escape of fibres from the control of twist at the front roller exit appear to have the same effect on yarn hairiness.

Roving storage appeared to reduce yarn hairiness and so too, yarn storage[302,365]. The storage of the roving prior to spinning had a remarkable effect on reducing yarn hairiness for the Bradford system[365]. The greater the fibre control during spinning (eg ASD system), the lower the yarn hairiness. The rubbing action of the flyer leg increased yarn hairiness. Coarser yarns tended to be hairier, higher singles yarn twist, combined with conventional two-ply twist, gave the least hairy two-ply yarns. Storing the yarn for a few weeks also decreased its hairiness[365]. **Srivastava** *et al*[411] reported that ring-spun yarns had more than twice, and flyer-spun more than three times, as many leading as trailing hairs, with their numbers being equal for ASD cap-spun yarn. There appeared to be a critical flume-setting on the Uniflex spinner, above and below which yarn hairiness may increase, a higher drafting angle being associated with a lower yarn hairiness. Yarn hairiness generally decreased with increasing traveller weight. Better fibre control during drafting and a reduced ribbon width at the exit of the front rollers reduced yarn hairiness[411]. Although two-ply yarns had more protruding fibres than singles yarn (of half the linear density) their average lengths were less and it was concluded that two-ply yarns were less hairy than singles yarns. The number of hairs longer than 0.5mm were also less for the two-ply than for the singles yarns[411]. Steaming mohair rovings before spinning on the Uniflex (high draft of 100) had no apparent effect on yarn hairiness. Although the APS flyer system (draft of 10) gave less hairy yarns than the high draft Uniflex system, the lengths of the protruding fibres were similar. It was concluded, however, that the Uniflex spinner was capable of producing yarns which were no hairier than those produced on the flyer spinner, in spite of it having a draft 10 times greater and a spindle speed of about 50% greater.

Srivastava *et al*[411,427] investigated the variation in yarn hairiness with the depth of layer of worsted spun yarn packages, for Uniflex (high draft) spun mohair/Fibro blend yarns. There was some evidence, but not conclusive, that the hairiness of the inner layers of the package was perhaps slightly less than that of the outer layers.

In the case of flyer spun mohair yarns, the number of hairs projecting beyond 3 mm was reported to be proportional to the square of the fibre linear density, longer fibres tending to produce less hairy yarns[354].

Turpie and Hunter[439] investigated the effect of fibre diameter, fibre length and supplementary additives on the hairiness of ring spun yarns processed on the Continental system. Yarn hairiness was found to depend mainly upon the fibre diameter, hairiness increasing with increasing fibre diameter (see Fig. 65). Within the range covered, neither the type of supplementary additives nor the mean fibre length had a material effect on yarn hairiness. Plying decreased the yarn hairiness, the effect increasing as the yarns became finer[439,750]. For both singles and two-ply yarns, the yarn hairiness also increased approximately linearly with an increase in mean fibre diameter, while the yarn hairiness also increased as the linear density increased.

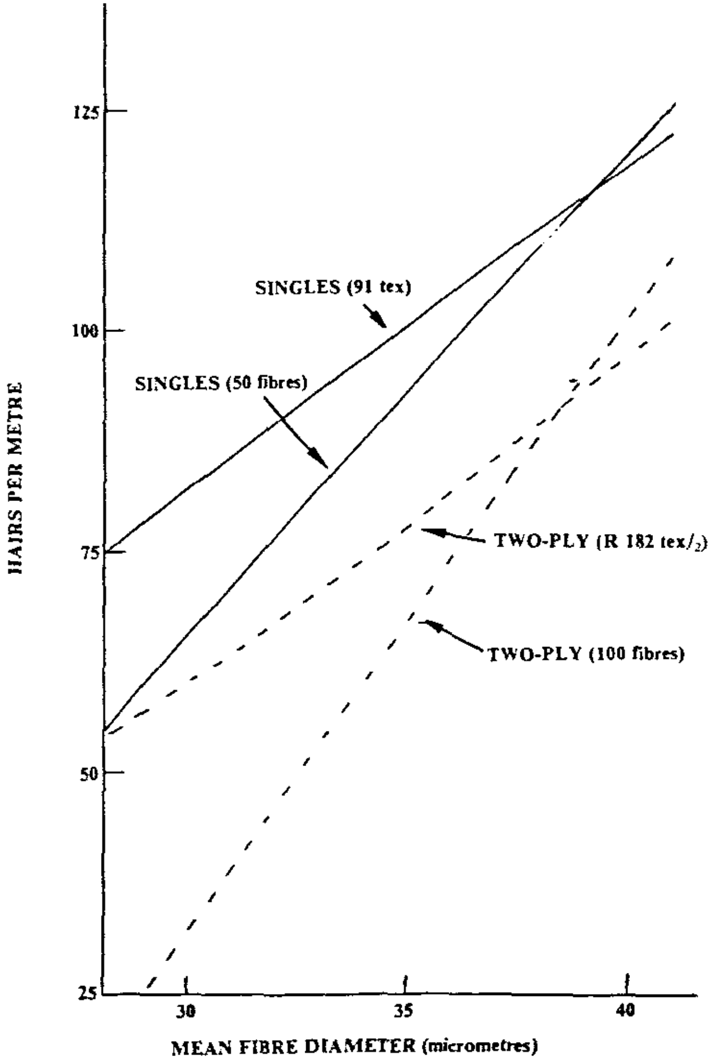


Fig. 65 Regression Curves for the Hairiness of Ring-Spun Mohair Yarns versus Mean Fibre Diameter(439).

It appeared that the two-ply yarns were considerably less hairy than singles yarn of the same linear density. The hairiness of yarns spun with an collapsed balloon was similar to that of yarns spun with an uncollapsed balloon. Certain of the yarns were also rewound, with and without wax being applied, in order to determine its effect on yarn hairiness. Rewinding increased the hairiness of the singles yarn by about 40% on average and that of the two-ply yarn by about 20% on average. Applying wax, by means of a solid wax disc during the rewinding process, did not materially alter the effect of rewinding on hairiness.

Barella[471] reviewed published work on the hairiness of mohair and other yarns.

Barella and co-workers[556,586,587,588,609,620,634,635,638,647,648,654,665,676,677,678,679,700,747] carried out a number of studies on mohair yarn diameter and hairiness, with particular reference to the effects of fibre and yarn parameters on these two yarn properties. Within the constraints of the ranges of yarns and parameters they covered, they found that yarn diameter was largely a function of yarn linear density[556,646]. Mohair yarn hairiness was found to be affected by fibre diameter and length, the mean and maximum hairiness values and mean length hairiness index depending upon fibre diameter and the maximum hairiness length index being closely related to fibre length[619], with yarn linear density and twist factor also having an effect. Coarser and shorter fibres tended to increase yarn hairiness.

The protruding fibres in mohair yarns, producing yarn hairiness, tend to be coarser[302], with the longer hairs mainly due to leading fibres (ie the ends which emerge first from the front rollers on the spinning frame). Fibre diameter appeared to be more critical than fibre length in terms of yarn hairiness.

Lubrication during preparatory processes reduces hairiness [365]. Increasing singles yarn twist, with conventional plying (folding) twist, also reduces yarn hairiness[365].

Singeing of mohair yarn (termed genapping) to reduce hairiness was practiced more than 60 years ago[5].

CHAPTER 21

WEAVING AND WOVEN FABRIC PROPERTIES

21.1 General

Mohair finds significant application in woven suiting and coating type fabrics, particularly in men's light-weight summer (tropical) suitings where it provides the wearer with considerable comfort. **Bowring and Slinger**[175] investigated the properties of tropical suiting fabrics woven from various intimate blends of wool and mohair. They concluded that the fabrics deformed more easily as the mohair content increased, possibly due to a concomitant increase in weave crimp. The results of Shirley Creasing and AKU wrinkling tests were in conflict, and wearer trials were considered necessary to resolve the matter. They concluded that the affect of finishing procedures could overshadow any trend due to mohair content[175]. Buttoning of the warp ends sometimes occurred with the mohair yarns, which could be reduced by frequently dusting the warp sheet with French chalk or possibly by sizing the warp, inserting a reciprocating rod in the back shed or by using a pair of stationary back rails. Unless care was taken when tying knots in the yarn, problems could be encountered with knot slippage, a double weaver's knot possibly being the solution[175].

Nicholls[132] investigated the effect of polyester fibre fineness on the properties of lightweight mohair/polyester (55/45) fabrics.

Slinger and Robinson[183] compared the physical properties of worsted fabrics made from merino/Corriedale Corriedale/Kid mohair and merino/Kid mohair blends. They processed the fibres on the Continental (French) system, (involving scouring (0.7% residual grease), carding, two gillings, rectilinear combing, gilling and auto-level gilling). The tops were dyed, recombed and then blended during gilling. Fibre shedding presented some problems with the warps which contained mohair, section marks also becoming apparent after finishing. When pirn winding the mohair, it was found necessary to increase the tension considerably in order to wind a hard pirn. Very few warp breaks and weft breaks occurred during the trials[183]. They found weave crimp largely unaffected by the fibre blend which contrasted with the results of a previous study[175]. The different fibre blends also did not appear to affect the AKU Wrinkling or Shirley crease recovery test results significantly[183]. The incorporation of Corriedale wool adversely affected the fabric handle but this was not the case when mohair was incorporated. The fabrics containing mohair had a higher uncrimping force than the fabrics containing wool. The presence of mohair reportedly decreased the elasticity but increased plasticity (propensity to deform permanently). Changing the weft from a two-fold to a three-fold yarn did not alter the fabric tensile properties. The fabrics containing the mohair were the least extensible[183]. They reported that commercially produced mohair fabrics tended to have relatively low weft crimp, possibly as a result of tentering under a weft tension and/or by chemical setting. They therefore investigated the effect of tentering the fabrics under a weft tension. As expected, it decreased weft crimp and increased warp crimp, this being associated with a deterioration in weft wrinkle recovery and improvement in warp wrinkle recovery[183]. The coarser fibres were associated with an increase in fabric stiffness.

Smuts and Slinger[296] related mohair handle to fibre friction.

Sidi[207,209,242] discussed management techniques and technical aspects in a mohair weaving mill and gave a weaver's check list for cloth quality and some details about acceptable and unacceptable yarn faults. All yarn faults below 150% yarn diameter (cross-sectional size) could be ignored and left in the cloth, where-as at the 200% level, faults could be thinned out provided they did not exceed 20mm. At the 200% level and exceeding 20mm, a yarn fault might need replacing. Once a fault reached the 350/400% diameter it would almost certainly have to be replaced, regardless of length. They specified that the yarn they purchase should contain no more than about 7 to 9 two-fold knots per kg and not more than 4 faults per kg of maximum dimension 400% x 20mm (for an R 44 tex/2 worsted yarn). They also specified that the mean end breakage per piece of cloth during weaving should not exceed 10 and also specified the maximum slub size.

Steinbach[339] discussed the utilization of mohair, in blends with wool or synthetic fibres, in woven fabrics, indicating such factors as blend composition, woven fabric construction and finishing. **Bellwood**[329,330] discussed the weaving, construction and finishing of woven fabrics produced from either worsted or woollen spun mohair/wool blend yarns, including pile fabrics and novelty yarns. For the manufacturing of sun-filter curtaining, leno weaving using mohair, was considered excellent[201].

Hunter *et al*[480] undertook a limited study of the effect of mohair fibre diameter on fabric physical properties. Four mohair lots, varying in fibre diameter from 25 to 30μm, were processed into 55/45 mohair/wool plain weave fabrics and two of the lots were also processed into all-mohair cavalry twill fabrics. An increase in mohair fibre diameter generally increased fabric air permeability, abrasion resistance, stiffness and drape coefficient but had little effect on the fabric tensile properties[480].

Bergmann[489,491] discussed fabric structural and other aspects of ladies costume and cape fabrics and velours. **Shiloh** *et al*[513] showed that the hygral expansion of wool and mohair fabrics was largely a function of weave crimp, with fibre properties such as diameter, staple crimp and bilateral structure only of importance insofar as they affect weave crimp (see Fig. 66). The "indirect" singeing of high quality mohair fabrics has been mentioned[616], one or two singeing passes being carried out without any shearing.

Smuts and Hunter[570] measured and tabulated (Table 94) a wide range of physical properties of some 60 woven suiting fabrics, their aim being to establish "average" or "typical" values for the physical properties of such fabrics which can be used as a basis of reference when similar fabrics are being evaluated in practice. The results were plotted against fabric mass and average values were calculated and tabulated for the various fabric properties. Some results for fabrics made from RWCS yarns were also given.

Most of the fabrics studied by **Smuts and Hunter**[570] were lighter than 200g/m^2 and contained less than 50% of mohair. The average fibre diameter of the wool used in the warp yarn was 21μm while that of the mohair or mohair-/wool blend used in the weft was about 27μm. Most of the fabrics had a mohair content of between 40 and 60% and variations in mohair content within this range had no detectable effect on the measured fabric properties. An increase in fabric mass increased the fabric strength, flexural rigidity, deaged IWS wrinkle recovery and deaged Monsanto crease recovery (the sum of the warp and

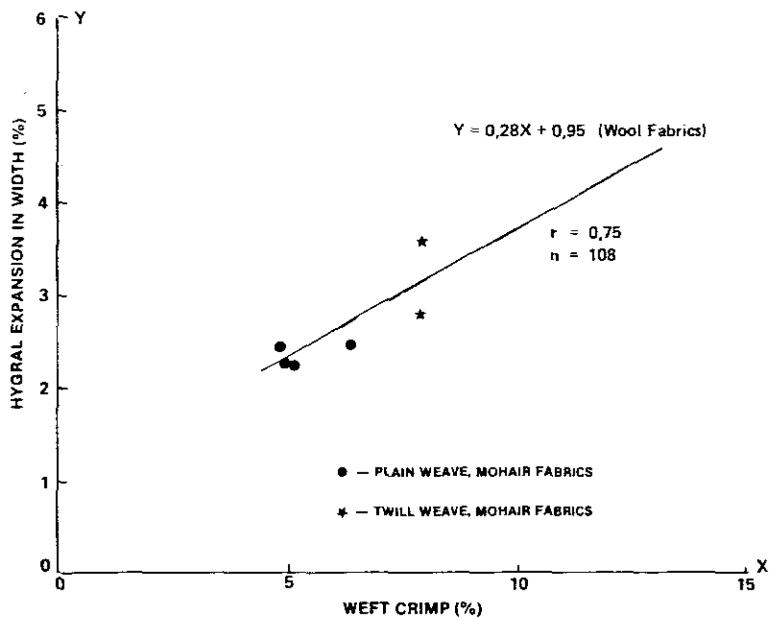


***Fig 66 The Relationship between Hygral Expansion in the Width Direction and Weft* Crimp for Plain and Twill Fabrics** [513].

weft). Therefore, for these properties, the "average" or "reference" values were a function of the fabric mass. None of the other fabric properties were significantly affected by fabric mass. It was found that the weft direction tended to have a greater breaking strength, stiffness and IWS crease recovery than the warp while the reverse was true for AKU wrinkling, extension at break and relaxation shrinkage. The seam slippage in the weft direction tended to be greater than that in the warp direction, while the tear strength and hygral expansion values were similar for the warp and weft directions. It was found that an increase in the average fibre diameter tended to increase fabric air permeability, IWS wrinkle recovery, stiffness and hygral expansion but tended to decrease the breaking extension and AKU wrinkle recovery values. There was a tendency for tear strength and relaxation shrinkage to decrease and for breaking extension, hygral expansion and AKU rinkle recovery to increase as the weave crimp increased. The AKU wrinkle recovery tended to deteriorate whereas the IWS wrinkle recovery tended to improve as the fabric thickness increased. Tear strength, breaking strength and Monsanto crease recovery all tended to increase as the product of sett and yarn linear density increased.

When the results of the fabrics containing RWCS yarn were compared with those of fabrics made from ring spun yarn (ie the commercial fabrics) it was found that, at the same fabric mass per unit area, the former tended to be less air permeable, more flexible and stronger than the latter. The other fabric properties were very similar for the two groups of fabrics. It was found that the RWCS twill fabrics had lower abrasion resistance, drape coefficient and air permeability but slightly better wrinkle recovery and strength properties than

TABLE 94[570]

AVERAGE VALUES FOR CERTAIN PROPERTIES OF THE MOHAIR/WOOL BLEND WOVEN FABRICS*

Physical Property	All Commercial Fabrics		All Commercial Plain Weave Fabrics		Fabrics from Source A		Fabrics from Source B		IWCS Fabrics	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Number of fabrics	45	—	37	—	16	—	23	—	18	—
Fibre diameter (μm): Warp	20,8(7)	18 – 26	20,6(5)	19 – 22	20,2(5)	18 – 22	21,0(4)	19 – 22	±21	—
Weft	27,5(14)	22 – 35	27,6(14)	22 – 35	24,0(7)	22 – 28	30,7(9)	26 – 35	±26	—
Approximate composition (%): Wool	59(24)	34 – 94	55(19)	34 – 73	61(11)	48 – 70	57(27)	34 – 75	50	50
Mohair	40(36)	6 – 60	43(27)	16 – 60	37(23)	16 – 52	43(36)	15 – 60	45	45
Sett (threads per cm): Warp	21(24)	15 – 40	20(9)	15 – 24	22(24)	18 – 40	21(25)	15 – 36	28(7)	24 – 30
Weft	*20(13)*	*13 – 24*	*20(11)*	*13 – 22*	*21(11)*	*15 – 23*	*20(13)*	*13 – 24*	*24(10)*	*20 – 27*
Resultant yarn linear density (tex): Warp	43(27)	29 – 91	42(17)	33 – 69	39(14)	29 – 49	43(20)	29 – 69	29(5)	27 – 32
Weft	50(34)	37 – 111	50(32)	37 – 111	48(23)	39 – 78	49(36)	37 – 111	35(9)	27 – 39
Yarn twist (t.p.m.): Warp-singles	"Z"591(19)	364 – 824	"Z"594(19)	364 – 824	"Z"599(25)	408 – 752	"Z"588(13)	436 – 724	—	—
-folding	"S"631(15)	490 – 950	"S"630(16)	490 – 950	"S"680(13)	570 – 950	"S"576(19)	270 – 840	—	—
Weft-singles	*"Z"466(15)*	*336 – 632*	*"Z"459(13)*	*336 – 572*	*"Z"452(16)*	*352 – 560*	*"Z"481(13)*	380 – 632	—	—
Tex twist factor: Warp	—	—	—	—	—	—	—	—	—	—
Weft	31(15)	22 – 41	31(14)	22 – 40	—	—	—	—	—	—
Weave crimp (%): Warp	6,7(30)	3 – 13	6,6(32)	3 – 13	7,0(33)	3 – 13	6,1(27)	3 – 9	7,2(22)	5 – 10
Weft	6,2(44)	3 – 15	5,7(43)	3 – 14	6,7(46)	3 – 14	5,7(34)	3 – 10	5,4(31)	3 – 10
*Cover factor***	*21(6)*	*20 – 26*	*21(2)*	20 – 22	*21(7)*	20 – 26	21(6)	20 – 25	22(5)	20 – 24
Mass per unit area (g/m^2)	200(15)	172 – 324	190(10)	172 – 255	196(10)	172 – 239	195(12)	169 – 255	180(9)	154 – 199
Fabric thickness (mm)	0,43(35)	0,31 – 1,08	0,39(11)	0,31 – 0,51	0,39(11)	0,31 – 0,46	0,42(15)	0,32 – 0,56	0,37(10)	0,30 – 0,44
Fabric density (g/cm^3)	0,48(13)	0,26 – 0,57	0,49(7)	0,43 – 0,57	0,51(7)	0,44 – 0,57	0,47(8)	0,38 – 0,54	0,49(4)	0,45 – 0,54
Air permeability measured at 98 Pa ($m\ell/s/cm^2/98$ Pa)	*25(52)*	5 – 54	*24(50)*	9 – 54	*16(43)*	*5 – 32*	*31(34)*	*10 – 54*	*22(41)*	*12 – 47*
Martindale abrasion resistance (% mass loss at 10 000 cycles)	4,8(64)	– 0,1 – 21,1	4,2(37)	– 0,1 – 6,7	4,5(25)	3,0 – 6,7	4,0(46)	0,3 – 6,7	6,4(26)	3,6 – 8,8
Bursting strength (kN/m^2)	871(10)	722 – 1091	855(10)	722 – 1091	886(10)	789 – 1091	866(11)	722 – 1085	904(9)	785 – 1003
Elmendorf tear strength (N): Warp	23(31)	14 – 45	23(31)	14 – 45	22(25)	15 – 31	23(28)	14 – 37	24(20)	17 – 30
Weft	*25(31)*	*10 – 48*	*25(33)*	10 – 48	23(21)	15 – 33	25(35)	10 – 48	21(24)	13 – 28
Mean	24(28)	13 – 42	24(28)	13 – 42	23(20)	17 – 31	24(27)	13 – 39	23(19)	16 – 28
Fabric breaking strength (N): Warp	296(14)	231 – 394	284(11)	231 – 358	287(13)	238 – 379	302(14)	249 – 394	313(12)	246 – 383
Weft	349(18)	217 – 572	355(19)	217 – 572	362(20)	217 – 572	345(19)	250 – 519	359(12)	256 – 421
Mean	323(12)	272 – 432	320(12)	272 – 432	325(12)	272 – 432	324(13)	275 – 422	336(9)	283 – 376
Fabric breaking extension: Warp	27(27)	15 – 45	27(28)	14 – 45	30(26)	18 – 40	26(31)	15 – 45	39(8)	32 – 45
Weft	23(26)	12 – 39	23(24)	15 – 39	26(18)	17 – 33	20(28)	12 – 39	23(20)	18 – 38
Mean	25(21)	18 – 37	25(20)	19 – 35	28(19)	20 – 37	23(21)	18 – 35	31(10)	26 – 39
Fabric breaking tenacity (cN/tex): Warp	6,9(12)	4,6 – 9,1	7,1(10)	6,0 – 9,1	7,0(11)	6,0 – 8,5	7,0(13)	4,6 – 9,1	7,8(10)	6,6 – 9,3
Weft	7,2(17)	4,7 – 11,8	7,3(15)	4,7 – 11,8	7,5(19)	4,7 – 11,8	7,2(12)	5,0 – 8,2	8,7(15)	5,6 – 11,9
Mean	7,0(12)	5,9 – 10,2	7,2(10)	5,9 – 10,2	7,2(12)	6,4 – 10,2	7,1(9)	5,9 – 8,1	8,2(10)	6,2 – 9,7
Drape coefficient (%):	60(6)	53 – 68	60(6)	53 – 65	60(6)	55 – 65	61(6)	53 – 65	55(7)	47 – 61
Cantilever bending length (cm): Warp	1,62(9)	1,4 – 2,0	1,59(7)	1,4 – 1,8	1,59(6)	1,4 – 1,8	1,65(8)	1,5 – 2,0	1,45(4)	1,3 – 1,5
Weft	2,10(9)	1,7 – 2,4	2,13(9)	1,8 – 2,4	2,02(7)	1,8 – 2,4	2,21(7)	1,9 – 2,4	1,76(6)	1,4 – 1,9
Mean	1,86(6)	1,6 – 2,1	1,86(6)	1,6 – 2,1	1,81(5)	1,7 – 2,0	1,93(4)	1,8 – 2,1	1,61(4)	1,5 – 1,7
Cantilever flexural rigidity (mN.mm): Warp	8,7(44)	5 – 27	7,5(21)	5 – 10	7,8(19)	5 – 10	8,7(28)	6 – 16	5,38(15)	3 – 6
Weft	18,3(29)	12 – 35	18,4(30)	12 – 35	16,1(23)	12 – 27	20,8(25)	14 – 35	9,72(19)	5 – 13
Mean	13,5(27)	8 – 27	13,0(24)	8 – 22	12,0(17)	9 – 17	14,8(19)	11 – 22	7,56(15)	5 – 10
AKU Wrinkling (wrinkle height in mm — de-aged): Warp	0,29(16)	0,20 – 0,41	0,29(15)	0,20 – 0,38	0,28(11)	0,24 – 0,37	0,31(16)	0,24 – 0,41	0,29(12)	0,23 – 0,36
Weft	0,43(15)	0,31 – 0,58	0,43(15)	0,31 – 0,58	0,41(11)	0,34 – 0,51	0,45(14)	0,32 – 0,58	0,37(16)	0,25 – 0,52
Mean	0,36(12)	0,26 – 0,44	0,36(11)	0,26 – 0,44	0,34(8)	0,30 – 0,39	0,38(10)	0,31 – 0,44	0,33(10)	0,29 – 0,42
Monsanto C.R.A. (de-aged): Warp	155(2)	147 – 159	155(2)	150 – 159	156(2)	152 – 159	155(2)	150 – 159	154(2)	149 – 158
Weft	151(2)	143 – 156	150(2)	143 – 153	151(2)	145 – 155	151(2)	143 – 156	151(2)	145 – 154
Total	306(2)	292 – 312	306(1)	293 – 312	307(1)	299 – 311	306(2)	293 – 314	304(1)	298 – 312
IWS wrinkle recovery (WR %): De-aged — Warp	44(11)	33 – 56	43(9)	33 – 49	44(9)	33 – 49	44(10)	36 – 52	46(8)	39 – 50
Weft	47(8)	39 – 57	46(7)	39 – 52	47(5)	43 – 53	47(8)	39 – 53	46(6)	37 – 50
Mean	46(8)	39 – 57	45(7)	39 – 51	46(6)	40 – 49	46(8)	39 – 51	46(6)	38 – 50
Aged — Warp	68(7)	58 – 76	67(7)	58 – 75	—	—	—	—	—	—
Weft	74(6)	65 – 87	73(6)	65 – 81	—	—	—	—	—	—
Mean	71(6)	62 – 81	70(6)	62 – 77	—	—	—	—	—	—
Relaxation shrinkage (%): Length	1,9(47)	0,7 – 4,9	1,7(46)	0,7 – 4,9	1,6(25)	1,0 – 2,6	2,0(49)	0,7 – 4,9	1,1(40)	0,3 – 2,1
Width	1,0(98)	– 0,3 – 4,6	1,0(99)	– 0,3 – 4,6	0,8(67)	0,0 – 1,7	1,1(84)	0,0 – 3,8	0,5(55)	– 0,2 – 1,0
Area	2,9(53)	0,8 – 7,6	2,8(53)	0,8 – 7,6	2,4(27)	1,4 – 3,4	3,1(44)	1,0 – 5,8	1,6(36)	0,5 – 2,6
Hygral expansion (%): Length	2,9(35)	0,4 – 4,9	2,8(36)	0,4 – 4,9	2,2(42)	0,4 – 4,2	3,2(27)	1,5 – 4,9	2,3(35)	1,0 – 3,8
Width	2,7(47)	0,3 – 5,5	2,7(50)	0,3 – 5,5	2,2(73)	0,3 – 5,5	2,9(31)	0,0 – 3,8	2,9(15)	2,1 – 3,6
Area	5,6(34)	1,7 – 9,1	5,5(36)	1,7 – 9,1	4,4(47)	1,7 – 8,2	6,1(23)	3,2 – 9,1	5,2(20)	3,2 – 6,5
Seam slippage (mm seam opening): Warp† : — Immediately at 118N	5,6(28)	2,7 – 11,9	5,2(22)	2,7 – 7,9	5,0(24)	2,7 – 7,8	6,3(27)	4,0 – 11,9	6,4(15)	4,6 – 8,0
: — After 2 min at 118N	6,5(25)	3,5 – 12,5	6,1(18)	3,5 – 8,4	5,9(23)	3,5 – 9,7	7,1(23)	5,0 – 12,5	7,5(12)	6,5 – 9,1
: — 2 min after reduction of load to 2,5N	4,1(38)	2,3 – 10,0	3,7(30)	2,3 – 7,0	3,6(32)	2,3 – 6,3	4,5(40)	2,3 – 10,0	4,8(23)	3,5 – 6,7
Weft†† : — Immediately at 118N	5,0(21)	3,0 – 7,3	5,0(18)	3,3 – 7,3	4,7(25)	3,0 – 7,1	5,3(14)	4,1 – 7,3	5,4(16)	3,7 – 6,0
: — *After 2 min at 118N*	*6,0(21)*	*4,0 – 9,3*	*5,9(20)*	*4,0 – 9,3*	*5,6(22)*	4,0 – 8,4	6,3(19)	5,0 – 9,3	6,4(15)	4,7 – 7,3
: — 2 min after reduction of load to 2,5N	3,4(30)	2,0 – 6,0	3,3(28)	2,0 – 5,1	3,2(31)	2,0 – 5,2	3,5(29)	2,0 – 6,0	3,6(23)	2,2 – 4,7

* — values in parenthesis are the respective CV's in %

** — The cloth cover factor K_c was calculated from:

$K_c = 0,1045\ (n_1 \sqrt{Tex_1} + n_2 \sqrt{Tex_2} - 0,00373 \times n_1 n_2 \sqrt{Tex_1 \cdot Tex_2})$ where n_1 and n_2 are the number of warp and weft threads per centimetre and Tex_1 and Tex_2 are the warp and weft yarn linear densities

† = warp threads slipping (or slippage in weft direction)

†† = weft threads slipping (or slippage in warp direction)

the RWCS plain weave fabrics. Some of these differences could have been due to the fact that the twill fabrics were slightly heavier than the plain weave fabrics. For most of the other physical properties, the plain and twill weave fabrics performed similarly[570].

Kienbaum[577] discussed the manufacturing and design of woven fabrics from worsted mohair/wool yarns, indicating the yarn properties and woven construction.

Smuts *et al*[651] investigated the effect of certain fibre properties on the shear properties, which are related to handle and drape, of wool and mohair/wool fabrics. For the mohair fabrics, the correlation coefficients were generally small in the case of shear stiffness and not significant in the case of shear hysteresis, the effects of fibre properties on the fabric shear properties apparently being small and of little practical importance. The shear stiffness of the mohair fabrics tended to increase as fabric thickness increased and was generally similar to that of the wool fabrics which contained wool fibres with a very low crimp. The fabric drape coefficient was found to be determined mainly by bending length, which in turn was primarily a function of fibre diameter. Shear stiffness had only a small effect, if any at all, on the fabric drape coefficient, the latter tending to increase as the shear stiffness increased. In general, the results of the investigation indicated that the various wool and mohair fibre properties studied had but a small effect on the shear properties of the woven fabrics. It is possible that the magnitude of the effects will be greater in the case of loosely woven or knitted fabrics[651].

Carnaby *et al*[668] reported on the development and properties of tropical fabrics containing various fibre blends, including mohair. They also reported on the fabric properties measured by the Kawabata system. The warp yarn was Sirospun consisting of a 50/50 blend of fine wool and polyester. Coarser fibres (eg wool and mohair) are often preferred for tropical suitings (worn in warmer climates) because such fibres result in stiffer fabrics which prevent the fabrics from draping closely around the body and also give a crisp and cool appearance and touch[668]. These properties are considered to be vital in a fabric worn next to the skin in a climate combining high temperature and high humidity. Such fabrics are normally required to weigh between about 180 and 250g/m^2. Singles yarn in warp and weft, together with warp sizing, are often used in Japan to produce fabrics of the required weight from a mixture of coarse and fine wool (or mohair) often a relatively fine wool is used in the warp and the coarse wool (or mohair or blends of wool and mohair) in the weft, the warp can either be two-ply, Sirospun or sized singles, while the weft is generally singles. Stiffness in the weft direction causes a more tubular fabric around the arms and legs, keeping the fabric away from the limbs, thereby leading to greater comfort. In Japan the fabric is often singed and set under warp tension, the latter accentuating the weft crimp. Polyester in the warp could lead to improvements in the fabric wrinkling performance, because the warp is more often creased during wear. **Kawabata** *et al*[843] reported on the use of objectively measured properties (Kawabata system) of summer (tropical) suitings, including mohair/wool blend weft and 22μm merino wool warp, to design tropical fabrics.

Malcik[661] compared the abrasion results obtained on a range of fabrics, including rayon/mohair, when using different abrasives.

In a comprehensive study, **Hunter** *et al*[716] investigated the effects of mohair fibre properties, particularly diameter and length, and yarn twist on the physical properties of plain and twill weave mohair and mohair/wool fabrics. They concluded as follows: Fibre length generally had little effect on the fabric physical properties, where-as fibre diameter in most cases had an important effect. Drape coefficient, stiffness, abrasion resistance and hygral expansion increased with an increase in fibre diameter, while wrinkle recovery (IWS Thermobench and AKU methods), shrinkage (felting and relaxation), strength and extension decreased with an increase in mean fibre diameter[716]. Fibre length and yarn twist, within the ranges covered, generally had little effect of any practical consequence. It also emerged that once differences in mean fibre diameter were allowed for (ie corrected for) there was little difference between the fabrics containing Kid, Young Goats and Adult Mohair. Fig. 67 illustrates some of the main trends.

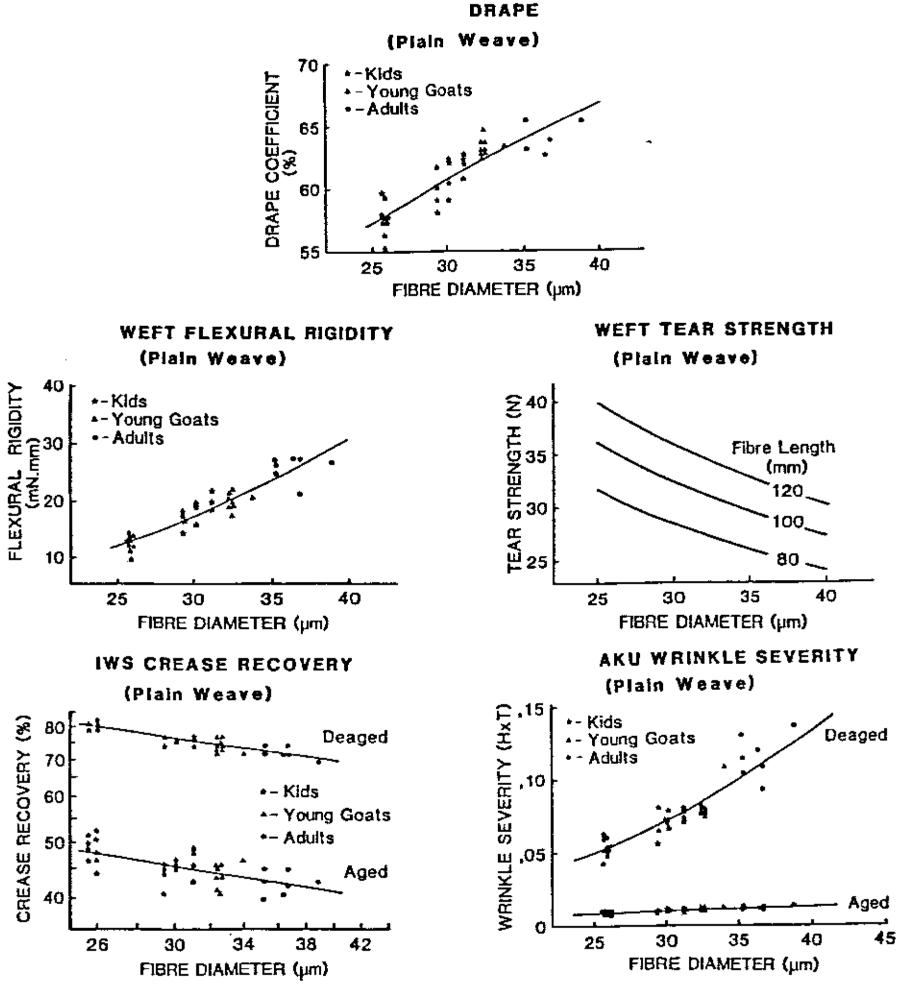


Fig. 67 Effect of Fibre Diameter on Certain Woven Fabric Properties[716].

Fujiwara[591,778] showed, how a high quality (good tailorability) mohair/wool fabric could be designed and characterised by objectively measured fabric properties as measured on the Kawabata (KES-F) system. He showed how different parameters, measured by means of the Kawabata system, could be used to distinguish between "good" and "bad" mohair fabrics. For example, the "good" fabrics had shearing (G) values lying between 0.4 and 0.6 while the "bad" fabrics generally had values greater than 0.6.

Galuszynski and Robinson[825] investigated the making-up of mohair/wool blend fabrics, recommending the chainstitch for reducing seam pucker due to the sewing thread. **John Foster and son**[1082], said to be the world's largest producer of mohair cloth, of which some 55% goes to Japan, has recently installed a computerised integrated manufacturing (CIM) system at their mill in Yorkshire.

*21.2 Woven Fabric Objective Measurement**

The objective measurement of those fabric properties important in the making-up (tailorability) and in the appearance of the garment after making up as well as those playing a role in fabric handle are increasingly being measured. Two systems of fabric objective measurement, namely Kawabata (KES-F) and FAST, have reached the market. **Carnaby** *et al*[668] **and Kawabata** *et al*[843] reported on the use of objectively measured properties (Kawabata system) of summer (tropical) suitings, including mohair/wool blend weft and 22μm merino wool warp, to design a suitable fabric.

Fujiwara[591] described the design of a mohair blended fabric, with emphasis in the control of fabric handle and quality by objective measurement. He also showed[778], how a high quality (good tailorability) mohair/wool fabric could be designed and characterised by objectively measured fabric properties as measured on the Kawabata (KES-F) system. He showed how different parameters, measured by means of the Kawabata system, could be used to distinguish between "good" and "bad" mohair fabrics. For example, the "good" fabrics, had shearing (G) values lying between 0.4 and 0.6 while the "bad" fabrics generally had values greater than 0.6. The fabric objective (Kawabata system) measured properties of a mohair/wool tropical suiting fabric was given[959,960], and so, too, the related yarn properties[960].

Niwa *et al*[1019] reported on the important handle, suit appearance and other objectively measured characteristics of a high quality mohair/wool tropical suiting fabric, using the Kawabata system of fabric objective measurement. Properties of particular importance included high SHARI (a cool feeling coming from a pleasant rough surface touch) and moderately strong KOSHI (springy stiffness) and/or HARI (spread/anti-cling), the latter being important for producing an air space between the fabric and the skin of the wearer. The TAV (Total Appearance Value) derived from the Kawabata system of fabric objective measurement provided a means of predicting suit making-up performance and appearance, with a value of 5 being excellent and 1 poor[1019].

Smuts *et al*[1036] reviewed the work published on the objective measurement of fabric properties, principally by the Kawabata KES-F and the FAST system, including a limited amount of work done on wool/mohair tropical suiting fabrics which had the desired crisp (SHARI) handle.

*See also previous section.

21.3 Wrinkle Recovery

Mohair is widely accepted to have very good *wrinkle resistance and recovery*, which, together with its stiffness, makes it an ideal fibre for use in comfortable light-weight tropical type fabrics. **Bowring and Slinger**(175), studying tropical suitings comprising intimate blends of wool and mohair, found that the AKU and Shirley laboratory wrinkle recovery tests showed opposite trends with variations in mohair content. In the case of the former, the wrinkle recovery deteriorated with an increase in mohair content (possibly due to concomitant changes in yarn crimp)(183) where-as the Shirley test showed the opposite trend. The authors(175) stated that the Shirley values were largely determined by the flexural rigidity and yarn crimp and that the AKU results were better correlated with wear performance. They also stated that finishing procedures could overshadow any trend due to mohair content.

Slinger(245), quoting **Krasny**(114), stated that mohair tended to produce creases of a rounded nature and as a result, they performed well in terms of appearance during wear. **Slinger**(245) found no consistent differences in the wrinkle recovery (AKU, FRL and Shirley methods) of fabrics containing merino, mohair and Corriedale, and concluded that fibre characteristics, such as fineness, had little effect on laboratory measured wrinkling. A limited wearer trial by **Slinger**(245) indicated an improvement in fabric appearance with decreasing mohair content. As expected, coarser fibres led to stiffer fabrics, there appearing to be little difference in the stiffness of wool and mohair fabrics when fibre diameter was constant. **Krasny and O'Connell**(151), on the other hand, had previously found that the Monsanto crease recovery and the wear wrinkling of a wool/mohair fabric were superior to those of an all wool (finer wool) fabric. Nevertheless, differences in fabric mass, pick density and thickness and in yarn linear density could have contributed to the observed differences(476).

O'Connell *et al*(300) reported that the wrinkle recovery properties of durable-press fabrics in blends of mohair, rayon and polyester, were excellent, the *finer mohair having superior Monsanto crease recovery properties to those of* the two coarser mohair lots. **Thorsen** *et al*(401) found that Corona treatment reduced the crease recovery of fabrics containing mohair, possibly due to associated increase in interfibre friction (and frictional restraining couple).

Kelly(396) investigated the correlation between different laboratory measures of wrinkle and crease-recovery, for a wide range of fabrics, including a limited number of mohair/cotton/polyester fabrics. **Kelly** also showed(454) that the wrinkle recovery of mohair blend fabrics improved with ageing (ie storage). It is important to note that the wrinkling of mohair(454), as in the case of wool, is *very adversely affected by "deageing", in which the fabric has been steam* pressed, immersed in water or subjected to other large changes in regain and temperature. A significant improvement in wrinkle recovery may be obtained by allowing the fabric to "age" for several weeks (or months) after such a process. Similar improvements in wrinkle recovery can be achieved by rapid ageing (termed annealing) under appropriate conditions of high temperature and regain(480). Nevertheless, such processes of "ageing" or "annealing" are generally not permanent, being largely nullified by any subsequent changes in moisture content and temperature.

Robinson *et al*(424) also reported better AKU wrinkle recovery for wool than for mohair/wool fabrics, as well as a noticeable effect of finishing on wrinkling(424), differences in yarn twist could have played a role, however(480).

Hunter *et al*[480] undertook a limited study on the effect of fibre diameter on the wrinkling of all-mohair and mohair/wool fabrics. Four mohair lots, varying in mean fibre diameter from 24.7 to 30.2μm, were processed into 50 tex S 380 and 50 tex S 640 yarns. The 50 tex S 380 yarns were woven, as weft, into plain weave fabrics ($\pm$ 200 g/m^2), a R40 tex/2 all-wool warp comprising a 64's quality wool being used. This meant that the fabrics comprised a 55/45 mohair/wool blend. Two of the 50 tex S 640 yarns were woven, as both warp and weft, into all-mohair cavalry twill weave fabrics ($\pm$ 280 g/m^2). When all other factors were kept constant then, contrary to general opinion, an increase in fibre diameter resulted in a slight deterioration in fabric wrinkle recovery as determined by the IWS and AKU test methods, although the results were not always consistent and were probably of little practical consequence. The wrinkle recovery performance of fabrics containing mohair relative to that of all-wool fabrics depended upon the particular test method used. For the IWS test, the fabrics containing mohair performed better than the all-wool fabrics while the reverse was generally true for the AKU test. This illustrates the danger of relying on only one laboratory wrinkle recovery test method since it could lead to erroneous conclusions. The heavier all mohair twill weave fabrics ($\pm$ 280 g/m^s) generally performed better than the lighter mohair/wool plain weave fabrics ($\pm$ 200 g/m^2) as far as wrinkle recovery was concerned. It was confirmed that "ageing" of the fabrics effected far greater improvements in wrinkle recovery than could be achieved by changing fibre diameter, blend or fabric structure, and the disadvantages of using coarser mohair fibres outweighed the advantages in the case of the yarns and fabrics studied[480].

In 1985 **Hunter** *et al*[717] summarised the work done to date at SAWTRI on the wrinkling of wool and mohair fabrics. They concluded that both in the case of mohair and wool, there was generally a trend for laboratory measured wrinkle recovery to deteriorate with an increase in mean fibre diameter, the trend being least pronounced and often absent for the Monsanto test. In the case of the IWS and Monsanto Tests, the mohair fabrics (ie mohair weft and wool warp) generally performed better than similar all-wool fabrics containing wool fibres of the same diameter as the mohair. For the AKU test, however, there was little difference between the wool and mohair fabrics of the same diameter. This once again illustrated the fact that different laboratory test methods can produce contradictory trends. The above-mentioned trends are illustrated in Figs 68 and 69. In this study it was found that the different atmospheric conditions (ie "standard" and "non-standard") generally produced similar trends in terms of fibre diameter.

Smuts[914,966] reviewed the research done on the wrinkling of wool and also reported some studies undertaken at SAWTRI on the wrinkling of wool/mohair blends. The main finding was that when using laboratory tests, such as the AKU or IWS (Thermobench) Wrinkle Recovery Tests, laboratory measured wrinkle recovery was mainly affected by the state of ageing (ie aged or deaged), but also tended to increase with a decrease in fibre diameter, the latter contrasting with popular belief. There appeared to be little difference between the wrinkle recovery of wool fabrics and that of mohair fabrics of the same fibre diameter, with the twill weave fabrics slightly superior to the plain weave fabrics. In a comprehensive study, **Smuts and Hunter**[1050] reported on the effects of fibre diameter and other properties of wool and mohair on the wrinkle recovery of mohair and mohair/wool fabrics as assessed by means of different laboratory instruments. They also found that laboratory wrinkle recovery tended to dete-

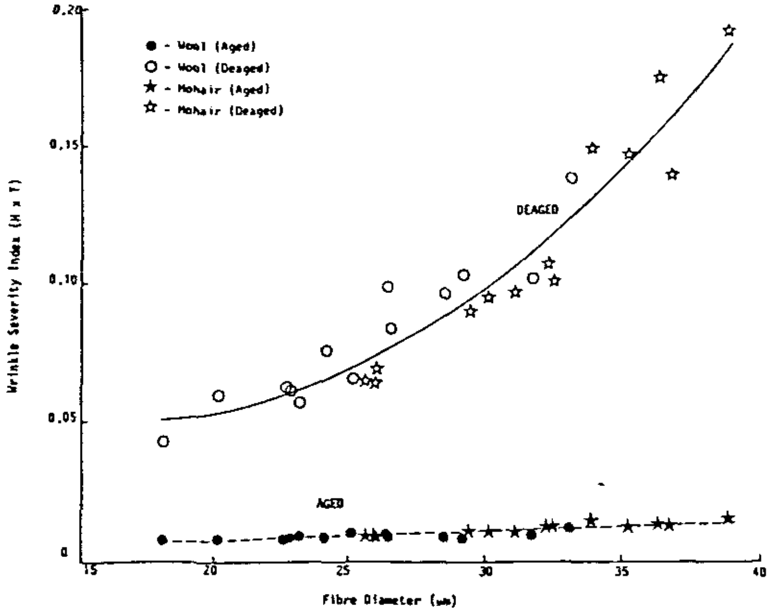


Fig. 68 AKU Wrinkle Severity Index vs Mean Fibre Diameter (Plain Weave : Weft Direction)(717).

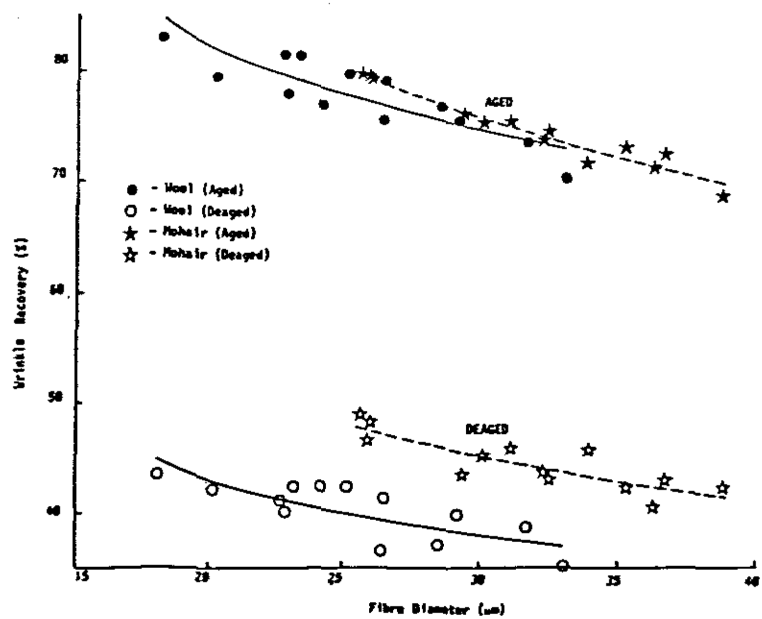


Fig. 69 IWS Thermobench Wrinkle Recovery vs Mean Fibre Diameter. (Plain Weave : Weft Direction)(717).

riorate with an increase in fibre diameter, the difference in wrinkle recovery of mohair and wool not being consistent, depending upon the state of ageing and the particular laboratory test method used (Figs 68 and 69). Nevertheless, the effect of fibre diameter was relatively small for aged fabrics, and ageing had a far greater effect on wrinkle recovery than fibre diameter[1050]. The crease (wrinkle) recovery versus diameter results of Kids, Young Goats and Adults appeared to lie on the same line (see Fig. 70).

To manufacture tropical lightweight (140g/m²) men's suitings from a blend of mohair and other fibres **Robinson and Silver**[369] employed a warp of polyester/cotton (50/50) and a weft of mohair 56%. No trouble was encountered with the weaving of the resultant cloth but it became apparent that because of the presence of cotton the wrinkle resistance of the cloth was poor[366,369]. To overcome this problem, use was made of a range of resins (polymers) which could possibly improve wrinkle resistance. The cloth was subjected to the following finishing procedures: crabbing, full width piece scouring, steaming and brushing, cropping, blowing and pressing. It was found that application of a Silicone resin led to excellent wrinkle resistance. In addition, the handle of the treated fabric was soft. After the treated cloth had been washed in an automatic washing machine, the wrinkle resistance was so good that pressing or ironing was unnecessary.

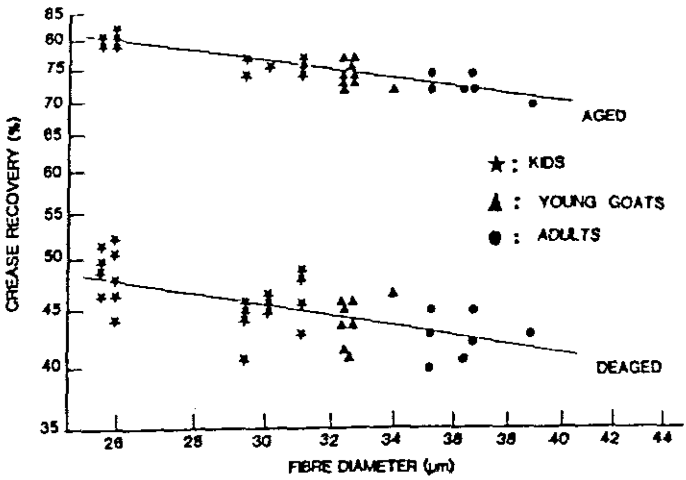


Fig. 70 Crease Recovery versus Fibre Diameter[716].

CHAPTER 22

KNITTING AND KNITTED FABRIC PROPERTIES

22.1 General

Mohair is used to great advantage in knitwear, particularly to impart a soft, lustrous and brushed ("woolly") appearance. Knitwear traditionally represented some 80% of mohair's outlets, but this sector is fairly sensitive to cyclical fashion changes. Historically large quantities have been used in ladies sweaters, the brushed appearance being typical, producing a highly lustrous fabric[581]. Mohair is often used in various blends with other fibres, such as wool, cotton, acrylic, nylon, silk, alpaca, angora rabbit hair, and polyester (often multifibre blends).

Originally mohair yarns were not considered suitable for machine knitting due to protruding hairs (fibres) or loopy yarns catching on the needles but, this can be overcome, and mohair yarns are widely used in machine knitting[281]. When brushed mohair yarns are used for machine knitting[674], it can sometimes lead to difficulties if the surface hairs become trapped in the needles, causing end-breakages[304]. Loop yarns can be knitted on coarse-gauge machines and laying in of coarse mohair yarns, and then brushing the fabric, is also possible. The shaggy brushed look has always proved popular in knitted mohair garments[304], this often being produced from yarn which is teazled after spinning. For machine knitting yarns, mohair is generally used in blends with either wool or acrylic[425] (or both), low "yarn-to-metal" and "yarn-to-yarn" friction facilitating the machine knitting of mohair.

According to **Reichman**[167,177], for good knitting of speciality fibre yarns, it is important to begin with properly wound cones, which are free of winding defects. Backwinding the yarn may be advisable to remove knots, faults and weak places and to add wax. Mohair blend yarns can be knitted on V-bed and circular machines. Dyed yarn should be waxed prior to knitting. Two-ply yarns are preferred from the point of view of pilling resistance, and stitch uniformity, although to save costs, two or three ends of yarn are often knitted. Fabric spirality could result from knitting singles yarn into a single jersey construction. A cationic softener is often applied during garment dry-cleaning or scouring to give the desired softness[167,177].

For knitting, the following mohair yarns have been used:

1) Loop yarns produced on novelty twisting equipment from 100 tex to 450 tex (more usually 180 to 210 tex)[66]. Sometimes 155 tex mohair yarn is fed with an R90 tex/2 worsted spun yarn.
2) Worsted spun yarns in which mohair is blended with wool. Linear densities are R160 tex/2 to R90 tex/2[66], usually one end of the former and two ends of the latter.
3) Woollen spun yarns, often produced from sweater clips of wool and mohair blends (often in either 15/85 mohair/wool or 25/75 mohair/wool).

Where heather effects are desired, mills have blended mohair with acrylic (eg Orlon)[66].

As already mentioned, mohair knitting yarn can be either looped and brushed fancy/novelty yarns, worsted spun (usually blends of mohair and wool) or woollen spun. The first mentioned can vary in composition from about 60 to 90% mohair (the binder and ground yarns being nylon and wool). Brushing of the garment can also take place. For example, all mohair or mohair/wool worsted fluffy yarn has been used in machine knitting[88], as well as mohair/space dyed acrylic[950], and 24% mohair/54% acrylic/22% polyester (also in a multi-coloured tweed effect). Knitted fabric has also been produced on two-needle bar Raschel[71].

The medium grades of mohair (24's, 28's, 32's and 36's) are mainly used in knitted outerwear, often knitted on 4 gauge V-bed machines (eg half-cardigan)[66]. Single ends (310 tex) mohair loop yarns can be fed together with a single end of two-ply worsted yarn (R90 tex/2) to the knitting machine or two ends of R90 tex/2 worsted mohair yarn (or alternatively one end of R160 tex/2). For machine knitting, 36 to 37μm mohair has proved fairly popular[1024], with 37 to 39μm being used for hand knitting, often in a blend of 80% acrylic/20% mohair. It has also been reported that up to 20% of 29/30μm mohair was blended with 35μm wool to produce hand knitting yarn. Kid and Young Goat mohair is used in machine knitting and Young Goat and even Adult hair in hand knitting. With the trend towards softness and lightness, more and more Kid mohair (and Young Goat mohair) has found its way into the knitting trade, even for the brushed look[1024].

Hunter[269] investigated the influence of different blends of wool and mohair, yarn friction, yarn linear density, amount of paraffin wax applied to a yarn, re-waxing, knitting speed and pre-tensioning weight on the stitch length and variation in stitch length obtained on a fully fashioned plain machine. He found that the stitch length and its variation were largely independent of mohair content but depended upon yarn friction and pre-tensioning weight. The lowest friction and CV of stitch length and longest stitch length occurred at a paraffin wax level of about 0.6μg/cm. Clearly, therefore, efficient control of yarn friction, by even and optimum application of paraffin wax, was important in terms of obtaining a uniform stitch length and therefore also uniform garment dimensions.

Hunter *et al*[303] investigated the dimensional stability of various blended mohair/wool plain single jersey fabrics during machine washing and tumble drying. It was found that the pure mohair fabrics showed little sign of felting shrinkage but exhibited loop distortion (cockling), felting shrinkage decreasing and cockling increasing as mohair content increased in the mohair/wool blends. Loop distortion was particularly severe during solvent dyeing. It was found that cockles occurred in the fabric where the yarn segment had a relatively high linear density and a relatively low twist. It was postulated that the loop distortion (cockling) was related to short-term variation in yarn torque, introduced (or at least aggravated) during the actual knitting, and was related to short term yarn irregularity and possibly fibre diameter. Various ways of reducing the cockling were investigated. Autoclave setting (for 2 minutes at a pressure of 34.3 kPa) was found to eliminate cockling[303]. **Robinson and co-workers**[410,500] also concluded that it was mainly yarn irregularity, often associated with coarse fibres, which was responsible for the cockling of single jersey fabrics, with cockles being associated with localised high yarn linear density and associated low twist.

Robinson and McNaughton[344] described a special technique of producing mohair pile fabric, suitable for rugs, on a sinker wheel knitting machine (26-gauge), where about 30% of twisted mohair roving (600 tex, 67 turns/m) was incorporated into every fourth stitch, with the other 70% being laid-in. The roving twist and fibre length ensured that all fibres were securely held in the fabric.

Lambert[402] described work carried out to develop 100% mohair fabrics which could be suitable for upholstery in automobiles and furniture, in one instance using 80 tex worsted yarn on an 8 gauge single jersey machine. This fabric was found to he unsuitable because of poor abrasion resistance and he recommended that fabric for such an end-use would need to be tightly knitted or woven from finer yarn.

Smith[483] discussed the knitting and other properties of yarn comprising a blend of high-bulk acrylic and mohair, the acrylic shrinking during heat treatment increasing the yarn bulk and forcing the mohair fibres to the yarn surface, thereby giving good aesthetics. Brushing or tumbling the fabric can increase the surface hairiness if so desired. Such yarn is also cross-dyeable.

Kennedy-Sloane[400,405,406] discussed designing knitted outerwear on hand flat V-bed machines, using mohair yarns in certain cases, and also carried out a detailed study[425] of the use of mohair yarns on V-bed machines. She reported as follows:

Three basic types of mohair knitting yarns are produced[425]:

i) Loopy mohair yarns made on novelty twisting equipment.
ii) Worsted spun yarns in which mohair is blended with wool or acrylic.
iii) Woollen spun yarns produced from sweater clips of wool and mohair blends.

The fancy loop yarns vary in mohair content from a low of 66% to a high of 92%, with nylon as a binder. With worsted spun yarn the mohair content varies from about 15 to 40%, the wool generally being of medium grade (54's), although occasionally it is of a 60/62's quality[425]. The woollen spun yarns generally have the lowest mohair content. A large percentage of mohair yarns are produced in brushed form, either by brushing the conventionally spun yarns, or by raising the fancy twisted loop yarns. Heather effects are produced by blending mohair and acrylic and then dyeing either the mohair or the acrylic components. In the 1950's mohair was knitted on a 4 gauge V-bed flat machine in a Half Cardigan structure[425]. Knitting open lacy structures is an effective way of utilising brushed mohair yarns, they can also be used in 1x1 rib structures which can be slightly raised (eg hand-teazling) to create a pile. The actual knitting of fancy mohair yarns on V-bed machines is facilitated by the yarn being fed in under minimum tension and using a loose cam setting (ie a low cover factor)[425]. Loop yarns can cause difficulties with the loops catching in the needle hooks, but this is reduced by knitting every alternate course with a smooth yarn of the same colour.

Kennedy-Sloane[425] tabulated the following yarn linear densities for V-bed knitting:

TABLE 95[425]

YARN LINEAR DENSITIES FOR V-BED KNITTING

	5 Gauge	7 Gauge	10 Gauge
Coarse	R 295 tex/2	R 177 tex/2	R 98 tex/2
Medium	R 222 tex/2	R 127 tex/2	R 80 tex/2
Fine	R 177 tex/2	R 98 tex/2	R 68 tex/2

For 6 gauge R177 tex/2 and for 8 gauge R 98 tex/2 yarns appeared suitable.

An optimum tightness of 13.5 for the rib and cardigan structures and 11.6 for the plain single jersey were suggested.

Hunter *et al*[520] found that fibre diameter, rather than fibre length, had the main effect on 1x1 rib knitted fabric properties, with fabric thickness, drape coefficient, stiffness and air-permeability increasing with increasing fibre diameter.

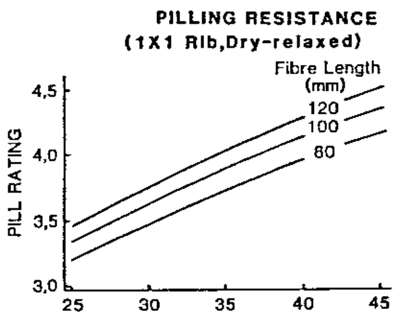
Goen[581] reported on the properties of mohair/cotton (10 to 40% mohair) fabric knitted without much difficulty into 1x1 rib on a V-bed and circular machine, it being found that the 40/60 mohair/cotton blend when dyed with an acid dye, produced a stylish heathered effect for a knitted sweater fabric[581]. Bursting strength decreased with increasing mohair content. **Goen**[763] and **Goen and Lambert**[663,682] reported on the knitting of wool, mohair (31μm and 90mm) and cotton yarns, using alternate cones of each type on a circular knitting machine, to produce a heathered effect after dyeing. The fibres were processed into 33 tex mohair and mohair/wool yarns which were knitted into 1x1 La Costa knit fabric on an 18 gauge (npi) circular machine. The heathered effect so produced was not as sharp or attractive as that produced by an intimate blend.

Georgiev[660] discussed the quality and use of mohair and other knitting yarns, and also reviewed various unconventional spinning systems, such as Novacore and Parafil.

Fried[482] reported on the laying in on circular single jersey machines involving mohair yarn producing pile and brushed surfaces. The physical properties of single jersey fabrics knitted from 80/20 mohair/wool, 60/40 mohair/wool, 40/60 mohair/wool and 50/50 mohair/silk have been compared [726].

Hunter *et al*[716] undertook a comprehensive investigation into the effects of mohair fibre properties on knitted (1x1 rib and plain single jersey) fabric properties. Using multiple regression analyses, they isolated and quantified the effects of the various fibre properties on knitted fabric properties such as pilling, drape, stiffness, bursting strength and washing shrinkage. They presented regression equations whereby the effects of changes in the various fibre properties can be calculated and predicted, illustrating some of the main trends graphically (see Figs 71 to 73). They found that for the knitted fabrics, fibre

EFFECT OF MOHAIR FIBRE PROPERTIES ON FABRIC PROPERTIES



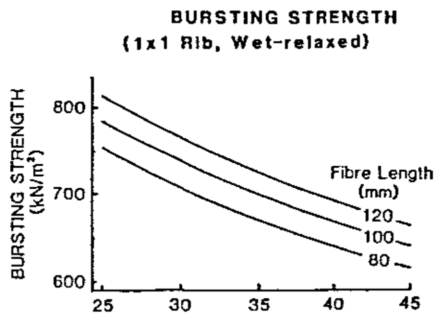


Fig. 71 Pilling Resistance (1x1 Rib, Dry-Relaxed)[716].

Fig. 72 Bursting Strength (1x1 Rib, Wet-Relaxed)[716].

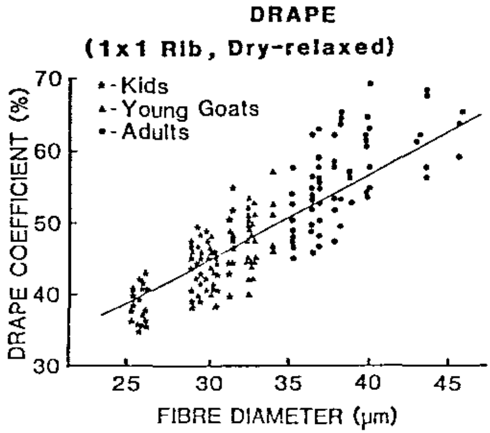


Fig. 73 Drape (1x1 Rib, Dry-Relaxed) [716].

diameter tended to be far more important than fibre length in explaining the variations in the fabric properties, with pill rating (ie pilling decreased), drape coefficient and stiffness all increasing with an increase in mean fibre diameter, the reverse being true for bursting strength and washing shrinkage[716].

Robinson and Shorthouse[720] reported on development work aimed at producing mohair yarns suitable for machine knitting into plain single jersey fabrics free from cockles. Friction spun yarns showed considerable promise and a 300 tex mohair blend yarn, comprising an outer sheath of mohair and a bi-component core of a woollen spun yarn and a polyester filament (textured) yarn, was subsequently developed. The yarns were knitted on a 5 gauge flat bed machine into single jersey. The knitting performance of these yarns was satisfactory and the garments were free from spirality and cockling and had good cover and excellent dimensional stability[720].

The availability, properties and applications of various types of knitting yarns, including mohair, have been discussed[750a].

A BTTG report[906] to the IMA lists the various mohair yarns (blends, yarn counts etc) used in knitting (hand, domestic, hand machines, commercial hand flat machines and commercial powered rectilinear machines) of various gauges. For fully-fashioned knitting, the following finishing route is given:

Make up garment -> Solvent Scour (optional) -> Brush -> Frame and Steam Press to size.

For "Cut and Sew" garments, finishing is as follows: Brush fabric (as required) -> Steam Relax fabric -> (perhaps Solvent Scour and Relax) -> Cut and Make up Garment -> Finish Press.

Jacobsen *et al*[1078] recently investigated the psychophysical evaluation of the tactile qualities of hand knitting yarns (including mohair) in ball and fabric states, applying various objective measurement techniques (eg KES-F3 compression).

22.2 Co-We-Nit

Work was carried out at SAWTRI over a number of years[200, 215,227,229,231,232,234,236,246] to explore the potential of the Co-We-Nit techniques (Raschel-fall plate warp knitting and inlay) for producing mohair fabrics suitable for various end-uses. Many new and attractive Co-We-Nit fabrics, such as soft furnishings, curtaining (particularly sunfilter types of fabric), men's shorts and jackets, ladies dress-wear and coatings[246], in mohair (coarser grades), were produced which had good dimensional stability.

CHAPTER 23

DYEING AND FINISHING

23.1 General

Dyeing and Finishing represent crucial stages in the production of mohair products of the outstanding quality and appearance associated with items bearing the label mohair. Although the dyeing and finishing of mohair are similar to those used for wool, there are certain differences (eg mohair does not mill easily)[25] and special precautions are often necessary for mohair, particularly so as to preserve its lustre, brilliant colours and other desirable properties. Although a vast literature exists on the dyeing and finishing of wool, much of which is applicable to mohair, there is not much literature available on the specialised knowledge (conditions and procedures) required for the dyeing and finishing[242] of mohair products, most of such knowledge being a well kept secret.

In 1960 **Villers**[82] summarised the available knowledge on the dyeing and finishing of mohair and gave details of the lustre and general finishing of mohair fabrics, including plush, plush-type imitation furs (eg cut-pile Astrakhans) raised-pile imitation furs and hair inter-linings. A process for the embossing of mohair has also been described in a patent[323]. Top dyeing has been the traditional route for mohair[674] and is considered to lead to the production of hand and machine knitting yarns which are softer, more attractive and with a longer pile[851]. Mohair can, however, be dyed in sliver (top), yarn or fabric form. In sliver (or slubbing) form, pressure dyeing can be employed and it has been shown that mohair fibres which are trapped or bent can be damaged, leading to fibre breakage during subsequent mechanical processing[233], the short broken fibres can also cling to drawing roller rubbers. **Kondo** *et al*[237] found indications that mohair scales are covered by a very thin membrane that has little affinity for dyes and postulated that mechanical processing could cause gaps in the scales of mohair thereby facilitating dyeing.

Acid and reactive dyes are often used to dye mohair[533], **Hill and Bell**[166], (quoted by **Kidd**[418]), reporting that acid dyes tended to be faster to washing when dyed on mohair than when dyed on wool. Industrial experience with solvent dyeing showed that mohair dyes more readily than Lincoln wool[418].

When **Kriel** *et al*[155] compared the dyeing behaviour of wool (20.7μm) mohair (26.8 and 37.7μm) and kemp (67.5μm), large differences in the rate of exhaustion were often observed, although the final exhaustion values generally differed only slightly. Differences in the rate of exhaustion depended upon the particular dyestuff used. In some cases, the rate of exhaustion of the finer mohair was similar to that of the wool and much higher than that of the coarser mohair while in other cases the dyeing behaviour of the two mohairs was similar, with a much lower rate of exhaustion than in the case of the wool. The mohair tended to dye to a deeper shade than the wool. They concluded that when dyeing blends of a 64's wool and BSFK (Kid) mohair, the dyestuff should generally be distributed approximately evenly between the two types of fibres but the mohair will be hypershaded (ie have a greater apparent depth of shade). They found that the dye exhaustion curves of kemp and BSH (37.7μm) mohair coincided completely, although the kemp did not have the same depth of shade as BSH or BSFK mohair dyed with the same concentration of dyestuff[155].

Swanepoel[188] investigated the dyeing behaviour (rates of dyeing and dyed appearances) of wool and mohair, both ranging in diameter from 21 to 30μm. Differences in depth of shade and the rate of dyeing of wool and mohair differed from one dyestuff to another, although the trends were similar for all the dyestuffs. The rate of dyeing of mohair exceeded that of wool of the same diameter, with finer fibres dyeing more rapidly than coarser fibres. The depth of shade of the mohair was greater than that of the wool of the same diameter and containing the same concentration of dyestuff, this being ascribed to the differences in the surface structures of the two fibre types, (ie the more lustrous nature of the mohair fibre surface[188]). For both wool and mohair, the depth of shade of fibres containing the same concentration of dyestuff increased with increasing average fibre diameter. According to **Veldsman**[201], mohair dyes more rapidly than wool of similar fibre diameter, because of its greater ratio of ortho-cortex, and also appears darker for the same dye uptake, because of its higher lustre. **Swanepoel**[191] summarised the current knowledge in the dyeing behaviour of kemp fibres in mohair.

Roberts and Gee[441] compared the dyeing behaviour of mohair with that of Corriedale wool of similar diameter. The rate of dyeing of the mohair was found to be greater than that of the Corriedale wool (see Fig. 74), this conclusion being in line with that of **Swanepoel**[188]. In addition, the equilibrium exhaustion was found to be higher in the case of the mohair. When mohair and the Corriedale wool were dyed to the same nominal depth of shade, differences

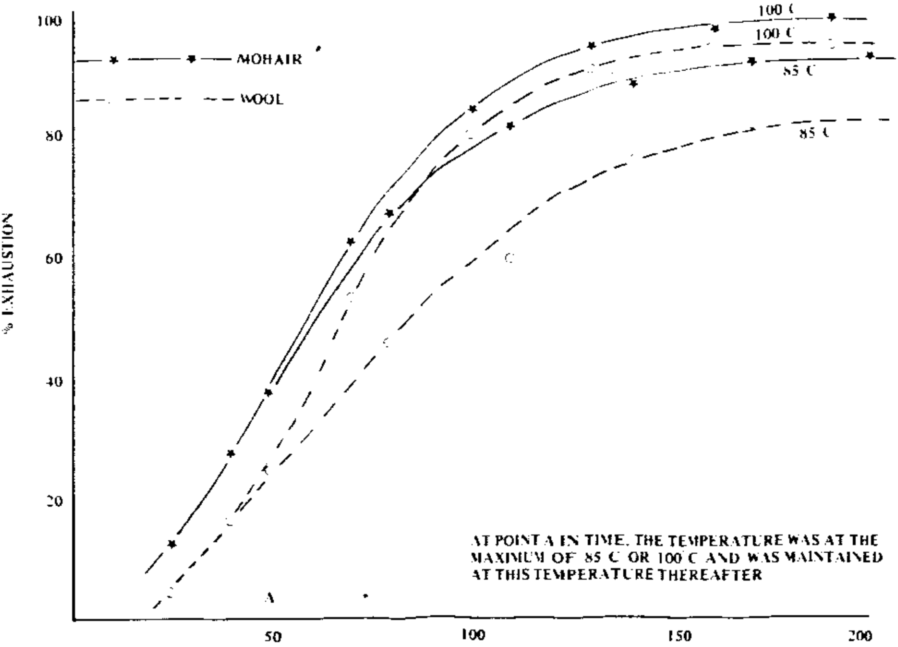


Fig. 74 Rate of Exhaustion of Reactive Red 84 (Lanasol Red 6G) at 1 per cent (omf) on Mohair and Corriedale Wool[441]**.**

in apparent depth of shade were very small when assessed both visually and by an instrumental technique. It was speculated that the frequently claimed greater depth of shade obtained on mohair relative to wool was caused by the greater lustre of mohair relative to that, for example, on merino wool and that, when this lustre difference was absent, the apparent strength difference falls away. The instrumental method gave results which supported the visual assessment.

Roberts[472] compared the wet (washing, rubbing and acid and alkali) fastness properties of mohair and Corriedale dyed with dyes from the acid levelling, 1:2 premetallised and reactive classes to three different depths of shade. They were generally similar, with those of mohair marginally better in some cases.

Galek[505] discussed the dyeing of hand knitting yarns containing mohair, dealing with pre-scouring (eg scouring between tapes in a four bath continuous scouring machine at 40°C), bleaching, dyeing and finishing. The residual oil and grease content of the yarn prior to dyeing should be about 0.3% (often it is about 3% prior to scouring). Bleaching such yarn, if required, would be either by the oxidative (hydrogen peroxide at 40°C) process or the yarns can be softened after dyeing by the reductive (sodium hydro-sulphite at 85°C) process. To achieve a very high level of whiteness, a reductive bleach can be followed by an oxidative bleach together with a fluorescent brightening agent. Because of its uniform physical make-up, mohair does not present any difficulty during dyeing. Dyes usually include equalising acid, premetallised, weakly acid, and chrome dyes, depending upon the shade and depths required. Mohair yarn can also be dyed in its brushed (raised) state. Brushed mohair/nylon yarns give no problems when dyed to medium and heavy shades, but pale shades require a blocking agent as in the case of wool/nylon blends[505]. **Skalmierska and Jurek**[579] discussed the hank dyeing of acrylic/mohair yarns.

Van Rensburg[522] compared the light fastness (fading) of dyes on keratin fibres (mohair, Corriedale, Falkland and merino wool) and found no relationship between lustre and lightfastness, the lightfastness rating or rates of fading being similar for the different fibres.

Veldsman[516] (quoting work by **Barkhuysen and Van Rensburg**) stated that, using liquid ammonia as a solvent, mohair can be dyed within a matter of 5 seconds.

Barkhuysen and co-workers[712,713] compared the dye fixation obtained on mohair by means of radio frequency (RF), exhaust and pad-steam techniques respectively. They found the fixation to be highest for RF. Practically no fibre damage could be detected during RF dyeing, with the fibre strength and quality (eg lustre) of mohair not being impaired. Energy saving of close on 80% could be achieved by using RF dyeing rather than conventional dyeing. RF drying (Fastran) has also been applied to mohair, the drying temperature not exceeding 60°C[927]. The following table[705] illustrates the advantages to be gained from RF dyeing (Table 96).

Van der Walt and Van Rensburg[725] showed that wool and mohair fabrics could be successfully dyed with metal-complex and reactive dyes using a foam applicator, with level and fast dyeings being obtained with wet pick-ups as low as 20%. **Ostervold**[702] described a machine for the vacuum impregnation of mohair/wool and other fabrics which enables wet pick-up to be reduced during

TABLE 96[705]
CONVENTIONAL VERSUS RADIO FREQUENCY DYEING*

	Aqueous (100°C)	RF (100°C)
Treatment Time (min)	90	35 (only 5 mins exposure to RF)
Dye fixation (%)	93	96
Alkali Solubility (%)	14,5	13,8
Urea Bisul. Solubility (%)	51	48
Lustre Value	68,8	96,9
Spinning Potential (MSS, r/min) 92 tex Z320 44 tex Z460	 9400 6300	 9900 8400

* Unpublished work by F.A. Barkhuysen & A.P.B. Maasdorp

dyeing and finishing. **Needles and Wasley**[203] reported on the dye (riboflavin)-sensitised graft photo-polymerisation of monomers (acrylamide and methyl acrylate) onto mohair and other fibres. The solvent dyeing and finishing of mohair and other fibres have been described in various patents[428]. The IWS pad-batch process for the cold dyeing of wool and mohair has been described[371], **Graham**[331] reporting its use for dyeing wool and mohair tops to pale and medium depths. The use of short liquor to goods ratios for the dyeing and finishing of wool and mohair fabrics has been discussed[438]. **Hayes**[617] has described the transfer dyeing, using reactive dyes, of mohair sweaters to obtain intarsia effects, (see also Ref.[486]). **Ingle**[170a] investigated the effect of solvents in the printing of mohair and nylon.

According to work done by **Gandhi**[119], (quoted by **Kidd**[418]) **and Onions**[98] mohair is set more readily than wool, **Onions**[98] stating that the relative ease with which mohair sets, accounts for its use in curled pile rugs and simulated Astrakhan fabrics. **Grenner and Blankenburg**[266] investigated the chemical setting, and associated damage, of crinkled mohair and wool yarns and found that a good degree of set could be obtained by boiling for one hour in a pH range of 4 to 6. This was, however, associated with a relatively high fibre damage in the case of the mohair. Reducing the setting time to 30 minutes led to an improvement in setting with less fibre damage. Setting and dyeing could be combined into one process[293]. **Guirgis and Onions** (quoted by **Leeder** *et al*[1069]) investigated the setting of mohair, wool and human hair.

Hunter *et al*[440] investigated the effect of liquid ammonia treatment on mohair fibre physical properties. Mohair was treated in liquid ammonia for different periods of time, and the effect of both fibre linear density and length of treatment on fibre supercontraction, tenacity, initial modulus, friction and extension at break, were determined (Fig. 75). It was found that, on average, super-contraction, extension at break, fibre linear density and with-scale friction increased with increasing time of treatment, whereas the fibre tenacity and initial modulus showed the reverse trend. Prolonged treatment in ammonia introduced some crimp in the fibres, particularly in the finer fibres, but reduced the lustre of the fibres and also caused some yellowing.

Roberts[434] investigated the effects of processing conditions, such as dry heat, steam, aqueous treatments of different pH and oxidising agents, on the mohair fibre (Young Goats) in terms of mass loss, yellowing and urea-bisulphite solubility. He compared the results with those obtained on a Corriedale wool

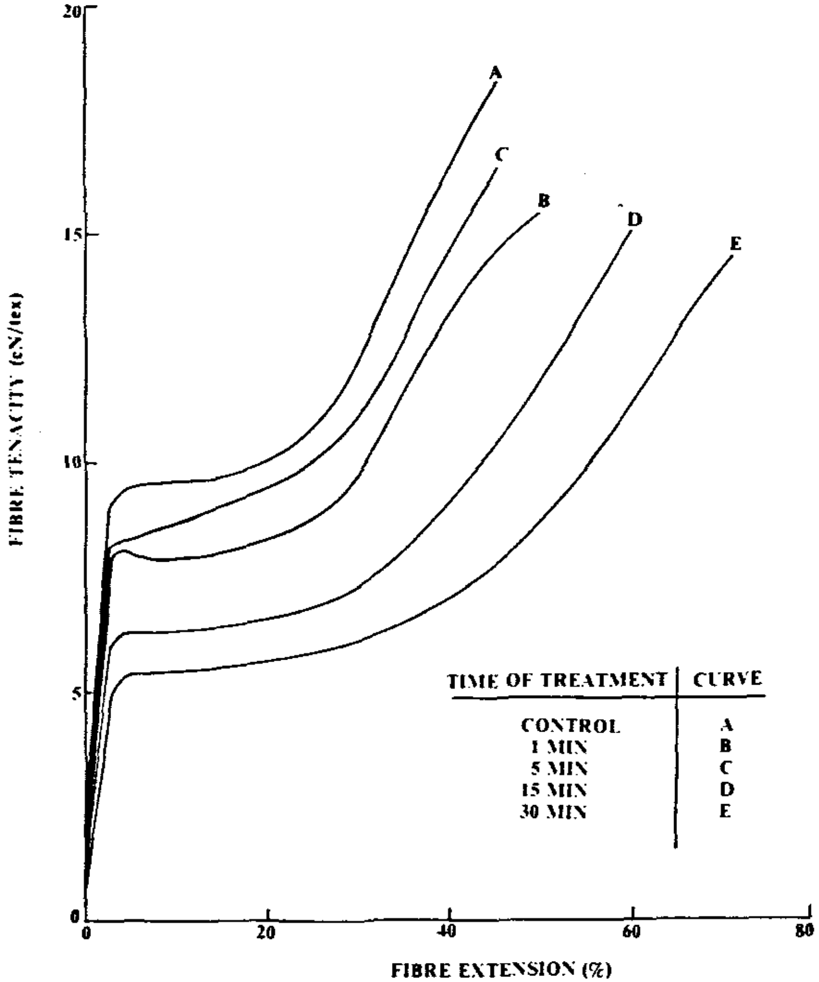
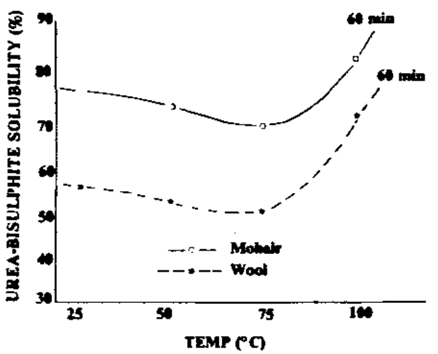


Fig. 75 Typical Load-Extension Curves of Ammonia Treated 10 dtex Mohair Fibres[440].

of the same mean fibre diameter (32μm). He found that the mass loss arising from aqueous treatments was greater for mohair than for wool but there were no great differences in terms of the tendency to yellow. Urea-bisulphite changes indicated that mohair was modified less than the wool under milder conditions but more under more severe conditions[434], the higher ortho-cortex content of mohair possibly being responsible for the observed differences. (Urea-bisulphite solubility of keratin fibres is generally decreased by heat and alkali, while it is increased by acids and oxidising agents, higher values being associated with higher ortho-cortical contents)[83]. Yellowing in a weak alkaline solution depended greatly upon the temperature, increasing greatly at temperatures above 50°C. Some of the results are illustrated in Figs 76 to 81[434].



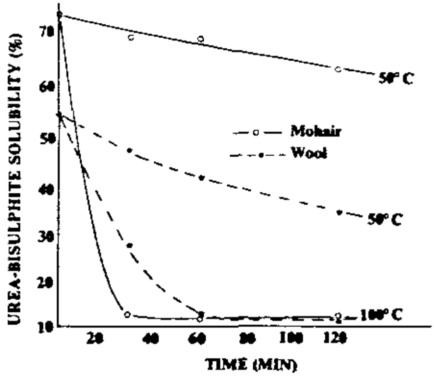
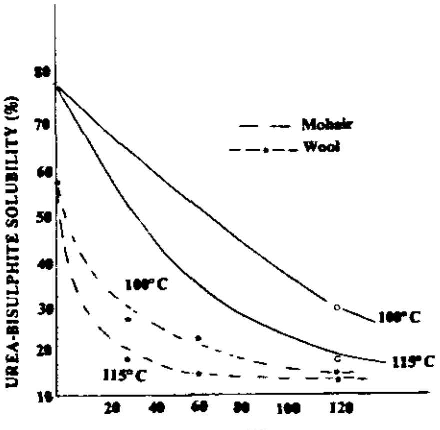


Fig. 76 Effect of Temperature of Strong Acid Solutions on the Urea-bisulphite Solubility of Mohair and Wool[434].

Fig. 77 Effect of Time of Immersion in Weak Alkaline Solutions on the Urea-bisulphite Solubility of Mohair and Wool[434].



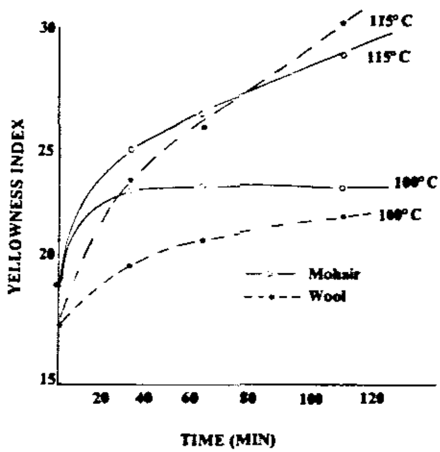
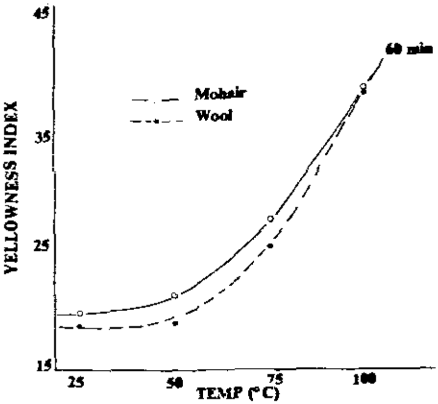


Fig. 78 Effect of Steaming Time on the Urea-bisulphite Solubility of Wool and Mohair[434].

Fig. 79 Effect of Steaming Time on the Yellowness of Wool and Mohair[434].



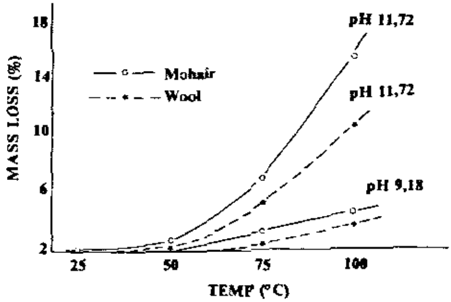


Fig. 80 Effect of Temperature of Weak Alkaline Solutions on the Yellowing of Mohair and Wool[434].

Fig. 81 Effect of Temperature of a Two Hour Aqueous Treatment at Various pH Values on the Mass Loss Suffered by Mohair and Wool[434].

Veldsman stated[201] that the finishing procedure of light weight wool/mohair fabrics is a highly secretive affair and it would appear that reputed firms have constructed special machines (or techniques) to accomplish a highly lustrous, resilient cloth. The following sequence of finishing operations was found to give a commercially acceptable fabric[201]:

Crabbing at the boil
Piece scouring (open width, if at all possible)
Steaming and brushing
Shearing (latter two operations can be repeated, if deemed necessary)
Blowing (decatising)
Hydraulic pressing
Autoclave setting (KD Process).

Schumacher-Hamedat *et al*[839], **Knott**[978], **Bereck**[968], **Sanchez and Guillen**[987] **and Cegarra** *et al*[973] reported on methods of depigmenting animal fibres.

It has been mentioned[1051] that harshness in mohair may be associated with low copper levels (ie copper deficiency). **Swanepoel and Veldsman**[208] described a method of decreasing the roughness (scratchiness) of coarse wool or mohair fabrics by means of an ethylene glycol bisulphite or a polyvinyl alcohol-bisulphite process. **Maasdorp and Van Rensburg**[642] investigated the prickliness of wool and mohair fabrics using a scanning electron microscope to study the surface fibres. They confirmed that the subjective ranking of prickliness increased as fibre diameter increased, and was related to the presence of coarse surface fibres.

Yin[925] investigated the effectiveness of two synthetic pyrethroid moth-proofing finishes on mohair fabrics. **Rivett and Logan**[982] **and Knott and Belly**[661a] discussed the moth-proofing of speciality animal fibres.

The singeing of mohair fabrics[1069] and the drying of mohair (**Smith** quoted[1069]) have been discussed. **Ahmad**[292] investigated rates of sorption of a number of organic solvents and reagents by mohair and their effect on the mohair fibre mechanical properties. He found that the imbibition values of Lincoln wool were slightly greater than those of mohair for all the reagents studied. The mohair fibres were weakened (as revealed by work to break) when they were immersed in the various reagents.

O'Connell *et al*[300] investigated the durable press treatment of mohair/polyester/rayon blend fabrics (230g/m) for use in men's slacks. The treated fabrics, and garments, were stable and smooth following machine wash and tumble drying. No shrink-resist treatment was necessary to stabilise the fabric to washing shrinkage. They[300] suggested that blends of mohair/polyester and rayon produced excellent menswear slack material, particularly when given a durable-press treatment. **Van Rensburg**[465] investigated the durable press treatment of a cotton(warp)/mohair blend (RWCS weft) fabrics, by means of DMDHEU and melamine resins.

Various articles[607,636] gave details of machinery suitable for the dyeing and finishing (including scouring) of fabrics containing mohair while others discussed[275] the finishing of mohair and mohair blend fabrics and the achievement of durable press (DP) mohair blend fabrics[305].

23.2 Light Degradation

Mohair is widely used in curtains and rugs, articles which can be subjected to considerable exposure to light during use, but it generally stands up well to such exposure. **Van Rensburg**[473] investigated the degradation of woven and knitted mohair fabrics by sunlight and ultra-violet light. Results obtained after ultra-violet degradation did not always agree with those obtained after sunlight degradation. The best protection against sunlight degradation was obtained by the application of a polyacrylate pigment binder, an ultra-violet light absorber, or certain dyes. Degradation was assessed in terms of changes in fabric bursting strength and whiteness.

Photo-chemical degradation of mohair appears to be similar to that of wool[56] although **Bruwer and Tait**[972] concluded that wool and mohair fabrics behaved somewhat differently to UV exposure (Xenotest).

23.3 Felting and Shrink-Resistance

Mohair has little tendency to felt or shrink during washing, this being largely attributable to its relatively smooth and unpronounced scale structure[6]. Nevertheless, if washed for prolonged periods or under severe conditions, mohair articles will felt and shrink. **Onions**[98] found a washing shrinkage of 33% for a woven wool fabric and 2% for a comparable mohair fabric, with corresponding values of 23% and 6%, respectively, for knitted fabrics.

Although mohair does not felt easily it can mill sufficiently to give a full cloth with a warm finish[220]. It can also take permanent pleats. **Thorsen and Kodani**[152] used a corona discharge method on wool and mohair tops to improve shrink-resistance. This also increased the sliver cohesiveness (drafting force). **Den Heijer**[138] investigated the conditions necessary in the Aachen felting test in order to produce maximum differences in the felting rate of various blends of wool and mohair in top form, a pH 1.5 being considered best for this purpose. It was found that the addition of as little as 20% of Kid mohair to a 64's quality wool reduced the felting shrinkage of knitted fabric considerably, with the decrease in felting shrinkage decreasing with increasing mohair content. **Greavu and Simion**(356) reviewed some of the factors which affect the felting (Aachen felt ball and other) of various animal fibres including mohair. Residual fatty matter had an effect on felt ball density, felting being lower when the fibres were cleaned. **Mitchell**(821) reported on the felting of machine knitted mohair fabric (eg by washing and drying) to achieve special effects. **Turpie**(705) suggested the use of a gaseous chlorination treatment to eliminate any felting propensity in mohair. **Pittman**(255) found the critical surface tension (CST) for untreated wool and mohair to increase when the relative humidity was lowered, from about 26 dynes/cm for mohair to 45% RH to about 33 dynes/cm at 0% RH, due to the removal of surface water. He also discussed the effect of surface water on the polymer coatings for mohair and wool(255). The CST of Corona treated mohair was 33 dynes/cm at both relative humidities.

23.4 Flammability and Flame Retardant Treatments

Keratin fibres, such as mohair, have traditionally been regarded as being safe from the point of view of flammability. Mohair may be ignited if subjected to a sufficiently powerful heat source, but will normally not support combustion and will smoulder for only a short period after the heat source has been removed. This can be ascribed to the high ignition temperature, low heat of combustion and low flame temperature of the fibre. The natural flame-resistance of mohair is connected with its chemical and morphological structure(357). Mohair was also one of the few fibres which met most of the earlier requirements for flame retardancy for contract markets (eg office furniture, hotels and theatres(1052)). Nevertheless, although, like wool, mohair does not burn easily, it cannot be regarded as completely flame resistant, and flame-proofing is necessary for it to conform to modern specifications(366) for flame resistance. Traditional high-density mohair and wool carpets were acceptable without treatment but fashionable long-pile low-density structures were classed as hazardous, unless specially treated(357).

Due to their inherently flame-retardant nature very little research was done on keratin fibres before 1970. In 1971, however, legislation was introduced in the USA requiring all carpets to pass a flammability test, called the *tablet test*. **Van Rensburg**(357) discussed the flame retardant treatment of mohair fabrics with titanium and zirconium salts according to certain IWS patents, as well as with a commercially available titanium-antimony complex and reported on the effect of three different flame-retardants: titanium tetrachloride, zirconyl chloride and a titanium-antimony complex on the Limiting Oxygen Index (LOI) value, degree of whiteness and certain mechanical properties of mohair fabrics. He found the LOI of untreated mohair fabric to be 24, some of the treatments inceasing it to above 32 (27 generally being regarded as the minimum required for a fabric to pass the vertical flame test). The flame retardants did not appear to affect the mohair fabric physical properties adversely, titanium chloride producing the highest LOI values but discolouring the fabric. Titanium antimony caused less discouloration (giving a creamish colour) but did not increase the LOI as much as titanium tetrachloride. Zirconium containing flame-retardants had the smallest effect on fabric whiteness(357), zirconium chloride (together with 4% citric acid) gave acceptable flame retardancy, which was fast to washing, with acceptable colour.

Veldsman[516] stated that the THPOH/Ammonia process of **Van Rensburg**[408] could be used for mohair, the peroxide used in the final stages bleaching the mohair and giving it a softer handle.

It was also reported[652] that wool and mohair upholstery fabrics were generally sufficiently flame resistant to meet moderate flammability tests such as DOCFF 1-70, DOCFF 2-70 and the Motor Vehicle Standard number 302. These fibres can be ignited, however, if they are exposed to a high temperature heat source, and they do support combustion under bone dry conditions. Consequently, fabrics composed of wool and mohair did not pass the flammability test for children's sleepwear, nor did they meet Federal Aviation Authority (FAA) standards for airworthiness of upholstery fabrics. A 50/50 mohair/Cordelan fabric survived a three-second and twelve-second ignition vertical flame test under bone dry conditions, both initially and after a four-hour boil test which approximated fifty home launderings and was used as a screening test for 50 washings. These results showed that the 50/50 mohair/Cordelan fabric would pass both the DOCFF 3-71 test for children's sleepwear and the FAA standards for compartment interiors[652].

By blending mohair with certain synthetic fibres or cotton, the problem of flammability could become more serious because these latter fibres often burn easily in the untreated state[366].

Fittig[560] reported on the burning behaviour of mohair, cotton, acrylic and polyester furnishings (upholstery). He[603] compared the flammability standards and draft standards for furnishings in various countries giving a table of standards. Tests were carried out on pile and flat woven fabrics, and recommendations were given for reducing flammability of mohair and other fabrics.

CHAPTER 24

FIBRE IDENTIFICATION AND BLEND ANALYSIS

24.1 Introduction

It is for various reasons (eg for labelling and Mark Certification purposes) important to be able to distinguish between mohair and other animal fibres and to be able to quantify the composition of a sample (be it raw fibre, top, yarn or fabric) which reportedly contains mohair (in any proportion), particularly where the mohair is blended with another animal fibre, such as wool. It is hardly surprising, therefore, that considerable research effort has been directed over the years, but more particularly since the early 1980's, towards developing reliable methods for distinguishing between mohair and other animal fibres, for accurately quantifying the composition of blends of mohair and such fibres and for verifying that a sample purported to be pure mohair is in fact so.

Wilkinson[1005] briefly summarised the papers dealing with fibre identification, presented at the Second International Symposium on Speciality Animal Fibres in Aachen in October, 1989. He pointed out that the list of possible techniques was quite long, but shortened if restricted to rapid, inexpensive and internationally accepted methods, shortened further if restricted to fibre mixtures of unknown origin in which suspect contaminants are in low proportion, shortened even further if the fibres or fabrics have been subject to pretreatments and probably obliterated if all the re-strictions are imposed.

Some tool and targets are listed in Table 97[1005].

TABLE 97[1005]
FIBRE IDENTIFICATION TOOLS AND TARGETS*

Tool	Reference	Target
1. Microscopy; light transmission and scanning electron, image analysis	1,2	fibre dimensions
	1,2	ellipticity
	1,2	surface features
	1	pigment distribution
	1	medullation
	1	cortical segmentation
2. Chromatography, electrophoresis	1,2	protein composition
3. High pressure liquid chromatography, gas chromatography	1,2	external and internal lipids
4. DNA hybridisation	1,2	cell nuclear remnants

*1: First International Symposium on Speciality Animal Fibres.
2: Second International Symposium on Speciality Animal Fibres.

Greaves[974] has reviewed the various methods of fibre identification and quantitative analysis of fibre blends. **Hamlyn** *et al*[1059] gave the following table (Table 98) of methods which have been proposed for the qualitative and quantitative analysis if keratin fibres.

TABLE 98[1059]
METHODS PROPOSED FOR THE ANALYSIS OF KERATIN FIBRES

	Reference
Amino-Acid Analysis	985
Scale-Height Measurement	742
Image Analysis	963
PAGE Analysis of Extracted Proteins	905
Internal- and External-Lipid Analysis	852
DNA Fibre-Profiling	892,975

A similar list was given elsewhere[1032]. Each of these will now be discussed:

24.2 Microscopic Methods

24.2.1 General

The first methods relied upon the use of a light microscope to examine the surface scale appearance (prominence, pattern and frequency of scales) of the fibre (eg fibre profile) [174] and then to classify the fibre as mohair or wool depending upon a subjective assessment of the nature, frequency and prominence of the scales. These eventually led to the modern scanning electron microscopic (SEM) methods. **Scheepers**[174], for example, reported on ways of distinguishing mohair from other animal fibres and suggested that the fibre profile was a reliable means of identifying mohair from wool, although he did not recommend the method for routine quantitative analysis of mohair/wool blends. It has been stated[89] that experts were able to detect the presence of wool, even lustre B.A. Wool, in good quality mohair by hand and eye, provided the wool content was 25% or more.

Satlow *et al* [128] investigated microscopic and other ways of identifying and quantifying different types of animal fibres, including mohair, and described a histo-chemical method of doing so, but this method had limitations, particularly for dyed fibres[174]. Round Trials held during the 1970's indicated that inter-laboratory agreement was rather poor when the light microscope method was used to determine the lend composition of wool/mohair blends[1038]. Nevertheless, **Kadikis**[819] contended that light microscopy could be used by an experienced operator to obtain accurate fibre and fibre blend identification, an experienced analyst being able to recognise and distinguish not only wool from speciality fibres but also between speciality fibres themselves. He stated that generally each fibre that may be present in a blend can be identified because each fibre has its own unique set of identifying characteristics, such as scale shape, scale location, distance between scales, changes in fibre diameter, distribution of pigmentation and in some cases fibre medullation. He went on to state[819] that often it was necessary to identify several of these characteristics in a single fibre before a positive identification can be made. Recently, **Wortmann and Wortmann**[1073] again concluded, however, that the SEM method was far superior to light microscopy for wool/speciality fibre blend analysis, particularly in the case of wool/mohair and wool/cashmere blends.

From the various papers presented at the Second International Symposium on Animal Fibres held at Aachen in 1989, **Wilkinson**[1005] summarised various aspects of the microscopic techniques as follows:

Examination of the surface features of fibres, which include scale shape, scale frequency, scale overlap and scale thickness, is a simple, direct procedure. The light microscope has a lower magnification and resolution than the more expensive and slower electron microscope.

The limitations of Microscopy are[1005]:

(a) Natural pigmentation and added dye mask the features.
(b) The features vary along each fibre, between fibres from the same animal and between fibres of the same type grown in different localities.
(c) The features are obscured or removed by weathering.
(d) Identification is too subjective.
(e) There is not full agreement on the extent to which (a)-(d) apply.
(f) Fibre terminology is not agreed. The strict definition applied by some countries to a particular fibre type means for example that white Iranian cashmere is cashmere in Europe and not cashmere in USA.

By assessing and/or measuring a number of surface features, it seems possible to be reasonably accurate in identifying straight speciality fibre lines and some simple fibre mixtures; in the latter case especially if the operator already knows the types of fibres being sought[1005].

The light microscope method of fibre identification is increasingly being replaced by the scanning electron microscope (SEM) method which is based upon differences in the scale thickness (or height) between fibres such as mohair and wool for example. One laboratory claims a high success rate with the scanning electron microscope in identifying cashmere, mohair, camel, llama and yak fibres over an 8 year period. An Interlab Trial illustrated that with practice, operators could successfully identify the proportion of wool and mohair in mixtures. Wool/cashmere mixtures were more difficult to quantify, but there is disagreement between laboratories on these points and indeed on which type of microscope is the preferred tool[1005]. Various forms of data handling improve discrimination, but the future would seem to lie with image processing and analysis and a very large databank for reference and comparative purposes[1005]. This method is discussed later.

24.2.2 Scale Length*

One of the earliest attempts to arrive at a more objective method was based upon reported differences in the scale frequency/length of mohair and wool, as viewed in a light microscope, and various workers investigated this[36,128].

*See Also **"SCALE PATTERN"**.

Although the scale frequency (per 100μm) was at one time used as a basis for distinguishing between wool and mohair (eg ASTM D276-72), that of wool being taken as above 5.5 and that of mohair below 5.5, subsequent work showed that scale frequency was not a reliable means of distinguishing between wool and mohair. According to early work, by **Skinkle**[16] for example, the scale length of mohair fibres was generally above 18.5μm and those of wool below 17μm and he concluded that if in practice, a scale length of 17.0 to 18.0μm is found, the fibre is most probably wool, confirmed by calculating S^3/D (where S is the scale length in μm and D is fibre diameter in μm). If S^3/D is below 140 the hair is wool. If a value for S of between 18.0 and 18.5 is found, the fibre is most probably mohair, this is confirmed if S^3/D is above 160. **Von Bergen**[17,34,202] also stated that the scale length for wool is generally around 10μm (8.5 to 10μm)[978] and that of mohair around 20μm (ie 5 per 100μm), although the scale length values for the long wools and beard hairs of carpet wools are generally similar to those for mohair. **Klenk**[53] also advocated the use of S^3/D for distinguishing between wool and mohair.

In contrast to the above, Mahal *et al*[26] found that S varied from about 10μm to about 40μm for wool, with an average of about 15μm and felt that the scale length (frequency) criterion was not reliable for distinguishing between wool and mohair. **Wildman**[36] also concluded, that neither scale length nor S^3/D was reliable for distinguishing between wool and mohair. The foregoing conclusions were supported by **Langley and Kennedy**[547] who found that, in the case of their samples, Buenois Aires wool had longer scale lengths (19.4μm) than mohair (14.7μm) and also larger S^3/D values. It was also reported[978] that Texas mohair had a relatively high scale frequency[895] and higher than that of Argentinian lustre wool[895,978]. **Kusch and Stephani**[641] also pointed out that, due to breeding, mohair can also have a high scale frequency and this parameter therefore cannot be used to distinguish between wool and mohair.

Mohair is generally more even in profile than either cashmere or camel hair fibres[547], the cashmere fibres having broader, thicker and shorter scales than mohair, cashmere having scales which are, on average, 85% of the lengths of those of mohair but which are thicker, wider and have distinct margins[547].

24.2.3 Scale Height (Thickness)

It is widely recognised that the scales on mohair fibres are generally less prominent (ie flatter or thinner) than those on wool (see Figs 82 to 84) and that it was largely this (together with the generally lower frequency scales) which was responsible for the characteristic lustre and smoothness of mohair and used to distinguish between the light microscopic profile of wool and mohair, although the operator needed considerable experience to be able to do so reliably.

It was the difference in scale height or thickness *h* (see Figs 85 and 86) which eventually led to the SEM method of distinguishing between mohair and wool and of quantifying blends of mohair and wool (even lustre wools). This method is presently, probably the most widely used for quantitative blend analysis of mohair/wool blends. Within this context it is important to note that the subjective method of fibre identification, based upon the microscopic (ie magnified) fibre profile, and the SEM method, are essentially based upon the same premise (viz scale prominence), although the subjective method depends upon the experience and expertise of the operator and tends to suffer from the disadvantages associated with subjective methods.

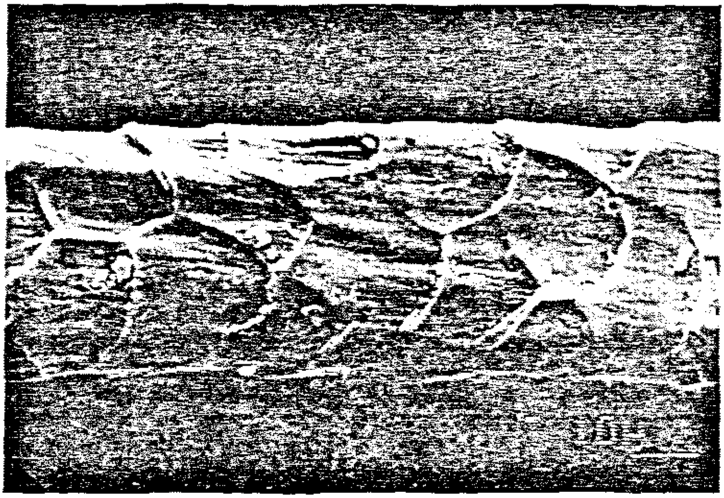


Fig. 82 Typical Scale Structures Of Wool as Viewed by Means of a Scanning Electron Microscope (SEM)[862].

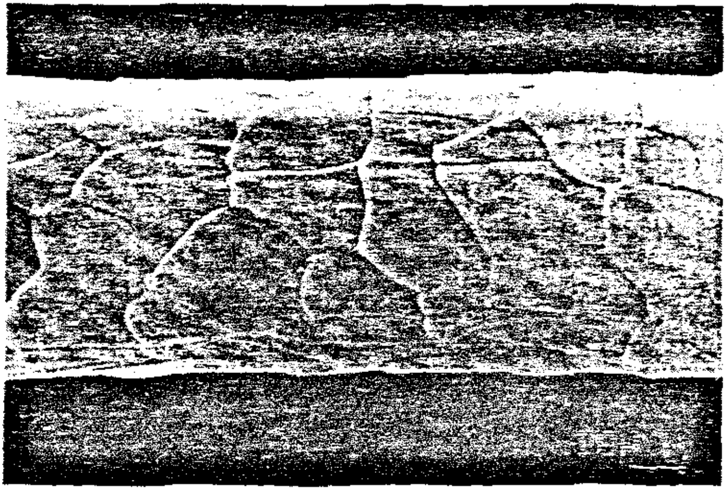
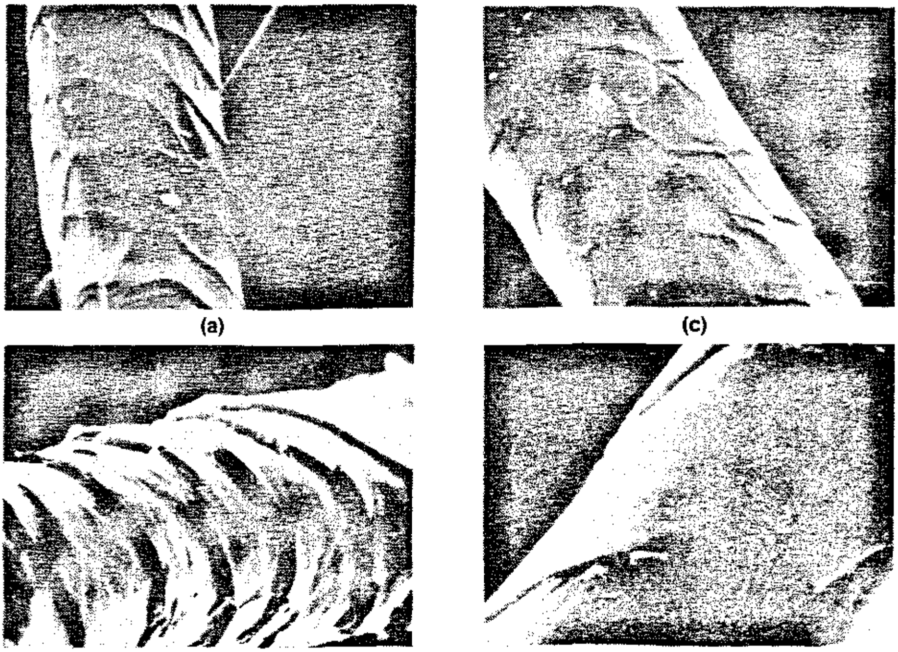


Fig. 83 Typical Scale Structures of Mohair as Viewed by Means of a Scanning Electron Microscope (SEM)[862].



(a) (c)

(b) (d)

Wool Fibres: (a) 1400x*
(b) 3300

Mohair Fibres: (c) 1400x
(d) 3300x

Fig. 84 Scanning Electron Micrographs of Fibres Showing Scale Structures: All Magnification Values Refer to the Original magnification[803,816].

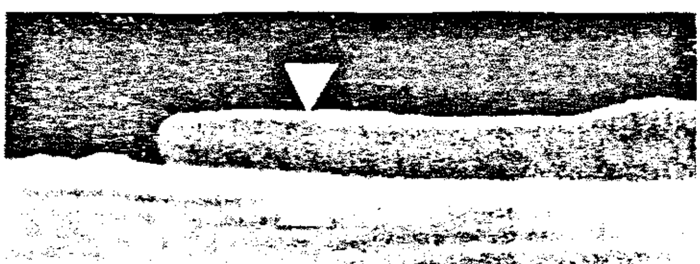


Fig. 85 The Magnified Scale as Viewed by Means of a Scanning Electron Microscope (SEM)[862].

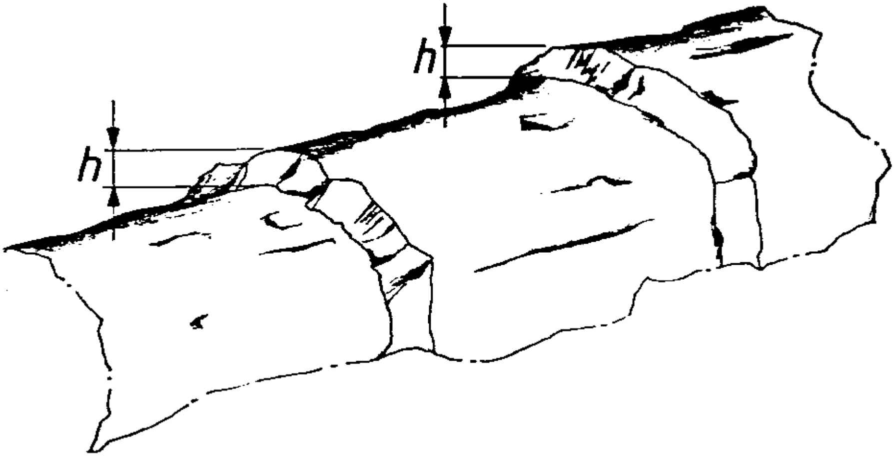


Fig. 86 Scale Height (Thickness), h, of a Fibre(803,816).

In one of the first studies (in 1958) relevant to the use of the scale height (or thickness) methods for differentiating between mohair and wool, **Oster and Sikorski**(65) showed that the scale thickness of merino wool is of the order of 1μm and that of mohair of the order of 0.4μm. **Dobb** *et al*(94) were among the earliest to observe that differences in scale height (distal edge) measured by electron microscopy could be used to distinguish between wool and mohair. Nevertheless, it was not until about 1980 that **Kusch** *et al*(512) used the difference in cuticular scale height, as measured by SEM, to distinguish between wool and goat hair.

Kusch and co-workers(497,512,562,595,614,641) were amongst the first to propose and use the SEM measured scale heights to distinguish between wool and various animal fibres, such as mohair, and to quantify the blend composition of such fibres. The scale thicknesses were measured at a magnification of 25 000 and the fibre diameter at a magnification of 1 000, fibres with a scale height greater than 0.6μm being classified as wool and those with a scale height smaller than 0.5μm as mohair(731,1038). In essence, the SEM method is based upon the fact that mohair scales are generally, but not always (as will be discussed later), thinner (ie have a smaller height or thickness) than those of wool, having an average thickness (height) of around 0.4 to 0.5μm, (0.2 to 0.4μm)(901), while those of wool, including lustre wools (such as Buenois Aires), have an average thickness (height) of around 0.8 to 1.0μm (0.6 to 1.1μm) (65,94,692,743,842,895,901). **Kusch and co-workers**(614,641) found that the scale height for wool ranged between about 0.7 and 1μm, for mohair around 0.5μm or less, for Alpaca around 0.25μm and for cashmere between 0.35 and 0.39μm.

Wortmann and Arns(842,862,879) concluded that the scale heights of speciality animal fibres rarely exceed 0.5μm, (generally 0.2 to 0.4μm)(842) while those of wool rarely fall below 0.5μm, (generally 0.6 to 1.1μm)(842) these rare occurrences being of little consequence in the application of the scale height method for analytical purposes. They found the scale height for the samples of wool they tested to range from 0.4 to over 1.0μm and that of the mohair samples they tested ranging from just over 0.1 to just over 0.5μm.

The following system of fibre classification according to the SEM method was given by **Phan** *et al*[895].

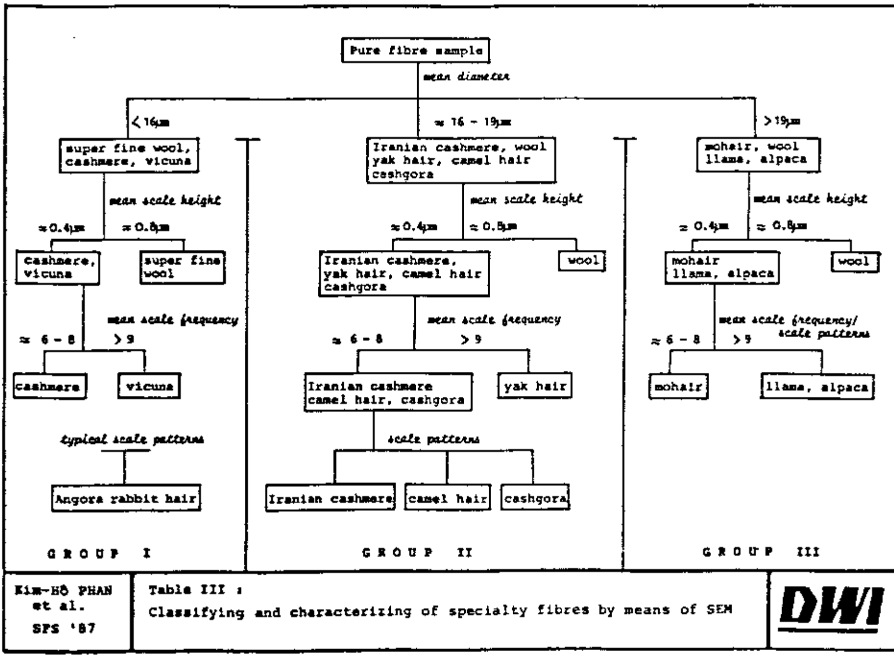


Fig. 87 Classifying and Characterising of Speciality Fibres by Means of SEM[895].

TABLE 98[895,901]
DATA OF SPECIALITY FIBRES EXAMINED BY MEANS OF SEM

Fibre type	Number of samples	Number of checked fibres	$\bar{d}$ µm	s µm	CV %	mean scale frequency -/100µm
Vicuna	1	200	10.4	2.2	22	11
Angora rabbit	20	2100	12.3	5.4	44	not measured
Cashmere	65	6625	14.1	3.5	25	6 - 8
Iranian cashmere	12	1260	16.9	4.4	26	6 - 8
Cashgora	2	400	16.6	4.2	25	6 - 7
Camel hair	31	3255	18.9	7.0	37	6 - 8
Yak hair	10	1050	18.6	6.4	34	9 - 10
Alpaca	32	3360	26.1	8.9	34	10
Llama	34	3570	27.5	10.4	38	10
Mohair	63	6615	31.9	9.5	30	6 - 7

$\bar{d}$: mean diameter
s : standard deviation
CV : coefficient of variation

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Table I : Data of specialty fibres examined by means of SEM

DWI

Phan *et al*[895] summarised the results obtained over the previous five years at the DWI on the application of the SEM scale height method to the identification and blend determination of animal fibres.

Phan and co-workers[895,901] presented Table 98 summarising the results of tests carried out over an extended period of time at DWI.

Wortmann *et al*[901] discussed the quantitative analysis of blends of wool and speciality animal fibres, such as mohair, by the SEM scale height technique and they presented the following summary of their results (Fig. 88).

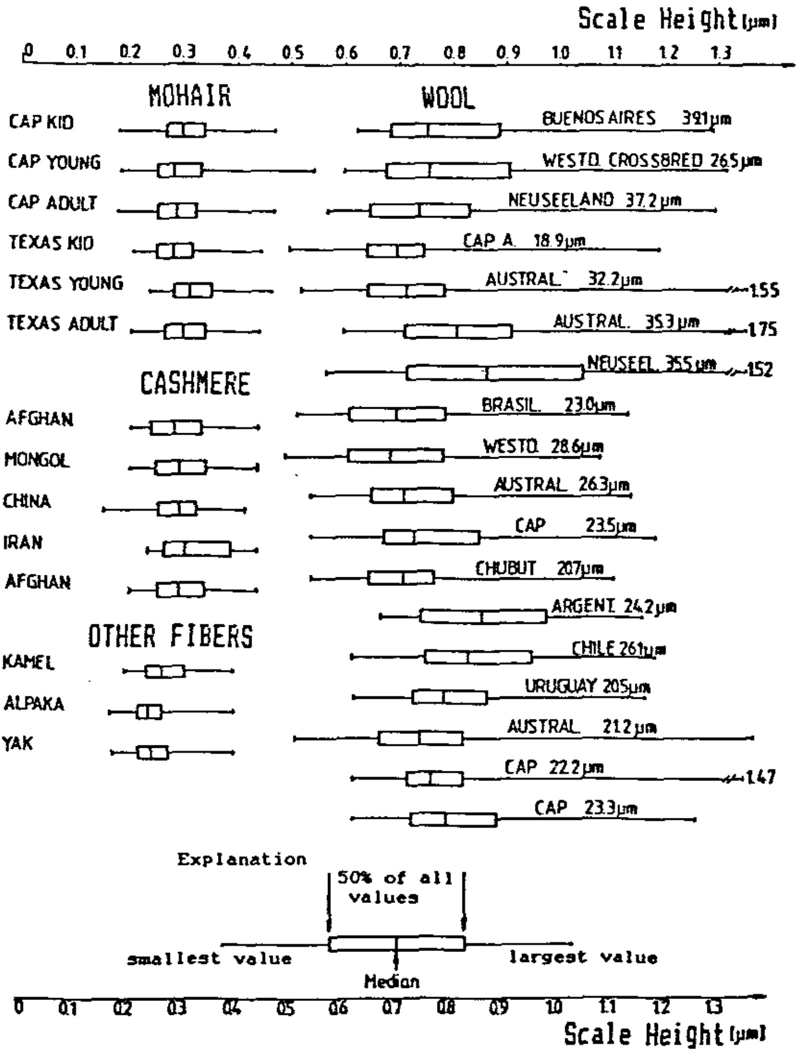


Fig. 88 Summary of the Results of the Scale Height Reading Measurements on 18 Wools and 14 Speciality Fibers as Box-and-Whisker Plots[901].

Various other workers, including **Turpie**[755], **Weideman and co-workers**[692,793,803,816,855,900], reported on the scale thickness (height) of mohair and wool fibres from various origins, showing that there was some overlap in the scale height distributions of wool and mohair (see Fig. 89)[816] and that, unless special care is taken, certain potential pitfalls and sources of inaccuracy could occur in the application of the SEM method. They found that the *mean* scale height of their mohair samples was below 0.6μm and that of wool generally above 0.7μm[793]. They reported[803,900] that individual scales on wool fibres could, however, vary from as low as 0.25 to about 1.8μm, while those for mohair could vary from about 0.12 to 1.0μm. They concluded that a sample could be classified as pure mohair if no scales exceeding 1μm were observed, whereas if a sample contained scales in excess of 1μm it could not be classified as pure mohair. They found the average scale height of 21 mohair samples to be 0.5μm (standard deviation = 0.12μm) and that of the 11 lustre wool samples to be 0.97μm (standard deviation = 0.25μm)[900].

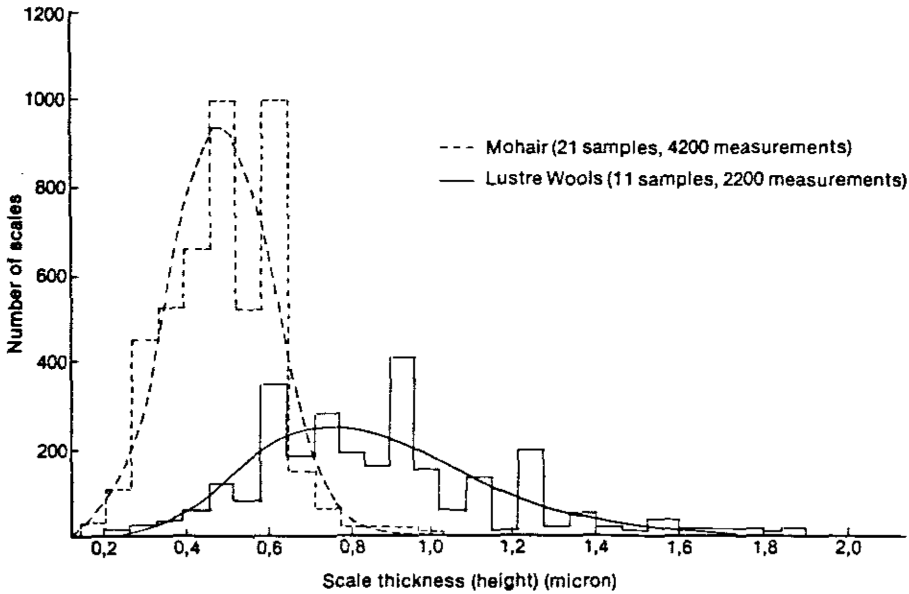


Fig. 89 Scale Height Distribution of Wool and Mohair[816].

Sagar *et al*[985] stated that, for the SEM method, the fibres have to be thoroughly degreased and that scale heights vary considerably along the same fibre, eg from 0.27 to 0.82μm for fine wool, thus lending support to the results reported by **Weideman** *et al* as discussed above. **Freddie and Mainfreni**[909] found the average scale heights of wool to range from 0.67 to 0.75μm, that for mohair from 0.36 to 0.39μm and that for cashmere from 0.37 to 0.49μm.

Taking all the results into consideration, therefore, it appears that the average scale height of wool is around 0.8μm while that for the various speciality fibres is about 0.4μm[895], although there is some overlap in the heights of individual scales.

Kusch and Stephani[641] reviewed and pointed out the various drawbacks of certain techniques proposed for the quantitative determination of animal fibres in blends with wool and synthetics, discussing the SEM Method in detail.

Phan *et al*[895] stated that even chemically treated wool retains some surface scales which could be used to identify such fibres as wool, and **Kusch and Arns**[562,594,595,614] described the application of the scale height method to both untreated and chemically treated fibres.

As already mentioned, considerable work has been carried out, particularly at the Deutches Wolforschungsinstitut (DWI), by researchers such as **Kusch, Wortmann, Arns and co-workers**[512, 562,595,614,743,762,842,901], to develop and promote the SEM method of distinguishing between mohair and wool and of fibre blend analysis[729,730,743,762]. **Höcker**[998] summarised the methods of analysis of animal fibres at DWI. He concluded that the SEM scale height method provided a reliable means of distinguishing between wool and mohair[998]. Details of the SEM method for quantitative blend analysis were given by **Wortmann and Arns**[742]. **Wortmann**[993] reviewed the 'state of the art' relating to the SEM analysis of wool/speciality fibre blends, presenting results of Round Trials. He concluded that given a certain amount of experience and dedication of the testing laboratory, the SEM analysis could be regarded as a reliable tool for blend analysis at all stages of processing. In 1986 DWI submitted a draft method[731, 993], entitled "Method for the Analysis of Blends of Wool with Unmedullated Speciality Fibers by Scanning Electron Microscopy", to the Speciality Fibres Working Group of the IWTO.

The formula of **Wildman**[36] is used[901] for determining the mass composition of blends when applying the SEM method (see below), the subscripts w and s referring to wool and speciality fibres, respectively, and w refers to the mass (weight) fraction (ww being that of wool).

$$w_w = \frac{n_w(\bar{d}_w^2 + s_w^2)}{n_w(\bar{d}_w^2+s_w^2) + n_s(\bar{d}_s^2 + s_s^2)} \qquad .....(1)$$

and

$$w_s = 1 - w_w \qquad .....(2)$$

where n in each case represents the number of fibres found for a given component and d and s are the mean diameter and the related standard deviation respectively for a given component.

The SEM method is presently regarded as one of the best for the routine quantitative analysis of blends of mohair and wool[909], having an accuracy of better than 5% (see Fig. 90[743]), the mean confidence limits for the SEM method being reported to be about 3.6%[901]. **Wortmann and Arns**[735,762] also reported on the accuracy of the SEM method and reported a mean absolute error of 1% for the blend composition of wool/mohair blends. **Wortmann and Freddi**[865] also reported on Round Trial results for blend analysis of mohair/

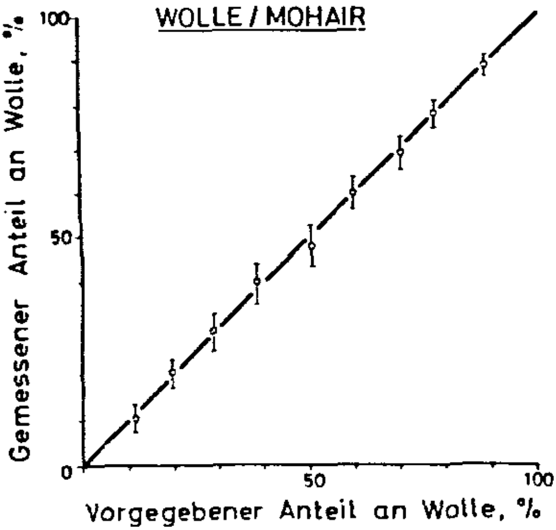


Fig. 90 Accuracy of SEM Blend Analysis[743].

wool blends using the scanning electron microscope technique, the results generally being within or just outside the 95% confidence limits.

The various methods of analyses of fibre mixtures and the results of inter-laboratory round trials have been discussed[833], a question mark being placed on the accuracy of blend determination of intimate mixtures of wool and hair fibres. The accuracy of the scanning electron microscope method was, however, illustrated for various blends of wool and animal fibres including mohair by **Wortmann** *et al*[938], thereby questioning statements made in two previous articles[833,836]. In response **Schiavone**[938a] stated that the EEC Working Group had, after inter-laboratory round trials, concluded that the SEM method was not suitable for standardisation on the basis of the present instructions, extensive experience in carrying out the test and further specifications of the equipment being considered necessary. Nevertheless, **Wortmann**[1038], recently again reported the results of Round Trials involving the quantitative analysis of wool/mohair blends by means of the SEM scale height (at the distal edge) technique. Good agreement was found between the different laboratories, the major error being the random error inherent in the microscopical approach to fibre analysis. The difference between the nominal blend composition and that found by the laboratories ranged from 0 to about 6%, with the 95% confidence limits for a 50/50 blend being about 4%.

Phan *et al*[895] concluded that to facilitate the characterisation and analysis of fibre samples, the following parameters should be taken into consideration:

- Cuticle scale height (the most important).
- Mean diameter and coefficient of variation.
- Mean scale frequency.
- Scale appearance.

Sich[990,1021] reported on the use of both the scanning electron microscope (SEM) and the light microscope for differentiating between certain animal fibres and concluded that there are times when both are necessary in order to make a reliable identification, for example when severe fibre surface damage precluded the accurate measurement of scale height. He summarised the capabilities of the two microscopic techniques in Table 99[990], the SEM being ideal where identification by means of surface characteristics is possible while the light microscope is preferable where internal fibre structural features (eg colour, pigmentation, medulla, vacuoles) need to be considered. **Sich**[990] concluded that both microscopic techniques were required to reliably and consistently identify mohair fibres, the SEM being used to identify the surface scale structure while the light microcope is used to identify the presence of vacuoles (air filled pockets) and medullation. **Sich**[990] showed some SEM photographs of mohair fibres which exhibited scale structures quite unlike the traditionally accepted scale structure of mohair, this lends support to the work and views of **Weideman, Turpie and co-workers.**

TABLE 99[990]
COMPARISON OF SCANNING ELECTRON MICROSCOPE (SEM) AND LIGHT MICROSCOPE (LM) FOR FIBRE IDENTIFICATION

	Scanning Electron Microscope	Light Microscope
Topography	+	-
Profile Edge	-	•
Interior:		
Color	0	•
Pigmentation	0	+
Medulla	0	+
Vacuoles	0	•
Refractive Index	0	+
Birefringence	0	+
Staining Techniques	0	+
Complete Fiber Length Examination	-	+
Manipulation During Examination	-	+
Sample Preparation	-	+
Speed of Examination	-	+

One of the problems of SEM lies in reliably distinguishing between different rare (or speciality) fibres, such as between llama and mohair[963] and it is troublesome to distinguish microscopically between fine pigmented samples of cashmere and mohair[547]. Because of this, attention has been devoted to modern analytical techniques such as nucleic acids (DNA)[873], lipid[916] and protein[597,689,775] analytical methods.

24.2.4 Multivariate-Analysis

The bivariant log-normal distributions (of fibre diameter and scale frequency) can be used to distinguish between mohair, cashmere and cashgora[998] and the bivariate microscopical characterisation of speciality animal fibres has been discussed by **Phan** *et al*[841]. **Phan** *et al*[850] applied the bivariate microscopic technique, involving fibre diameter and scale frequency, to characterise mohair and llama fibres, while **Wortmann** *et al*[881] described the application of the bivariate distribution (log-normal) of the scale frequency and fibre diameter to characterise cashmere, mohair and cashgora fibres, the scale frequency of mohair ranging between about 5 and 10 per 100μm, virtually independent of diameter. **Schnabel** *et al*[1055] reported that the bivariate distribution of diameter and scale frequency, determined by means of a light microscope, enabled mohair and wool to be accurately distinguished in their blends.

Teasdale[898] reported on the application of multivariate analysis to characterise and identify animal fibres using, the diameter and scale frequency of wool and mohair for purposes of illustration. He[898] applied multivariate analysis, using diameter, and scale frequency and diameter and medulla diameter to the characterisation and identification of mohair and wool. For mohair he found[898] scale frequency to be independent of mean fibre diameter. He found that mohair fibres had low scale frequencies, below about 7 per 100μm, particularly for the finer mohair, where-as that of wool decreased from about 10 per 100μm for a diameter of about 16μm to less than 6 for a diameter of about 35μm[896]. **Hermann** *et al*[1087,1095] concluded that to discriminate between fibres which are very similar, eg BA wool and mohair, a biased form of discriminant analysis or a cluster analysis, with the use of three variables (fibre diameter, scale frequency and scale form) can successfully be applied using a light microscope.

24.3 Image Analysis

Robson and Weedall[1001] reported on the application of image analysis of the cuticular scale patterns of speciality animal fibres to facilitate fibre identification and blend analysis. They described[983] a system of fibre measurement, including fibre scale and cross-sectional shape and dimensions and also a description of scale patterns from SEM images using image processing and analysis techniques. They measured scale dimensions, scale shape, scale orientation and scale-scale interaction as detailed in the table below[1001]:

TABLE 100[1001]
GROUPINGS OF SCALE PARAMETERS MEASURED

Grouping	Parameters
Dimension	Area, Perimeter Scale Interval, Aspect Ratio
Shape	Circularity, Rectangularity, Percent Fill, Bending Length
Interaction	Number of contacting scales, Average Contact Length
Orientation	Angle of scale lie

24.4 Fibre Friction Method

One of the consequences of the differences in the surface scale structure of wool and mohair is a difference in the single fibre friction, more particularly against-scale friction of wool and mohair[22,296]. This has been explored by various workers to distinguish between wool and mohair.

Smuts and Slinger[296] developed a method[316,318], based upon the against-scale friction of single fibres, of distinguishing between mohair and wool, the friction of mohair being significantly lower than that of wool when tested against an ebonite rod.

Smuts *et al*[510] found that the frequency distribution curve of the single fibre friction of a diverse range of mohair was displaced from that of wool, although some overlapping occurred (see Fig. 91).

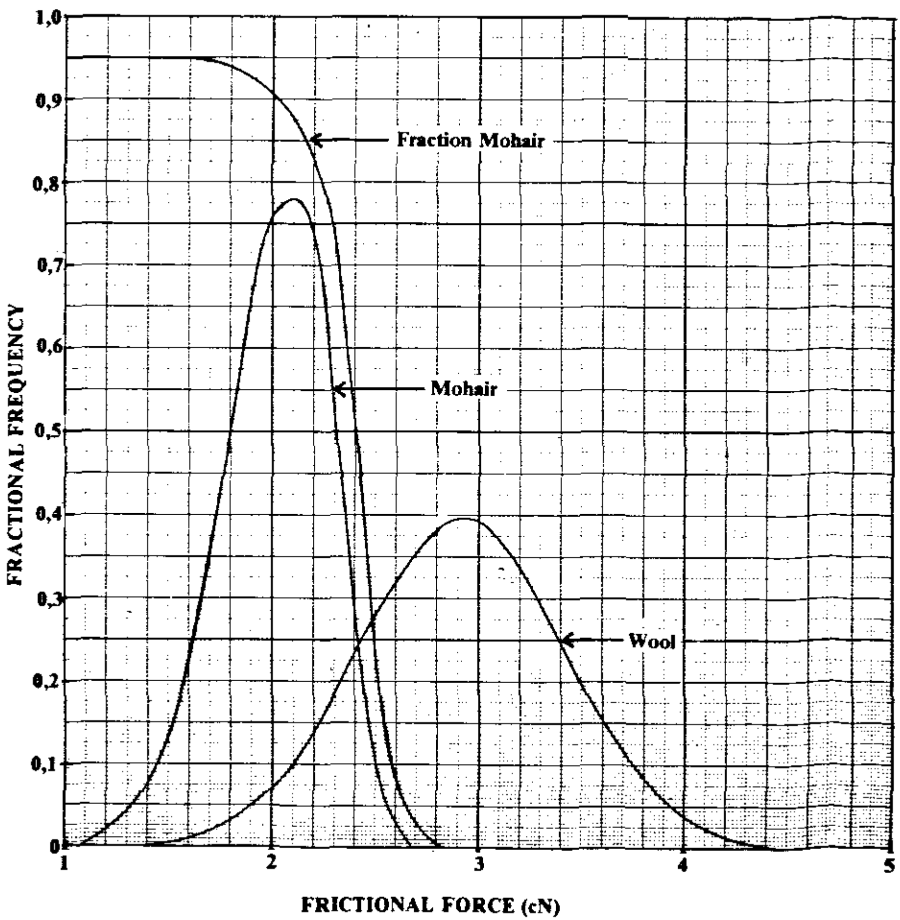


Fig. 91 Scaled Distribution Curves of Fibre Friction for Mohair and Wool and the Fractional Chances of Being Mohair[510].

For fibres in the undyed and unprocessed state, the differences between the wool and mohair fibre friction were more distinct than for fibres which were removed from finished fabrics. The frictional force increased slightly with increasing fibre diameter and crimp. A method was described whereby a fairly accurate estimate of the blend ratio of fabrics could be made on the basis of single fibre friction[510]. There was a good correlation between the against-scale friction of dyed undyed fibres, for both wool and mohair, although dyeing generally increased the fibre friction. **Weideman and Smuts**[692] showed that mohair and wool against-scale friction was correlated with scale thickness (height), with the latter differentiating better between wool and mohair than the former. The average against-scale friction (μ) was 0.42 for mohair and 0.53 for wool.

Landwehr[544] suggested using "scale engagement" (fibre-against-fibre "against-scale" frictional peaks) in water and air, together with fibre diameter, to distinguish wool from mohair. The number of frictional peak values exceeding the normal force values for mohair were lower than those for wool, in either air or water or both, with the values for Kid mohair higher than those for Adult mohair. Solvents affected the results, with mechanical processing (action) also possibly having an effect.

Although the fibre friction method appears to be suitable for determining the mohair content of mohair/wool blend fabrics it has several disadvantages. It is time-consuming and tedious, the surface characteristics of the ebonite capstan rods change constantly, necessitating a regular calibration procedure and various factors such as fibre linear density, fibre type (within and between breeds), and finishing variables, can affect the results to some extent[510]. Furthermore, it is difficult, if not impossible, to measure the friction of very short fibres (eg from velours).

24.5 Tensile "Modulus"

Lopez and Pons[332] reported on the tensile properties of mohair and wool and also on the differences in the elastic moduli of the two fibres. **Vigo** *et al*[511] and **Vigo and Barella**[459] studied the initial modulus of mohair and wool, for elongations between 2.5 and 8%, showing that in the Hookean region the modulus of mohair was generally greater than that of wool. The clearest distinction appeared to occur at an elongation of 6% where the modulus for wool was less than 0.95 cN/dtex and that for mohair was greater than 0.95 cN/dtex. The use of this criterion for wool/mohair blend analysis was considered. **Subramanian** *et al*[709] investigated the use of the stress at 2.5% extension (strain) to distinguish between wool and mohair. There was a fair degree of overlap between the wool and mohair values, this becoming greater as stress was measured at higher strain (elongation) values[709]. Thus a limiting value (criterion) of 0.85 gf/dtex was used for the finer fibres, a value of 0.55 gf/dtex applied to the coarser fibres (over 10 dtex), the higher values applying to mohair.

Bendit[416] questioned the application of the terms "initial" moduli, "moduli" or Hookean region to the initial part of the stress strain curve for keratin fibres, stating that observed differences in the crimp of wool and mohair could be responsible for the observed differences in their "moduli".

24.6 Amino-acid Analysis Of Formic Acid Extracts

The proteins extracted from wool (and mohair) by formic acid are assumed to be largely (but not solely) derived from the intercellular material (cement) of the Cell Membrane Complex (CMC)[1076]. **Bauters**[494,589,714] **and Bauters and co-workers**[524,525,536,540,568,574] at ITF proposed the use of differences in the protein composition (amino acids, glycine and tyrosine) of the formic acid extracts of wool and mohair for characterising mohair fibres and for determining the blend composition of a wool/mohair blend (in the grey and dyed states), the extract of mohair being richer in the proteins glycine and tyrosine[714]. Two fractions were separated from each of the formic acid extracts, the one being soluble in water, the other insoluble, the latter being characterised by a high tyrosine content, its proportion in the mohair extract being higher than in the wool extract. It was concluded that the same category of proteins was extracted from mohair by formic acid and aqueous propanol. The amino-acid composition of the fraction insoluble in water of formic acid and aqueous propanol extracts of mohair was similar. **Bauters**[714] concluded that the proteins extracted with formic acid did not only come from a single morphological element, such as the cell membrane complex[714].

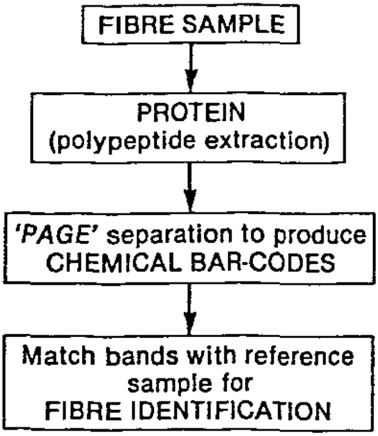
The chemical method proposed by the ITF-NORD, was improved through more information about the actual materials in the blend and by the determination of two parameters, the fineness of the fibre and amount of proteins in the extract [540,568,573]. Studies[574], showed that longer extraction times gave better differentiation between wool and mohair with respect to extracted proteins. The formic extract method is, however, not considered suitable[641,909], for chemically treated (eg dyed, bleached or chlorinated) samples. The SEM method was considered more suitable[909], provided some cuticular cells remained on the fibres after any treatment.

24.7 Electrophoretical Techniques (Page)

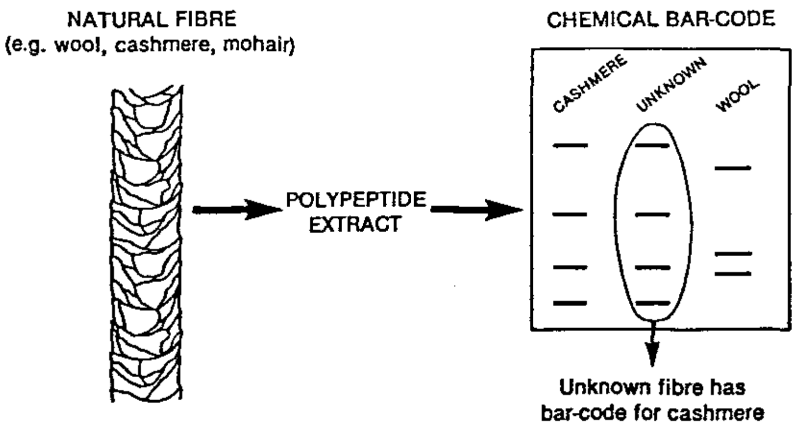
Protein fractionation, using different electrophoretical techniques, such as two dimensional polyacrylamide gel electrophoresis in the presence of sodium dodecyl sulphate (2-D-SDS-PAGE) described by **Marshall and Gillespie**[420], for the identification of animal fibres, has been extensively investigated by various workers. Polypeptides from a number of animal fibres have been resolved successfully, using either one- or two-dimensional polyacrylamide gel electrophoresis in the presence of sodium dodecyl sulphate (ie 1D or 2D-SDS-PAGE). Using, for example, radio-labelled polypeptides, speciality fibres can be resolved utilising charge in the first dimension, followed by molecular weight in the second dimension[985,1024]. The proteins of fibres are dissolved, chemically held apart, by, for example, S-carboxymethylation (SCM), and fractionated on the basis of molecular weight or electric charge. The number, position and concentrations of the fractions are compared with standards or with authentic samples. The abovementioned are powerful tools for protein studies.

Speakman and Horn[790] dissolved different animal fibres in alkali reducing gels and the resulting solutions were examined by polyacrylamide-gel electrophoresis in the presence of sodium dodecyl sulphate (SDS-PAGE) whereby up to seven classes of polypeptide could be separated and molecular weights determined. The differences between the molecular weights of the polypeptides (particularly in the first group having molecular weights between 55 000 and 35 000) could be used to distinguish between certain animal fibres (eg merino wool, mohair and cashmere), after SDS PAGE, the bands from these polypeptides being intensely stained by Coomassie Blue and sharp.

To differentiate between proteins (polypeptides) extracted from the fibres of different species of animal fibres, notably between goat and wool fibres, extensive electrophoretical (SDS-PAGE) studies were carried out on S-carboxymethylated hair proteins (SCM-proteins)[121,248,283,286,312,420,421,541,563,641,643,645,686,689,744,794,795,796,820,863,922,985,992,998]. Densitometric evaluations of the protein patterns are usually used[998]. The protein pattern may, however, be significantly modified by chemical modification of the fibres (eg finishing and weathering). The British Textile Technology Group (BTTG) represented[939] their chemically based method of fibre identification as follows (Fig. 92).



Schematic representation of speciality fibre identification procedure.



Speciality fibre identification technique.

Fig. 92 Schematic Representation of Speciality Fibre Identification Procedure[939].

The two-dimensional SDS polyacrylamide gel electrophoresis (2-D-SDS-PAGE)[417,421,541,563,641,643,689,690,696,795,861,905,922], (eg electrophoresis without SDS (sodium dodecyl sulphate) in the first dimension method followed by electrophoresis with SDS in the second dimension) method showed particular promise, for differentiating between various animal fibres, although it is expensive and time consuming(863,992). Mainly, for this reason, **Wortmann and other workers**(247,313,421,541,775,790,795,863,864,904,905,924,970,979,980) investigated the use of the relatively simple one-dimensional electrophoretical method (proteins separated according to differences in their molecular weights) to distinguish between, certain animal fibres.

If proteins are extracted (as S-carboxymethylated derivatives ie SCM) from hairs (fibres) of different genetic origin, and separated in an SDS-containing one-dimensional polyacrylamide gel (1D-SDS-PAGE) according to the molecular weight, patterns are obtained which show differences in the number and arrangement of the protein bands(421,794,795,796,998) or "spots". **Wortmann and co-workers** showed(863,864) that the 1D-SDS-PAGE method could be used to discriminate between, for example, mohair and llama fibres and could also be used in combination with other methods, such as lipid analysis, SEM and light microscopy(864). Chemical modifications of the fibres, by industrial finishing (eg formaldehyde treatment), affected the appearance of the electrophoretic patterns but only reducing the resolution of the protein pattern in cases of severe fibre damage(689,782,864). The main analytical problem was the extremely low extractability of chemically modified or severely weathered fibres(863,905), (reduction followed by carboxymethylation being more sensitive than reduction alone)(795,863).

According to **Wortmann** *et al*(904) the relatively new simple one-dimensional electrophoretical fractionation of isolated hair protein usually shows a lower resolution for the separation of proteins compared to the more time consuming two-dimensional procedures(643,689) but can detect differences between the hair protein patterns of various animal fibres of textile relevance(286,796). A method was devised(795,863) for distinguishing between llama and mohair. In addition to the separation of SCM hair-proteins, results of SDS-PAGE and of isolectric focussing of non-derivated proteins have been described(774,780). **Speakman and Horn**(790) showed that if the proteins are electrophoresised in the reduced form, *the 1D-PAGE technique can distinguish between merino wool, mohair and* cashmere but not between mohair and alpaca. **Carracedo** *et al*(775), using a similar procedure in conjunction with isoelectric focussing, concluded that the technique can differentiate between two different animal species. **Laumen** *et al*(980) standardised the 1D-SDS-PAGE method, which enabled separation between the SCM proteins from mohair, llama, cashmere and yak as well as their blends. **Laumen** *et al*(970,979) also described the use of computers in the objective analysis of protein patterns produced by means of 1D-SDS-PAGE of SCM proteins. Reference proteins, with well-known molecular weights, enable the patterns to be standardised and the accuracy is improved by performing all experiments under standardised conditions. They discussed the results of applying this technique to the separation of mohair, llama, cashmere and yak proteins and their blends(829,970,979). It was concluded that the standardised 1D-SDS-PAGE delivers semi-quantitative predictions for each composition of llama/ mohair blends.

Marshall *et al*(643), using acidic gels, showed that the 2-D-PAGE techniques, can distinguish between mohair, wool, alpaca and camel, the main differences being in the high-sulphur proteins. **Kusch and Stephani**(641) also concluded that acidic gels were more useful for this purpose but used alkaline gels for mohair/ wool blends while **Stephani and Zahn**(690) used alkaline gels for analysis of speciality fibres and their blends.

Tucker *et al*[992] concluded that 2D-SDS-PAGE procedures can distinguish between wool and goat fibres while one dimensional techniques can distinguish between merino wool, mohair and cashmere.

Tucker *et al*[922] used the 2D-PAGE technique, (alkaline gel in the first dimension and SDS in the second dimension), to compare the proteins of fibres from individual goats. They concluded that the 2D-PAGE technique, using either acidic or alkaline gels, does not unequivocally differentiate between cashmere, mohair and cashgora fibres, (ie between different goat fibres) although it does differentiate between wool and goat fibres[922,992]. It can only distinguish unequivocally between cashmere and mohair fibres when used in conjunction with transmission electron microscopy and lipid analysis.

Marshall *et al*[820] reported on the use of the *enhanced detection sensitivity* of silver stained SDS-PAGE patterns for distinguishing between the proteins of wool and speciality fibres such as mohair.

Stephani and Zahn[690] concluded that by making use of the spots on the electrophoretic pattern (gel electrophoretic analysis) of radio labled keratins which were specific for hairs of different taxonomic origin, blends of animal fibres could be qualitatively analysed. Semi-quantitative statements about the blend ratios were possible by means of densitometric measurements of the hair type-specific spots on the fluorogram.

24.8 Internal and External Lipids

Lipids are found inside mohair and other animal fibres (called internal lipids which largely originate from the CMC) and also on the surface (external lipids deposited on the fibre surface from the sebaceous glands (grease) or sudoriferous glands)[1076], the main components of the internal lipids being free fatty acids, cholesterol, triglycerides and wax esters[810].

Fatty acids in degreased (ie surface grease removed) wool (and mohair) can be divided into *free* fatty acids (a lipid fraction containing palmitic, stearic and other acids, collectively referred to as internal fatty acids) which are extractable with organic solvents and thought to be located in the CMC, and *bound* fatty acids which can only be extracted readily with alcoholic alkali treatment[740,1072]. The free fatty acid compositions and ratios of the internal lipid fractions have been used to identify different animal fibres.

Wojciechowska *et al*[1080] indicated that the changes in the external lipids depended, both qualitatively and quantitatively, on the position along the fibre where they are sampled.

Tucker *et al*[992] reviewed the chemistry of speciality fibres and the work done on the composition of internal lipids, stating that the fine speciality animal fibres, such as mohair, consist mainly of protein, water and internal and external lipids. Together with proteins, the cell membrane lipids (ie internal lipids) are the main components of the cell membrane complex (CMC)[846], the latter forming a network (continuous phase) throughout the whole fibre, thus contributing to cell cohesion. Similar to weathering, textile finishing causes a change in the lipid composition of keratin fibres[846]. Lipid analysis, for fibre discrimination, was considered to be confined to untreated samples but could be regarded as complimentary to other analytical techniques such as PAGE and SEM[846]. High Pressure Liquid Chromatography (HPLC) and Gas Chromatography (GC) techniques are used for studies on the external and internal lipids on or in the fibres[1005]. Wool generally has the highest external lipid content, with the lowest saponification value. Fractionation of external lipids from various fibre types shows some significant differences, but there is wide variation within each fibre type. The quantity of external lipid (surface grease) was found to be much higher for wool (15.7%) and yak (12.3%) than for mohair (5.1%). Internal lipids, derived it is believed from the inter-cellular cement holding the cortical cells together, tend to show similarities across fibre types[1005].

Rivett *et al*[852,896] and **Logan** *et al*[930] used a combination of modern analytical techniques, particularly HPLC and GC, to examine the lipids extracted from the intercellular regions of various speciality animal fibres and reported on the use of sterol and fatty acid compositions of different animal fibres, such as wool and mohair, as a means of fibre identification. They found that cholesterol, demosterol, palmitic, stearic and oleic acids accounted for the majority of the lipids in these fibres[852]. They concluded that HPLC sterol and GC fatty acid analyses could be a useful additional procedure to the conventional methods for distinguishing between various animal fibres and presented the HPLC analysis, in the form of comparable profiles, as a means of distinguishing between protein fibres from different origins. **Rivett** *et al*[852,896] showed that, according to their sterol analysis, cholesterol and demosterol were the major sterols in the internal lipids of wool and goat fibres; with the ratio of cholesterol to demosterol being about 2:1. The sum of palmitic, stearic and oleic acids accounted for the bulk of the fatty acids present in the solvent extract. Nevertheless, where cashmere and crossbred fibres had between 5 and 10% of linoleic acid, mohair only contained traces. Mohair on the other hand yielded relatively high levels of oleic acid[896].

Logan *et al*[930] showed that cashmere and cashgora contain 5 to 10% of free linoleic acid where-as mohair only contains trace amounts and that this could be used to distinguish mohair from cashgora and cashmere when the fibres have not been scoured or chemically treated. It was suggested that, the ratios of palmitic: linoleic, stearic: linoleic and oleic:linoleic could be used to differentiate mohair from cashmere and cashgora[992].

Körner and Kalkbrenner[912] carried out detailed analyses of the cell membrane lipids of various animal fibres, including mohair, and reported that the lipid composition of all the fibres analysed was rather similar to that of wool, consisting mainly of sterols, free fatty acids, ceramides, cerebrosides and cholesterol sulphate. **Körner**[846] used chromatographic techniques, such as thin layer chromatography (TLC) and gas liquid chromatography (GLC), to study the internal lipids of speciality animal fibres and according to him lipid analysis, as a means of identifying different animal fibres, should generally only be applied to untreated fibres. Using thin layer chromatography **Körner**[846] found the qualitative lipid compositions of mohair, yak, alpaca and cashmere to be similar and also similar to that of wool, with cholesterol, free fatty acids and polar lipids being the main components. Triglycerides and cholesteryl esters and some unidentified products were present in minor amounts. The polar lipids of all the samples consisted mainly of ceramides, cerebrosides and cholesteryl sulphate.

Although it was initially suggested that the ratio of cholesterol to desmosterol could be used to distinguish between various speciality animal fibre types, such as wool, yak and goat fibres, analysis by **Tucker** *et al*[992,1004] and **Logan** *et al*[930], of a large number of wool and goat fibres, showed that the ratio was too variable, ranging from 1.7 to 2.6 for wool and from 1.8 to 2.7 for goat fibres[930,992,1004]. They investigated the free fatty acid composition and found that palmitic, stearic and oleic acid accounted for 82 to 97% of all the free fatty acids present, with that for mohair being 96%. Mohair extracts contained more oleic acid than the cashmere or cashgora, while the latter two contained more linoleic acid (5 to 10%) than mohair (less than 2%). It was suggested that the differences in the linoleic acid contents of the extracts, and the ratio of free palmitic to linoleic acid, could be used to distinguish mohair from cashmere and cashgora, even for soap scoured samples. **Negri** *et al*[(1072)] found that bound and free fatty acids in degreased wool fibres were affected to varying degrees by processing treatments (eg scouring and dyeing).

24.9 DNA Hybridisation

Deoxyribonucleic acid (DNA) is present in the nuclei of living cells[(1005)]. It is the 'genetic blueprint' and unique to each individual. If the DNA of known origin hybridises (binds) with, or matches, DNA from an unknown source, identification of the unknown source is, in theory, absolute. DNA is present in all cells of the living animal, trace quantities remaining in the hair bulb and shaft during the growth of the keratin fibre[(848)]. DNA exists in the keratinised dead cells of the fibre within the nuclear remnants, but the extent to which it is modified or degraded, leached out or irreversibly trapped is not accurately known[(1005)]. Sensitive recovery and detection procedures were developed to isolate these residual DNA components and chemical probes to characterise the DNA fragments[(848)]. It was concluded[(969,998)] that there appeared to be two different kinds of DNA storage compartments, one which is easily accessible by chemical pre-treatments and another which is less accessible and which may hold the most potential for fibre analysis.

Kalbé *et al*[(845,875,892)] for the first time described the preparation of DNA from animal fibre shafts, concluding that the species of the fibre/hair shafts could be exactly identified by DNA hybridisation experiments and that the isolated DNA allowed new possibilities of identifying species. **Meyer-Stork** *et al*[(849)] reported on their work dealing with the isolation of high molecular weight DNA (1.4 x 107 Dalton, 20 000 base pairs) from hair shafts, which allows the species identification of the hair samples investigated. **Berndt** *et al*[(907)] and **Kalbe** *et al*[(892)] investigated the use of DNA analysis to distinguish between different types of animal fibres, and to characterise different fibre blends, such as alpaca/mohair. **Sagar** *et al*[(985)] concluded that the identification of residual molecular genetic material eg (DNA) was the most promising way forward.

With respect to DNA-based speciality fibre analysis, **Nelson** *et al*[(1000)] reported on an extraction procedure which resulted in the isolation of purified DNA in only one working day and also improved the quantity of DNA extracted. They stated that recent advances in molecular biology, may provide techniques, based upon the analysis of DNA, for the identification of animal fibres and the quantification of blends of such fibres. Problem areas in terms of quantitative analysis included the effect of chemical processing (eg scouring, bleaching and dyeing) and light damage on DNA levels[(1000)]. **Höcker**[(998)] pointed out that the amount of DNA present in the fibre can be reduced by heat treatments, and by chemical treatments such as oxidation and reduction process.

Berndt *et al*[(969)] also discussed the progress and limitations of the DNA analysis technique for fine animal fibre identification. They gave the following steps in the DNA isolation, purification and hybridisation (Fig. 93). They stressed, however, that external influences, particularly thermal treatment and chemical treatments, such as oxidisation and reduction, reduced the amount of DNA naturally present in keratin fibres. Although the DNA is never reduced to zero, a quantitative determination may no longer be possible. They concluded that the answer to speciality animal fibre analysis lies in cloning probes which are more specific than the probes available, enabling one to distinguish between sheep and the different breeds of goats as well as between camel and the different genotypes of cameloids. They also concluded that there was a question mark, however, as to whether chemically or thermally treated fibre blends may ever be analysed quantitatively and that the concept of the two different compartments containing DNA, one easily and the other one less easily accessible, had still to be proven.

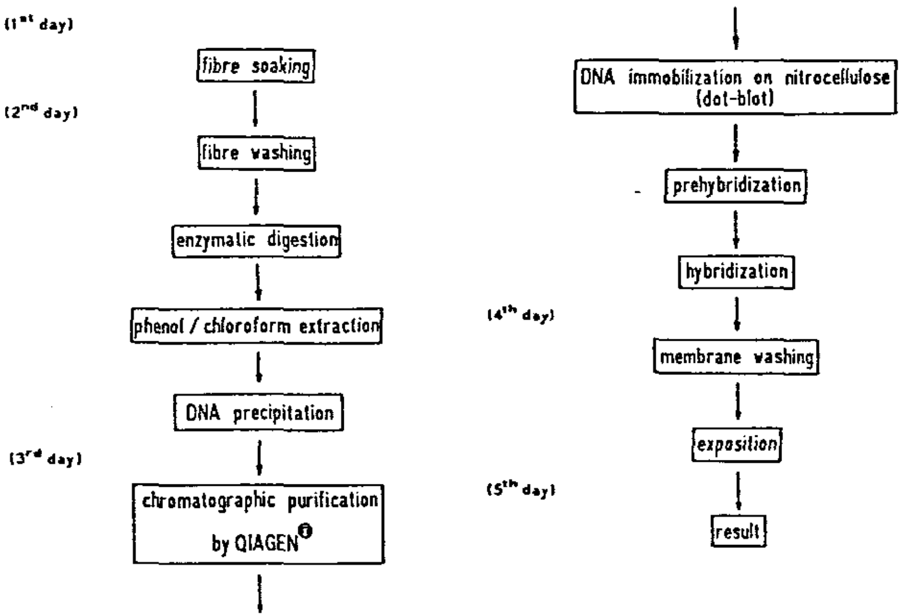


Fig. 93 The Steps of DNA Isolation Purification and Hybridisation[969].

Hamlyn *et al*[976] discussed the application of molecular biology (applied molecular genetics) to animal fibre identification and reported preliminary results on the recovery and analysis of DNA from natural fibres. High molecular weight DNA was isolated from various samples of speciality animal hair fibres, the DNA being readily recoverable from both hair shafts (cryogenically milled) and from isolated cuticles using standard molecular biology techniques. The DNA so isolated was characterised by dotblot hybridisation probing[976]. Their basic procedure is illustrated in Fig. 94[976] and involves spotting the sample DNA directly onto a membrane prior to hybridisation with a labelled DNA probe. They listed various problems (Table 101) which at that time needed solving before the new technology could be exploited by the speciality fibre industry.

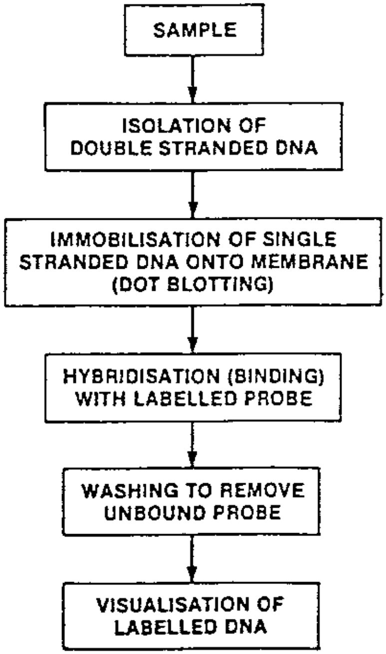


Fig. 94 The Basic Sequence of Events for the Analysis of DNA by the Dot-Blotting Technique[976,1059].

TABLE 101[976]
CURRENT LIMITATIONS OF DNA HYBRIDISATION TECHNOLOGY

A. Requirements for non-radioactively labelled probes
B. Unable yet to distinguish closely related species
C. Need to quantify DNA hybridisation
D. Reduce length of time required for analysis
E. Characterisation of very low levels of DNA

Hamlyn *et al*[1059] stated that the isolation of high-molecular-weight DNA from animal hair shafts[892,1000] had encouraged investigations into the potential application of DNA hybridisation techniques to the identification of speciality fibres at the species level[845,975]. They[1059] gave the sequence of events for the analysis of DNA by the dot-blotting technique. A major limitation of the DNA hybridisation technique[1059], in relation to speciality fibre identification at the time, was the absence of a specific DNA sequence which allowed differentiation between DNA obtained from a sheep and that obtained from a goat[969,1059]. **Hamlyn** *et al*[1059] reported on the identification of a sheep-specific fragment of DNA that can be used to distinguish between DNA samples extracted from wool and cashmere/mohair[1059].

BTTG has been studying the application of highly species specific DNA probes (oligonucleotide)[1079,1083] to identify goat fibres.

24.10 **General**

Lupton and Loughlin[403] investigated the use of different dyes to distinguish between wool and mohair, and although some contrast between the dyed wool and mohair was observed, they concluded that it was not a suitable way of distinguishing between the two fibres.

Hudson *et al*[818] discussed the application of high performance liquid chromatography (HPLC) to the identification of different types of keratin fibres (eg wool, mohair, cashmere and rabbit hair), NMR being used to authenticate each peak on the chromatogram where possible. Although the same components may be present in most samples, their ratios were generally different.

Tucker *et al*[861] examined a range of speciality fibres, eg mohair, cashmere, yak and camel, by means of transmission electron microscopy (TEM), scanning electron microscopy (SEM) two-dimensional electrophoresis (2D-PAGE), and amino acid analysis (AAA). They discussed the potential and limitations of each of the techniques, and stated that 2D-PAGE could be used to distinguish between wool and goat fibres.

Sagar *et al*[985] discussed the applicability and limitations of the various techniques, such as optical and scanning electron microscopy and optical and infrared spectroscopy, proposed for fibre identification. They concluded that optical reflectance spectroscopy was unlikely to be a viable technique for discriminating between speciality fibres while Fourier Transform Infrared Spectroscopy (FTIR) in the reflectance mode may provide the basis for a fibre fingerprint technique. They also investigated the HPLC technique for amino-acid analysis. They concluded that HPLC analysis of amino-acids by pre-column derivatisation or by using an alternative to the normal ultraviolet detection system (eg mass or infrared detectors) appeared to be a possible proposition requiring more method development. It would, however, necessitate the creation of a large database, such an approach would lead to a probability analysis. Recent developments in HPLC column technology had introduced the possibility of analysing extracted proteinaceous material without the need for hydrolysis to amino-acids.

Spilhaus[991] summarised the regulation and enforcement of fibre content labelling requirements for luxury fibre, fabric and garments in the US, the term wool including from the fleece of sheep or lamb, hair of the Angora or Cashmere goat and may include Camel, Alpaca, Llama and Vicuna.

Various papers discussed the identification of animal fibres and the analysis of their blends[575,641,766,840,857,939,998] in general.

CHAPTER 25

THE INTERNATIONAL MOHAIR ASSOCIATION (IMA)

The International Mohair Association (IMA) was formed on 21 November 1974 for the purpose of promoting the use of mohair[748], protecting its members against unfair competition and trade malpractice and to ensure the maintenance of the highest quality standards associated with this luxury fibre[903]. Members come from agriculture, commerce and industry, and the IMA consists of various product groups.

The most important functions of the IMA were reported[1065] to be the promotion of mohair internationally, the collection and dissemination of market information and the running and support of the Mohair Laboratories (Mohairlabs), and Mark schemes and labelling. All parties with mohair interests were brought together into a single organisation with the main purpose of promoting the image of mohair and its uses, as a speciality textile fibre[615]. The membership of the IMA is divided into two sections, viz Growers and Users. The IMA created a forum for all parties to discuss their mutual interests and problems and to exchange ideas, from which a very sound understanding resulted to the benefit of everybody concerned. Much confidence and stability were engendered through the advent of the IMA. This was apparent throughout the trade right down to the grower[615]. In 1992 the IMA had 141 members from all the corners of the globe (21 countries)[1061] and spanning every phase of the textile chain[1070]. The objects of the IMA are:

(a) To promote, advance, watch over and protect the interests of Members owning, carrying on or interested in the trade or business of Growing, Trading in raw or Scoured Mohair, Combing, Spinning, Manufacturing or Dyeing and Finishing of Mohair and other allied industries.

(b) To acquire, preserve and disseminate useful information and statistics relating to the production and stocks of Mohair and the sale thereof and to the manufacture of Mohair goods and to other allied industries.

(c) To adopt brands or marks indicative of standard specifications and to confer on Members the right to use such brands or marks on goods made in conformity with such standards.

(d) To watch over, protect and advance the interests of Members owning, working or interested in such industries and trade and for such purposes to propose, support or oppose any legislative or administrative measures whatsoever affecting Members and to promote and protect the interests of Members by combined action.

(e) To afford to Members all such assistance whether advisory, legal or otherwise as shall appear fit and proper to IMA or to the Council.

(f) To promote, establish, co-operate with, become a member of, act as or appoint trustees, agents or delegates, manage superintend, lend monetary assistance to or otherwise assist any associations and institutions incorporated or unicorporated with objects altogether or in part similar to those of IMA.

(g) To establish, strengthen, administer or contribute to any company or friendly society or trade exhibition and generally to grant donations which may seem to the Council or IMA conducive to the interests of IMA and its Members.

(h) To incorporate a company or companies and delegate to such company or companies such of the powers of IMA as the Council of IMA shall think fit.
(i) To do all such things as may, in the opinion of the Council of IMA be incidental or conducive to the attainment of the above objects.

CHAPTER 26

MOHAIR MARK

The International Mohair Association (IMA) Mohair Marks (Labels) were introduced in 1976, and in 1992 were registered in 21 countries, with the registration of 10 countries pending[1070].

A "Diamond Mark", for woven fabric containing a 100% mohair weft was introduced in 1988[885] but subsequently dropped. Furnishing velours with 100% mohair pile, irrespective of the backing, come in for promotion under the Gold Label system, the Silver Mark being allocated to goods with a minimum pile content of 70% mohair. Finished woollen goods, such as stoles, blankets, scarves etc with a minimum mohair content of 70%, have a Silver rating, while ladies piece goods, for apparel manufacture, must contain a minimum of 25% *mohair to qualify for promotion*[409]. A *minimum of 70% mohair is required for* the IMA Gold Mark in hand knitting yarns[526], with at least 40% for a Silver Mark[526].

The Following Gives the IMA Rules for the Use of the Trade Mark (Label)

KNITTING YARNS/GARMENTS

Gold Label

Yarns containing 70% Mohair and above. Not exceeding 27 microns - **SUPERKID**

Yarns containing 70% Mohair and above. Not exceeding 32 microns - **KID**

Yarns containing 70% Mohair and above. 32 Microns and higher - **MOHAIR**

Silver Label

Yarns containing 40% Mohair and above. Not exceeding 27 microns - **SUPERKID**

Yarns containing 40% Mohair and above. Not exceeding 32 microns - **KID**

Yarns containing 40% Mohair and above. 32 microns and higher - **MOHAIR**

Any other fibres constitute the balance in each case. Control is dependent upon appearance and handle as well as fibre composition. Micron tolerance is 2½%.

LADIES FABRICS, BLANKETS, SCARVES ETC

Gold Label - minimum of 70% virgin Mohair by weight.

Silver Label - *minimum of 25% virgin Mohair by weight.*

In all cases, the balance of the fabric must be composed of natural fibres. A tolerance of a maximum of 10% of other fibres in the fabric is permitted provided such fibres are for reinforcement or visible decoration effects.

MENSWEAR FABRICS

Gold Label - qualities containing 50% or more mohair by finished weight, or qualities containing at least 30% of Kid Mohair by finished weight - the Kid Mohair conforming to the official IMA definition of Kid Mohair (ie 32μm or finer).

Silver Label - qualities containing at least 25% Mohair by finished weight. In all cases, the balance of the fabric must be composed of natural fibre. A tolerance of a maximum of 10% of other fibres (but not man-made fibres) in the fabric is permitted provided such fabrics are for visible decoration effects.

CHAPTER 27

MOHAIRLABS

In order to achieve better and more consistent fibre diameter and length test results worldwide, the IMA Mohairlabs Association was formed in 1984, and now annually runs international inter-laboratory Round Trials on the basis of which the right to use Mohairlabs stamps is awarded to those laboratories which achieve the prescribed accuracy during the Round Trials[903].

Mohairlabs was formed with the following purpose, aims and membership:

PURPOSE:

The purpose of the Association is not to conflict with already established Textile Testing Associations (such as Interwoollabs) but recognises the need for specialist knowledge and expertise necessary for accurate testing of Mohair, due to certain fundamental differences between Wool and Mohair. The most significant of which, is the much greater variation in fibre diameter inherent to mohair.

THE AIMS:

The aims of the Association are:

1 To develop co-operation between member Laboratories with the view to standardisation of test methods, in order to achieve correct and uniform test results on mohair.
2 To promote the confidence of all processors and users of mohair, in the accuracy and integrity of Member Laboratories Test results.
3 To assist all interested parties in resolving disputes arising from differences in test results.
4 To undertake to investigate and establish Standard Rules for any aspect of mohair testing which may from time to time become necessary.
5 The method of application of the aims are defined in the Rules of the Association.

MEMBERSHIP:

1 The Association shall be open to all suitably equipped Textile Testing Houses, which have applied to, and complied with the entrance requirements and who agree to abide by the Rules of the Association as administered by the Technical Committee.
2 Membership of the Association does not imply full membership of the International Mohair Association.

CHAPTER 28

MOHAIR APPLICATIONS AND END-USES

28.1 General

The textile application of mohair goes back many thousands of years, the fibre finding application in almost every conceivable textile end-use. Today up to 80 to 90% of mohair consumption (especially Adult hair) can be affected by fashion[1077].

It has been stated that mohair is an animal fibre possessing all the characteristics of a divine creation[25], and the presence of mohair in a material is considered to lend elegance and quality to it[294]. Mohair[630] is sought after for its comfort, it being warm in winter and cool in summer and highly durable. For example, in lean worsted type lightweight tropical suitings, mohair is regarded as a "cool" fibre, where-as in brushed articles, such as shawls, stoles, rugs, sweaters and blankets, mohair provides warmth (bulk) without weight[667]. Velours (also embossed) have always been one of the most popular outlets for mohair. Mohair's characteristics of hard wearing durability, resilience (springiness), moisture absorption, comfort, lustre and smoothness make it ideally suited to many applications in apparel and interior textiles. Because of its general smoothness and low static propensity (except under dry conditions) mohair does not collect dust or soil very easily[25] and is also easily cleaned (stains are easily removed)[785].

Traditional "mainstays" of mohair have been blankets, stoles, scarves, travel rugs and hand-knitting yarns[435], "fluffy look" ladieswear in fancy yarns, ladies couture clothes and mohair velours for furniture[435]. Mohair comes into its own and is probably unequalled in brushed (also called "candy floss" mohair in certain cases) fabrics and plush and velour fabrics. As early as the 1870's, imitation furs, using mohair pile fabrics, were made[425], and mohair plush for upholstery was already popular by the 1890's. Mohair was used as automobile upholstery and rugs, and as upholstery in railway carriages more than 60 years ago[5]. and in 1924 America had all the automobile upholstery made from mohair[25]. Mohair pile furnishing fabrics were already very popular more than 70 years ago[25]. Before the second world war, "uncrushable" mohair velvet was already made.

Mohair noils were used in carpets more than 60 years ago and they were also blended with wool and other noils for the making of woollen cloths and blankets[5].

Mohair has traditionally found outlets in plush and pile fabrics (eg velours in furnishings and upholstery), hand-knitting, men's suitings, blankets and rugs[934], garment linings[785]. Its lustre, resilience, smoothness, hard wearing and crease resistant properties makes mohair valuable for upholstery and any pile fabric (eg plush, velvet and (moquettes)[785] and it is virtually unsurpassed for general durability[34], recovering very quickly after being crushed. The smooth fibres do not allow dirt to collect readily, and stains are generally fairly easily removed.

Mohair blends very well with other fibres and is usually used in blends. It has been blended with many fibres[317,633,674,753,824,947], such as wool (including superfine merino and lambswool) alpaca, ramie, linen, cotton (eg 90% Super-Kids/10% long staple cotton)[630], silk, cashmere, mink and man-made (regenerated and synthetic), with wool being the most popular. Some firms have experimented with multi-fibre combinations, for example of alpaca, silk, wool and mohair[769]. Mohair/silk blends combine lustre, softness and silkiness. One firm even offered a mohair/wool/acrylic/polyester/rayon/cotton blend yarn[623].

More than 70 years ago a fine mohair singles yarn was twisted with a singles cotton yarn, the cotton being removed by carbonising the fabric afterwards[1,14].

The use of alginate, in combination with mohair, to produce a lightweight *fabric, was mooted as early as 1945*[25] *and mohair "tweed" yarns and "space*-dyed" yarns[623] have been mentioned.

In the 1950's, blended fabrics were stated to be the rule, with Tex-air suits in 50% mohair/50% wool - very successful[425]. In the 1950's mohair was used for fine dress goods and raised overcoatings in which loop yarns were used in pile, with the brushed pile effect replacing drawn pile. Mohair was also used in bouclé, knop and slub yarns[425].

The highest prices are generally paid for mohair used in apparel, particularly fashion clothing, with that paid for fibres used in carpets and upholstery generally much lower[684], the primary product price representing only between 2 and 5% of the value of the end-product[1077]. Fashion interest in mohair has, however, proved to be cyclical[261], and the only way to counteract its effect on the mohair industry as a whole is to increase the all-round versatility and end-use application of mohair.

Roorbach[509] stated that, at one time, Europeans tended to put mohair into everything from underwear, to outerwear to upholstery.

Van der Westhuysen[1046] gave the following table (Table 102) for the application of the different types of mohair.

TABLE 102[1046]
COMPOSITION OF THE MOHAIR CLIP AND APPLICATION

TABLE 1. COMPOSITION OF THE MOHAIR CLIP AND APPLICATION

Type of hair	Fashion application	% of Clip	Competings fibres	Comparative non fashion value
1. Superfine and fine kid (24-28 micron)	Wide application in mens and ladieswear — extremely sought-after	3	Superfine wool, cashmere, alpaca, Angora rabbit hair, etc.	Production is so limited that it remains relatively good.
2. Kid (29-30 micron)	Finds application in mens- and ladies-wear — sought-after.	13	Fine wool	Fair
3. Young goat (31-34 micron)	Used in mens- and ladieswear and in household softs (upholstery). Sought-after when in fashion.	12	Wool and artificial fibre	Limited
4. Fine Adult (34-36 micron)	Application mainly in knitting industry and brushed products (blankets, etc). Other applications limited when knitting is not fashionable.	20	Wool and artificial fibre	Limited
5. Strong Adult (37-40 micron)	Application only in brushed products, carpets and curtains. Alternative application limited.	50	Lustre wool and artificial fibre	Extremely limited at price of, or lower than, carpet wool.

In the second half of the 1980's the various end-uses of mohair were given[767] as follows:

TABLE 103[767]
MOHAIR CONSUMPTION

End-Uses	Share (%)
Hand Knitting Yarns	65
Men's Suiting Fabrics	15
Women's Woven Accessories and Rugs	12
Woven Furnishing and Velours	8

Recently (1992), **Van der Westhuysen**[1077] stated that 70 to 80% of mohair went into brushed knit-wear, 10% into ladieswear, 7 to 10% in home furnishings, 7% into menswear and 1% into home industries, most of which are subject to fashion cycles. Mohair is increasingly being used in machine knitting, this generally favouring the finer quality of mohair viz Young Goat and Kid[953]. Very fine Kid mohair is processed on the woollen system for the production of knitting yarns and velour for winter coats[953]. Adult mohair finds applications in the brushed look and especially in the hand knitting sector[1046]. It was estimated in 1983[613] that something like 80 to 85% of the world supply of mohair was used in knitting, about 20% of this being consumed in hand knitting. It has been stated[672] that fashion in mohair hand-knitting yarns tend to go in cycles of approximately six years.

During 1984, for example, textured effects in mohair were very fashionable, these including brushed, nubbed, tweeded, space-dyed and flat/shining surfaces[670].

The finest mohair (Kid) is used principally in the hosiery and fine lightweight suiting trades[426] and occasionally for stoles[98], noil (short fibres removed during combing) also being used in the case of the former[426]. Grade 3 mohair (English System of grading) is used to make lofty open shawls and scarves (coarser qualities tending to be used for shawls and blankets as well), as well as hand knitting fancy-effect yarns, whilst Grades 2 and 3 mohair are used to produce curly pile rugs[98,426]. Grades 4, 5 and 6 are used in considerable amounts, either in pure form as weft or blended with lustre and medium crossbred wools, to make tropical suitings, generally as weft with a fine wool worsted warp. These qualities are also used to produce pile fabrics, traditionally with cotton backing. Grades 4 and 5 are used for upholstery and for covering soft toys[98] etc. The lowest quality pieces are used in the production of interlinings[98,426].

Short and coarse mohair has limited applications and is generally used in less expensive products[798]. Short mohair can be processed on the woollen system provided it is not too coarse[798]. **Sanderson and Wilkinson**[988] investigated the characteristics, performance and end-use of low quality crossbred mohair, and certain other animal fibres, in blends with New Zealand wool.

Mohair noils are used in wool/mohair blend coatings and also in carpets, blankets and hats and also found application in the hosiery trade[426]. Mohair noils are used in woollen blends when lustrous fabrics are desired, for example in apparel wear with surface effects.

Some of the outlets/applications/end-uses of mohair are listed alphabetically in the next section and in some cases examples are given below: In **upholstery, furnishings,** and **drapes**, for domestic, office, cars, trains and theatre seats[34], medium quality mohair (eg long Young Goats and fine Adults)[281] can be used[25].

Kienbaum[342] gave the following table for the lower critical values for the pile density factor Dp in worsted furnishing fabrics (Table 104)[342].

TABLE 104[342]
LOWER CRITICAL VALUES OF THE PILE DENSITY FACTOR Dp (IN WORSTED)*

	velvet with pile alignment		upright pile velvet		
Pile yarn	low	normal fibre crimp	low	normal fibre crimp	strong
Cotton	2.9				
Linen	2.9				
Wool	2.55	2.3	4.75	4.3	3.9
Mohair	2.55		4.75		
Polyacrilonitrile	2.2	2.0	4.5	3.75	3.2
Polyamide	2.2	2.0	4.5	3.75	3.2
Polyester	2.65	2.4	4.95	4.5	4.05

*Dp = Np x tex x 0.001
Np = number of pile loops/cm

Used in the interior and automotive markets, because of its hardwearing nature, mohair velours and moquettes are still an important source of upholstery[1027]. Mohair velvet has also been permanently vulcanised to sponge rubber to produce a special kind of carpet material for automobiles[309].

A popular use of mohair (often Kid)[631] is **men's suitings**, particularly summer and tropical (Panama) suitings, generally in blends with wool (occasionally in all mohair) but also in numerous combinations with other fibres, sometimes in intimate blends, but usually as weft[34] (often singles mohair weft and two-fold fine wool worsted warp)[25,34,88,89,196,785], blends of Kids and Young Goats also used[281]. Mohair has a reputation for coolness[25], crispness, good wrinkle recovery and good durability. Mohair/wool/ polyester blends have also been used for tropical suitings[703]. Another example is the "unstructured" suit in 30% Kid mohair and 70% worsted, a "Young looking" button-two style with patch pockets and no lining[409]. One of the original men's mohair fabrics was a plain or semi-fancy piece dyed suiting sold in the early 1930's[582] to countries in South America. The development of the first yarn dyed mohair suiting commenced in 1950 and considerable quantities of such fabric have been sold worldwide. In 1992 it was estimated that 70% to 80% of mohair menswear is consumed in Japan[1077], where the fabrics were considered to be the most adaptable to the hot and humid summers[1030], accounting for between 10 and 12% of summer suit sales. Kid hair (often fine) is mainly used in Japan for men's suitings, it being important that it is kemp free[1024], and a high quality suiting fabric is produced from superfine Kid mohair[800]. One popular men's suiting in Japan consisted of 60% Summer Kid hair and 40% superfine wool[798], while another contained 60% Summer Kid hair, 33% superfine wool, 6% cashmere and 1% vicuna[798]. Mohair has also found application in sports-jackets[484] in worsted fabric (eg 50/50 wool/mohair), woollen jacketing (80/20 wool/mohair) and evening wear (mohair/wool barathea)[457]. In Japan, men's winter suitings have also been made in a 30/70 mohair/wool blend, using Adult mohair[1024].

Mohair was quite popular in **linings** for clothes, such as suits (sometimes combined with wool, cotton or rayon)[25,34,202] during the Victorian era[25].

Mohair also found a popular outlet in **mens** and **ladies coats** and **overcoats** (woven and knitted; woollen and worsted[697] eg bouclé, velour, fleece and worsted)[34,88,202], with the shorter mohair types often being used in overcoats[88,460]. Other examples include wrap-around coats, alpaca/mohair coats, mohair/acrylic/nylon shaggy pile coats, coatings (knitted and woven) with short brushed and short pile wool and mohair, also coats with brushed mohair on both sides or mohair fleece on the face and wool or cotton on the back[633]. **Vonberg**[141] has discussed various structural possibilities.

Mohair has been used in various **bed coverings**, using for example a wool and mohair worsted loop (fancy) yarn[281] which was heavily raised on both sides and piece-dyed[280]. One firm used 27μm mohair in a blend (33/70 mohair/wool) with fine wool, to produce very fine and soft **blankets**[1024]. A typical mohair blanket construction in the USA was 75% mohair, 21% lambswool and 4% nylon[630]. Mohair blankets form one of the traditional end commodities produced from the lustrous mohair fibre. Mohair blankets are characterised by their low mass, soft and silky handle, excellent insulation properties and luxurious appearance. They reign supreme in a class of their own as high quality blankets[350]. **Robinson** *et al*[350] investigated three novel methods of producing mohair blankets and compared them with the conventional method of weaving. These three types of blankets could be produced on conventional equipment utilising needle punching, warp knitting and weaving machines, respectively. In the case of needle punching some patterning effects were obtained using special scrims. In warp knitting, new designs and cellular effects were readily obtained and in weaving the mohair was kept to one surface only so as to produce a "non-slip" blanket. Fibre retention in these blankets, measured in terms of the single fibre withdrawal force, and the results obtained on the blankets produced by conventional and unconventional means, were also discussed. The blankets compared favourably with the traditional blanket.

Kid or Adult mohair (worsted spun) has been used for men's **socks**[1035], while 25% mohair/75% acrylic mohair socks have been used for hiking, ankle socks, girl's knee socks and socks for farmers[1014]. Mohair in socks is stated to mitigate sweating and odours and to reduce the worst impact of wearing Wellington boots. The socks are proving popular with people who wear boots continuously because of wet working conditions[1014]. Mohair/nylon (for reinforcing) socks, including cushion (plush) soles, are also proving popular, particularly for out-door, leisure and active wear (ie hiking, mountaineering and sports). Mohair socks, with cushion (plush) soles, were recently reported to be very popular for sportswear[1068,1071]. Mohair is stated[1071] to combine comfort with high insulation and exceptional durability and to be less prone to trap odour forming bacteria.

Leg warmers[630] are produced from finer grades of mohair and in 40/60 mohair/acrylic)[630].

Mohair has found application in **wigs** and **switches** for theatrical purposes[34,202] and also as dolls wigs (it appears that the authentic Victorian porcelain doll had a wig of mohair). The length of fibre required is about 20cm.

Mohair has also found application in **carpets, rugs,** and **mats** (machine and hand-made) with long or short pile, often with hand-block printed designs, often comparing favourably with hand-made oriental rugs[34,36], usually medium quality mohair[25] being used, kempy mohair also finding application in carpets[934]. Mohair noils were used in carpets more than 60 years ago. Blends of Lincoln wool and mohair were used in Australia to produce "Scottish" mohair tartan rugs of loop yarn construction[280]. The use of mohair in tufted carpets was mentioned[347], it performing better with cotton and jute primary backing, excessive fibre shedding sometimes tending to occur with a polypropylene backing. Mohair is also used in Lesotho, for example, for hand-made carpets. *The hand-spinning of a two-ply, S-twist wool core spun yarn with 80% Lesotho* mohair and 20% Cape Blend 700 tex "Superfluffy" yarn has been discussed[789]. One Japanese firm produced carpets containing between 60 and 100% mohair[1024].

In former years, mohair was used in **interlinings** (usually lower quality mohair in blends with other fibres, such as coarse hair)[25,36] and in **machine beltings** and **press cloths** (usually in blends with wool and coarse camel hair)[25,36].

Sweaters (eg 80/20 or 50/50 acrylic (bulked or unbulked)/mohair)[697] or *80/10/10 mohair/nylon/acrylic, also 70/30 polyester/mohair for golf sweaters.*

Mohair has also been used in **imitation Astrakhan,** a long uncut pile fabric. For this purpose the mohair need not be spun but can be warped as a roving[36], it being possible to use kempy and "mushy" mohair. Mohair yarn can also be treated to form a permanent wavy appearance (curled yarn) which then can be woven in a manner to initiate fur fabrics, such as Astrakhan and other natural animal pelts, fancy doubled mohair yarns, eg curled mohair yarns, having been used for the pile of rugs, Astrakhans etc[102]. Mohair was already used in imitation animal furs (eg mohair Astrakhan) more than 60 years ago[5,14], often fairly short mohair and cut hair[36] being used (eg wool undercoat with a mohair nap)[88]. In one example, 78%mohair/13%wool/9%nylon was used in knitted jacquard animal skin patterns for fully lined jackets.

In the case of **pile fabrics,** the long lustrous pile is bound into the base of the fabric (sometimes cotton yarn has been used as the backing or warp[25]) and *can then be curled and embossed, by ingenious construction and dyeing meth-*ods, to imitate furs and to produce materials which are not only attractive but serviceable[34,202]. Usually medium quality mohair is used[25].

In the case of **ties** (woven and knitted)[630], once very popular in the USA[36], and very hard wearing and crease-resistant, the warp can consist of a very high quality merino wool and the weft of mohair or mohair blended with 30 to 50% wool[36].

In **ladieswear** (brushed and unbrushed) eg skirts, capes, suits, jackets, tops and dresses, blends involving Kid and Young Goat mohair[281,458,460,484] have been used and sometimes mohair, in the form of a cut top, has been blended with wool to produce two-tone dyeing effects[36]. Co-ordinates have been produced in various blends (eg mohair/wool/nylon)[655] and leisure tops, evening gowns[458], waist coats, skirts etc[961] and Kimono-look jackets[624] have also been produced.

Mohair "Tweeds" have been produced (eg men's jackets and ladies tweeds), also soft mohair check tweeds as Chanel-type suits).

For **ladies suitings**, a mixture of Adult mohair and British wools has been used to develop a tweedy type cloth for jackets and skirts for winter wear[1024].

Stoles and **shawls** are popularly produced from mohair loop and fancy yarns[88,281,484], in Victorian days loose textured shawls, made from mohair (fine Kids) worsted yarn, often being worn with a lightweight silk shawl over them[25].

One firm used a 70/30 polyester/mohair yarn (R98 tex/2 and R74 tex/2) for men's knitted **golf shirts**, the yarn being used in either natural or dyed (package or skein) form[214].

Velours find application in upholstery (also for vehicles)[14,727] furnishings[220,934], curtains[798], seat covers[798], drapes and bedspreads[442], sometimes embossed[442]. Mohair **velvet** has also proved popular, generally consisting of a mohair pile and a cotton ground.

Mohair has been used in special Weave Effects (herringbone designs, ribbed diagonals, open basket weaves, spot effects, bouclé, three-ply, and three dimensional designs)[442,523], and pure mohair twill fabrics have also been produced. Mohair/Lycra has been used to produce a plush or suede surface.

Meckel[604] reported on the application and wear performance of mohair and other fibres, in furniture upholstery.

Vogel[507] described the use of a mohair/wool blend fabric, as a medical textile in the metal industry. Thermal and physiological properties and wear performance were studied and reported.

Vonberg[141] gave some details of various woven fabric structures in which mohair and mohair blends were used.

Leather made from the pelt or skin of the Angora goat is useful for ornamental purposes and for the manufacture of gloves, purses, bookbinding and novelties[34]. Mohair (Angora) skins have also been used for Teddy Bears.

Koch *et al*[423,479] made recommendations on the care of mohair velour and other types of fabrics with specific reference to dry-cleaning. Because of its smoothness, mohair articles are generally easy to clean[36]. **Engelbrecht**[1042] has discussed caring for and cleaning mohair articles. He suggested that mohair should be washed (pure soap flakes) in luke-warm water (avoiding high temperatures and mechanical action), softeners may be used, spin-drying is recommended but never tumble-drying, with drying flat, preferably not in the sun. Dry-cleaning can also be used. A soft brush can be used to restore the pile, with brushing taking place in the direction of the pile.

Stavridis and Speakman[54] found that the "white spots" (light specks) which had occasionally developed in mohair plush[239,351] used as upholstery fabric, were due to the presence of looped fibres in the pile, the looped fibres being formed during spinning, singeing (gassing) eliminated the problem. The defect could be removed by damping the fabric and brushing it with a stiff brush.

Grobler[1044] estimated that the cost of the mohair fibre represented only 2% of the retail price of a mohair suit, the cost of the top would represent 4%, that of the dyed yarn 9% and that of the fabric 37%. Various articles[14,88,34,36,202,220,281,309,409,425,442,484,508,523,551,624,630,653,697,769,798,822,899,934] refer to mohair applications and end-uses.

28.2 Mohair Product List

Accessories (hats, gloves, handbags, etc)
Airgun Darts
Airline Blankets
Ankle Socks (girls)
Artificial Hair
Astrakhan
Athletic Socks (hosiery)
Auto-textiles (floor coverings, carpets, boot liners, hoods, door trims, seats, upholstery, panel shelf) Automobile Seat Covers

Bath Sets
Bath Mats
Bed Covers (eg bedspreads, blankets and rugs)
Bedspreads
Beltings and Press Cloths
Blankets
Blazers
Bloussons
Bobby Socks
Boot Linings (auto)
Braid
Brilliantine
Bunting (flag cloth)

Candlewick (bedspreads and dressing gowns)
Capes
Car Coats
Cardigans
Carpet Tiles
Carpets, Rugs and Mats (Axminster, Wilton, Tufted, Needlepunched, Hand-knotted, Knitted)

Casualwear
Ceremonial Robes
Chenilles (carpets, socks, etc)
Cloaks
Coats
Coffin Linings
Cords (and Tassels)
Crepon Goods
Curtains (damask, brocades, satins or velvet)
Cushion Covers

Decorative Trimmings (eg for coats, hats, shoes)
Dinner Jackets
Dolls Wigs
Domestic Textiles
Drapes/Draperies (automobiles, aeroplanes, trains, buses, domestic, office and industrial)
Draperies (furnishings)
Dress Suits

Dresser Covers
Dressing Gowns
Duvets

Eiderdowns
Evening Gowns
Evening Wear

Fabric Art
Fabric Panels
Fabric Sculptures
Fake Furs
Fancy Yarns
Fibre Art
Fire Blankets
Flags
Fleecewear
Floor Carpeting (aircraft, automobiles and buildings)
Foot Muffs
Foot Warmers
Fringes
Fur (imitation)
Furnishings

Gilets
Gloves
Gowns
Golf Club Head Covers
Golf Shirts

Half-hose
Hand Crocheted Articles (shawls, stoles, etc)
Hand Knitting Yarn
Hand-knotted Carpets
Handwear
Home Furnishings
Horse Blankets
House Slippers (felt)
Household Textiles

Imitation Furs
Infants Blankets
Ink-transfer Pads
Interlinings
Interior Panels

Jackets
Jerseys
Jumpers

Kelims
Kimono - "Look" Jackets
Knitted Jerseys
Knitting Yarn
Knitwear

Ladieswear
Lamp covers (shades)
Leg Warmers
Leisurewear
Linings

Mantle Cloths
Machine Knitting Yarns
Mats
Mens Suits
Menswear
Mops
Mourning Scarves
Mufflers

Neck Ties
Neckwear
Needlepunched Carpets, Blankets, etc
Nets (laces and drapery materials)
Nightwear
Night Gowns
Novelty Yarns

Oriental Rugs
Overcoats

Paint Rollers
Paint Brushes
Palm Beach Cloth
Panama Suits
Persian Carpets and Rugs
Pile Fabrics (upholstery, etc)
Plaids
Plush Fabrics
Ponchos
Pram Hoods
Press Cloths (eg filters)

Quilts

Raincoats
Residential Upholstery
Reversible Lining
Robes
Roller Brushes
Rugs (prayer, etc)
Runners (table, etc)

addle Blankets
carves
atter Cushions
atter Rugs
at Covers (cars, trains, planes)
awls

"Sheepskin" Covers (real and imitation)
Sicilians
Skirts
Slippers
Smoking Jackets
Snow and Ski Gear
Socks
Soft Furnishings
Soft Toys
Soldiers Uniforms
Soft Furs
Sports Jackets
Sports Clothes (knitted)
Stoles
Stuffed Toys (pile fabrics, shaggy or cut)
Sweaters

Table Covers (eg cloths, mats and runners)
Tam-o-Shanters
Tapestries
Tapestry Yarns
Teddy Bears
Theatrical Wigs
Thigh-length Cardigans
Ties
Toilet Covers
Track Suits
Travel Rugs
Tray Cloths
Trench Coats
Trimmings (for coats, dresses, shoes, etc)
Trunk Linings
Tunics
Tweeds
Tyre Cords

Underblankets
Underlays
Uniforms
Upholstery

Velours
Velvets

Waistcoats
Wall Covers
Wall Hangings
Wigs and Switches (eg for theatrical purposes)
Womenswear
Wraps

CHAPTER 29

REVIEWS, BIBLIOGRAPHIES AND BOOKS

29.1 Reviews

Villers(82), in 1960 reviewed the processing and applications of mohair and also gave a detailed list of common mohair fabrics and their weave structures (over 200 structures given), including 100% mohair fabrics, the latter including plain weave, cord effects, crépes, whipcord, twilled vesting.

Srivastava(309), broadly reviewed mohair production, properties, processing and end-uses.

Kidd(418) **and Tucker** *et al*(992) reviewed the chemistry of speciality animal fibres other than wool, while the chemistry of various natural protein fibres has also been reviewed(414). **Veldsman**(516) reviewed the chemical and physical properties and processing of mohair and **Broda and Wlochowicz**(639) reviewed the fine structure, molecular structure and chemical composition of mohair and wool. **Zahn**(994) also reviewed the structure and chemistry of mohair while **Spei** and **Holzem**(1048) reviewed the characterisation of fibre keratins, including mohair.

Work on mohair carried out at SAWTRI was reviewed on various occasions(504,539,605,649,695,699,710,745,781,864), particularly detailed reviews being given by **Veldsman** in 1970(201) **and Turpie** in 1985(705).

Kusch and Stephani(641) published a comprehensive report on the quantitative analysis of blends of mohair with wool and synthetic fibres, while **Tucker** *et al*(992) also reviewed various aspects relating to fibre identification.

Wortmann *et al*(880) summarised the various papers presented at the 1st International Symposium on Speciality Animal Fibers, held at the German Wool Research Institute (DWI) in October, 1987 while **Wilkinson**(1005) briefly summarised the papers presented at the second such Symposium held in October, 1989.

McGregor(894) *briefly reviewed some of the work done on the processing,* production and marketing of mohair.

Smuts(914) reviewed work published on the wrinkling of wool and wool blends, including wool/mohair blends.

Bereck(968) reviewed the nature of the natural pigments found in animal fibres, and the bleaching there-of, including mohair. **Knott**(978) reviewed fine animal fibres and their depigmentation.

Ryder(984) reviewed the production and properties of goat fibres, such as mohair around the world.

In 1991 **Hunter**(1031) briefly reviewed textile related studies on mohair during the 1980's.

Smuts *et al*(1036) reviewed work done on the objective measurement (mainly by means of the Kawabata KES-F and the FAST systems) of fabrics, including a limited amount of work done on wool/mohair fabrics on the Kawabata system.

Leeder *et al*(1069) have recently produced a fairly comprehensive review of mohair and other goat fibres.

Various other reviews(469,646,949,1040,1041) of relevance, have also appeared from time to time.

29.2 **Bibliographies**

A reference list of articles on mohair has been given[265]. **Srivastava** *et al*[309,393] published a bibliography on mohair, with **Strydom**[412] adding a number of additional references. **Blankenburg and Teasdale**[558] published a Bibliography on Mohair and other speciality animal fibres in 1982. A bibliography[869] of publications on scientific, technical and commercial aspects of speciality fibres, including mohair, and covering the period 1971 to 1987, has been published.

29.3 **Books**

A textbook by **Asquith**[413] dealing with animal fibres including mohair has been published. **Van der Westhuysen** *et al*[533] published a book on Angora goats and mohair in South Africa, and also reported briefly on the processing of mohair.

Ryder[785] has published a booklet dealing with cashmere, mohair and other luxury animal fibres. **Uys**[872] has published a book on the history of mohair in South Africa, covering the period from 1838 to 1988. A book by **Harmsworth and Day**[977] describes the breeding and husbandry of sheep and Angora goats and also outlines industrial techniques, such as scouring and carbonising.

ACKNOWLEDGEMENTS

The author is indebted to the IMA and CSIR for part sponsorship of this work and to Mrs L. Dorfling, of the CSIR Division of Textile Technology, for her valuable assistance.

A special word of thanks is also due to my wife for the many long hours spent in typing, checking and preparing this review.

THE USE OF PROPRIETARY NAMES

The names of proprietary products where they appear in this review are mentioned for information only. This does not imply that they are being recommended to the exclusion of other similar products.

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