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Part I: Its Measurement Employing a Photo-Electric Technique

by

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ABSTRACT

A photo-electric device (called a Medullameter), which provides a measure of the amount of light scattered at the fibre/medulla interface of all medullated fibres in a sample, and therefore of the degree of medullation, was built at SAWTRI based upon the design of an instrument developed at the Wool Research Organisation of New Zealand.

In this introductory study, the instrument as well as certain factors which could affect its readings were evaluated and a calibration and test method developed for mohair. The instrument was found to be stable over long periods and suitable for the routine measurement of medullation in mohair.

A fairly good relationship was found between the Medullameter reading and the percentage area medullation, as measured on a projection microscope although the correlation was not good enough to allow the one to be accurately predicted from the other. If it is assumed that all fibres with a medulla to diameter ratio greater than 0,6 were kemp then, for the mohair samples studied, the kemp fibres contributed approximately 80% towards the Medullameter readings.

INTRODUCTION

Medullated fibres, which have a hollow or partially filled central canal (medulla) running in either a continuous or fragmented form along their length, can be a source of problems in many end uses[1-7] mainly because they tend to differ in appearance from the rest of the fibres.

Of all the types of medullated fibre which occur in both wool and mohair[5-7], those collectively called *kemp* and which tend to have a relatively large medulla and to be relatively coarse, probably are the most unwanted in the final product. There are occasions, however, when such fibres are acceptable or even desirable for special effects, such as in certain types of carpets and woollens. More generally, however, the presence of even a small amount of kemp in a high quality mohair, normally 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 more circular in cross-section than lower grades[8]. Kemp is always present in the fleece of the kid[7, 9] and is present in the hair of all animals[10] to a greater or lesser extent[9]. The amount of kemp can be controlled by selective breeding but it seems that it is not possible to eliminate it entirely[5,11]. In well-bred mohair the kemp count is generally low (less than 1% according to von Bergen[12]) and after processing a value of less than 0,3% should be aimed at, according to Spencer[10]. Years ago, the amount of kemp in South African mohair was found to range from approximately 0,5% to 11%[7,11]. Since then the quality of South African mohair, which is now generally rated the best in the world, has greatly improved with respect to kemp. Nevertheless, a recent authorative opinion[13] is that there is still room for improvement in the latter respect.

As already mentioned, kemp is a special, extreme, case of medullation but there does not appear to be a readily definable and measurable distinction between kemp and other medullated fibres. There are traditional definitions of kemp[14,15] but it seems that any medullated fibre with a large ratio of medulla diameter to fibre diameter will have the same appearance as kemp. According to ASTM method D2968-75 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 *med* fibres. Furthermore, all fibres with a medulla, whether it be continuous, broken or lattice type, are collectively called *medullated* fibres. Fibres with a relatively large medulla and which have cell membrane residues criss-crossing the medulla (i.e. the so-called lattice types) are probably the worst kind of medullated fibre.

Apart from the ratio of the medulla diameter to that of the fibre, the length of the medullated fibre is another very important property. Aggravating the matter is the fact that the diameter of kemp also seems to increase with mohair length and diameter[16]. Furthermore, the degree of kempiness (% kemp) in mohair also tends to increase as mean fibre diameter increases[5].

The main problems associated with the presence of kemp (and possibly medullated fibres in general) are their chalky white appearance, apparent inability to dye to the same shade as the solid fibres and their effect on handle, stiffness and prickliness. The chalky white appearance of kemp is caused by the decreased length of the light path through the fibre material and light refraction at the fibre/medulla interface. This, and not poor dyeability, is mainly the cause of the different appearance of kemp fibres after dyeing[17,18]. Because medullated fibres (and particularly kemp) tend to lie on the surface of the yarn[19] (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.

Not surprising, Srivastava[5] 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.

Clearly, a knowledge of the degree of kemp in a sample is desirable, and various methods exist for measuring the degree of medullation, including manual separation, microscopic[20-22,23], flotation, gravimetric/chemical[24] and refraction[4,25]. According to Khan[3] the microscopic method provides a better quantitative index of medullation than any other method. Most of the abovementioned methods are rather time consuming, however, and also require a rather skilled and experienced operator.

Photo-electric methods based upon differences in light refraction 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 would also affect the photo-electric values. Furthermore, the occurrence of vacuoles[26] (small voids), which seems to be a characteristic of mohair rather than of wool[27], could also affect medullation values obtained photo-electrically, the occurrence of vacuoles apparently increasing with increasing mean fibre diameter. Photo-electric techniques cannot, however, 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, as found by Ross[28], photo-electric methods could be suitable for estimating the degree of kemp in mohair. Because the ratio of kemp to med fibres varies from mohair to mohair[5] (the number of kemp fibres tending to be smaller than that of the med fibres[5]) such estimates of kempiness can be expected to be only approximate.

Recently an instrument, the WRONZ Medullameter, was developed by the Wool Research Organisation of New Zealand (WRONZ) for measuring the degree of medullation optically (photo-electrically). Because of the apparent potential of this instrument for providing a relatively quick and reliable measure of medullation coupled with the fact that medullation, more particularly kempiness, is most undesirable in good quality mohair, it was decided to investigate the application of this type of instrument in the measurement of medullation in mohair. This report deals with an introductory study which was undertaken to evaluate the instrument and to establish a test method for the routine measurement of medullation.

EXPERIMENTAL AND STANDARDISATION OF METHOD

The Instrument, its Principle of Operation and Calibration

An instrument, called the Medullameter, and which is based upon the WRONZ design (see also references 4 and 28) was constructed at SAWTRI (See Figs 1 and 2). In concept and mechanical design it closely follows the original WRONZ design with some minor changes in the electronics. The changes in the electronics were dictated by the availability of components rather than to

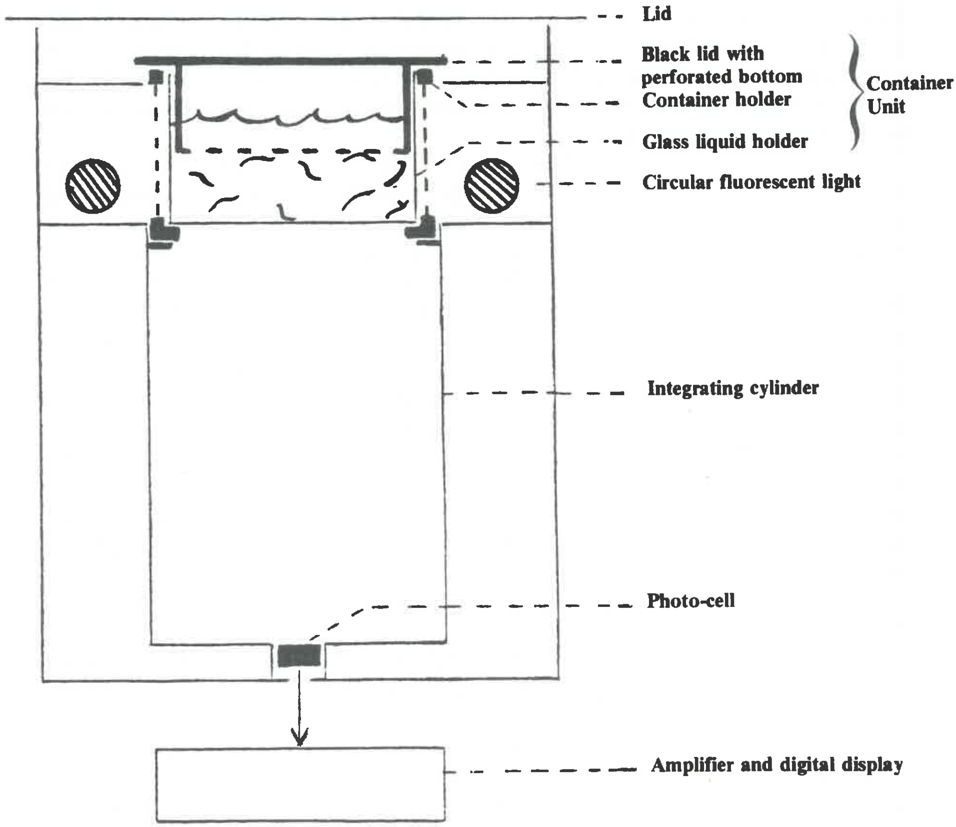


Fig 1 – Diagram of Medullameter

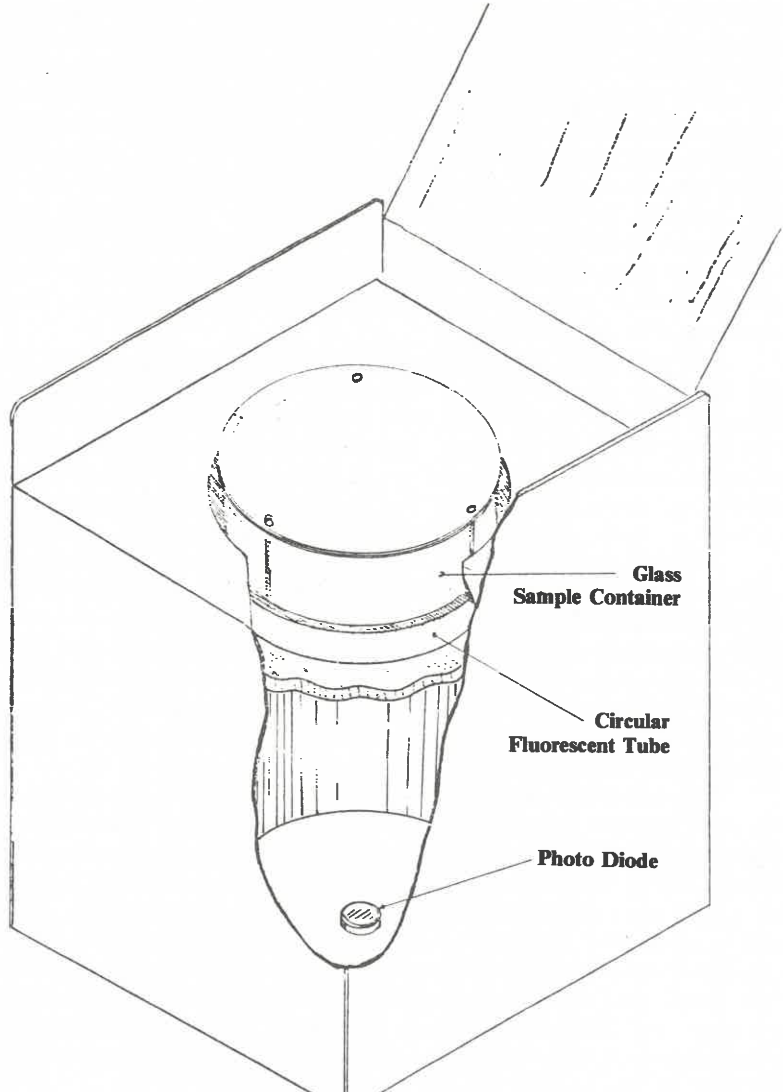


Fig 2 – Cut-away sketch of Medullameter improve on the original design. For ease of operation, the control and indicating sections of the instrument were removed from the body of the instrument and accommodated remotely in a flat desk top package. The instrument uses differences in light refraction to obtain a measure of medullation. Placing a sample of keratin fibre snippets into a liquid having the same refractive index as the fibres, results in light refraction only occurring for those fibres which have a hollow place or core (i.e. medullated fibres) when light passes obliquely from fibre material to medulla void and vice versa. Theoretically, under these conditions, refraction occurs only at the interface between the solid fibre and the medulla void and the amount of refraction (light scattering) for a "unit" mass of fibre is directly proportional to the degree of medullation, expressed as percentage area medullation.

An important consideration when using an optical method based upon light refraction, such as in the present case, is the choice of the liquid in which the fibres are to be immersed, the main considerations being its refractive index, colour and effect on the fibre. Benzyl alcohol, which has a refractive index almost identical to that of wool and close to that of mohair (see Table 1) and which is both colourless and non-toxic was chosen as the dispersing liquid. From the point of view of avoiding air bubbles this liquid is also convenient.

The following procedure, chosen to minimise the effect of factors which could possibly influence the results, was used: The same liquid container was used and it was always filled to the same level (approximately 460 mℓ of liquid). Small marks were made on the container, the container holder and the container lid. By means of these marks the three components could be assembled in exactly the same way relative to each other each time a test was done. These marks also helped to ensure that the container unit as a whole could be placed in the Medullameter so that it was always orientated in the same way.

Zeroing of the instrument was carried out with the container unit, filled as prescribed with benzyl alcohol, in position. Ideally the Medullameter should be calibrated so that its readings approximate the percentage area medullation as measured by the projection microscope. In the present case, however, doing this would have resulted in the Medullameter being incapable of registering small changes ($< 1\%$) in area medullation. This limitation in precision was regarded as unacceptable and consequently the calibration setting was adjusted to the maximum sensitivity possible without sacrificing long term stability. In this case, one Medullameter unit was equal to approximately 0,25% area medullation (not allowing for the effect of fibre diameter) when using samples weighing 500 mg at 65% RH/20° C.

For practical reasons it is important that the Medullameter lends itself to quick and easy calibration. To achieve this, the Medullameter was first calibrated with some fibre samples of known medullation, after which routine calibration checks were undertaken by means of a stainless steel ring constructed

TABLE 1

REFRACTIVE INDICES OF RELEVANT FIBRES AND LIQUIDS

	REFRACTIVE INDEX*
Wool[29]	μ_{s}^{II} : 1,553 to 1,555
	$\mu_{s}^{\perp}$: 1,542 to 1,546
Mohair[30]	μ_{s}^{II} : 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

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

to give quite a high Medullameter reading. The ring gave a reading of 42 units at the particular sensitivity selected. This was equivalent to approximately 6,5% area medullation, which falls near the upper end of the estimated range for mohair. Subsequent calibration therefore merely entailed the zeroing of the instrument with the container filled with benzyl alcohol, and then adjusting the calibration until the required reading was obtained with the stainless steel ring immersed in the liquid. An important requirement of this calibration procedure is that the reflection properties of the ring remains unchanged over long periods. Periodic checks with standard fibre samples are advisable to detect any changes in the reflection properties of the calibration ring. The Medullameter was found to be very stable and exhibited very little drift.

It was found that the Medullameter readings varied according to the position of a small stainless steel rod or the fibre sample in the container. For the fibre samples this only occurred when the fibres were not properly dispersed and remained in a cluster. When the stainless steel element (rod) or the cluster of fibres was placed in the centre of the container the readings tended to be higher than when the rod or sample was placed near the perimeter of the container. It is therefore important always to uniformly distribute the fibres throughout the benzyl alcohol and to place the calibration ring in the same central position.

Table 2 shows that, provided the samples are uniformly distributed throughout the liquid volume, the repeatability was good.

Yellowing of the benzyl alcohol sometimes occurred after prolonged use and it cannot therefore be re-used for extended periods. Nevertheless, provided the benzyl alcohol is not exposed unnecessarily to air, heat or light, it can be used for a fairly long period (Table 3). Various other techniques had to be adopted and precautions taken to ensure accurate and reproducible results, some of the more important ones being given below.

TABLE 2

VARIATION DUE TO RE-DISTRIBUTION OF THE SAME SUB-SAMPLE COMPARED WITH BETWEEN SUB-SAMPLE VARIATION*

SAMPLE	SAME SUB-SAMPLE RE-DISTRIBUTED		USING DIFFERENT SUB-SAMPLES	
	Reading Number	Medullameter Reading	Sub-sample Number	Medullameter Reading
E	1	18,5	1	20
	2	18,5	2	22
	3	18,5	3	18
	4	18,0	4	20
	Mean	18,4	Mean	20,0
	SD	0,25	SD	1,63
	CV %	1,4	CV %	8,2
H	1	48,5	1	48
	2	44,5	2	51,5
	3	46,0	3	46
	4	46,5	4	48
	Mean	46,4	Mean	48,4
	SD	1,65	SD	2,29
	CV %	3,6	CV %	4,7

* — Tested in benzyl alcohol and calibrating ring = 42 Medullameter units

1. Air bubbles must be removed from the liquid since they can effect the readings considerably.
2. The Medullameter lid should be left open between measurements and the container with liquid removed whenever possible so as to prevent possible heat build-up in the liquid which could affect its refractive index and could also possibly accelerate the degradation of the liquid. The actual readings, however, are always taken with the lid closed.
3. It was unnecessary to clean out the inside of the container between tests, any fibres remaining in the container or clinging to the black lid having no measurable effect on the Medullameter reading. Only when changing to a different liquid will it be necessary to clean and dry the container thoroughly.
4. The fibre snippets have to be evenly distributed in the liquid, this being achieved by cutting the fibres into segments approximately 25 mm in length and by thorough stirring.
5. The Medullameter reading should be taken as soon as possible after the fibres have been immersed to minimise any effect due to the liquid penetrating the medulla.
6. The liquid should be filtered between tests to remove the fibres, dust and any other contaminants.
7. Preferably the same sample preparation procedure, particularly cleaning, must always be adhered to. The sample must be scoured according to a method (method B) which will be described presently.

Materials and Method of Sample Preparation

A set of wool tops (prepared by WRONZ from two carpet wools for calibrating the Medullameter) and some greasy mohair samples, selected to cover approximately the same percentage area medullation range as that covered by the WRONZ samples, were used. Some relevant properties of these wool tops, mohair samples and certain other samples are given in Table 4.

The tops were tested in the condition in which they were received, i.e. they were not cleansed or otherwise treated. A sampling method generally used to sample a top for fibre diameter measurement (IWTO-8-61 (E) reprinted 1966) was used. This meant that the amount of top, namely 500 mg, required for a test on the Medullameter was merely cut from a top to the length required (i.e. $\simeq$ 25 mm). Several segments of top (each approximately 25 mm in length) were cut from the one end of the top and were split along their length until the required mass (i.e. 500 mg) was obtained. For routine testing, core samples would ideally

TABLE 3

EFFECT OF "AGE" OF BENZYL ALCOHOL ON MEDULLAMETER READING (MMR)

SAMPLE NUMBER	FRESH BENZYL ALCOHOL (≃ 25 mm snippet length)				BENZYL ALCOHOL APPROX. 1 MONTH IN USE (≃ 25 mm snippet length)				FRESH BENZYL ALCOHOL (≃ 5 mm snippet length)			
	Mean MMR*	SD	CV %	n	Mean MMR*	SD	CV %	n	Mean MMR*	SD	CV %	n
80 D	63,5	1,73	2,73	4	64,2	1,13	1,75	6	62,3	1,50	2,41	4
MOH 1	14,0	0,82	5,83	4	13,9	0,25	1,80	4	—	—	—	—

* — Calibrating ring = 42 Medullameter units

TABLE 4

SOME DETAILS OF MOHAIR AND WOOL SAMPLES*

SAMPLE DESCRIPTION	Overall Fibre DIAMETER** (μm)	MEDULLATION+	
		% Area Medullation	Medullameter Reading++
Miscellaneous Mohair			
A : XFK	29,1 (65)	1,7	15
B : BSH	37,5 (49)	0,5	10
C : BR	39,5 (57)	1,2	7
D : BSYG	31,9 (40)	0,2	9
E : XFH	36,6 (65)	3,1	20
F : BSFK	25,9 (62)	0,6	7
G : BH	35,0 (53)	0,8	10
H : XK	29,0 (98)	6,4	48
I : XH	24,3 (103)	7,8	51
J : BSFH	30,5 (67)	1,8	10
K : Australian	32,6 (52)	1,5	17
MOH 1 : (greasy)	26,4 (38)	1,6	14
MOH 15: (greasy)	47,6 (28)	1,7	11
XFH	35,7 (30)	2,3	13
Kempy mohair	27,6 (54)	6,1	33
M7 : Bas	24,8 (58)	1,3	18
M9 : Bas	23,9 (71)	2,3	22
M11 : Bas	30,6 (96)	6,8	45
Bas Sw	28,1 (31)	8,4	46
MOH 1 : (top)	23,8 —	1,5	15
MOH 10: (top)	38,0 —	0,1	10
MOH 15: (top)	44,8 —	0,9	13
Noils	27,5 —	14,3	52
Miscellaneous Kemp and Med Fibres			
Kemp X	109,3 (56)	81	214
Kemp (from kempy mohair)	69,5 (44)	53	145
Kemp (from sample H)	113,3 —	75	155
Kemp (from sample I)	72,5 —	61	167
Kemp (pooled)	70,5 —	59	147
Med (pooled)	46,2 (34)	19,9	86

* — figures in parenthesis are the respective CV's

** — includes all fibres within the sample

\+ — value is generally based on one measurement only

++ — calibrating ring = 42 Medullameter units

TABLE 4 (continued)*

SAMPLE DESCRIPTION	Overall Fibre Diameter** (μm)	MEDULLATION+	
		% Area Medullation	Medullameter Reading++
Wools			
BR 3 (top)	21,5 —	0	9
BR 16 (top)	25,1 —	0	10
BR 46 (top)	29,4 —	0,2	8
BR 50 (top)	17,3 —	0	8
Carpet Wool			
As received	32,8 —	21,2	81
True kemp only	74,4 (61)	63	171
Kempy wool top	21,4 —	1,9	30
WRONZ Calibration Wools			
0 D	34,0 (51)	0,6	12
20 D	37,4 (73)	3,2	27
50 D	37,9 (72)	8,5	51
80 D	37,4 (70)	10,9	64
100 D	41,8 (75)	19,0	77

* — figures in parenthesis are the respective CV's

** — includes all fibres within the sample

\+ — value is generally based on one measurement only

++ — calibrating ring = 42 Medullameter units

suit the method selected because the fibre length of such samples would be approximately the same as that of the samples used here. The sample was thoroughly blended prior to taking sub-samples for testing.

The greasy mohair samples were sampled as recommended (IWTO-5-60(E)) for fibre length measurement.

Sample Scouring Method

Initially, the samples were scoured in a succession of baths containing petroleum ether, lukewarm water with wetting agent, distilled water, ethyl alcohol and methylene chloride (DCM). This will subsequently be referred to as scouring method A. The samples were then conditioned thoroughly (open on gauze trays) at 65% RH and 20°C for at least 24 hours before testing. All vegetable matter was removed before weighing and testing. It was subsequently observed that for most of the samples scoured in this manner, the fibres had a milky appearance when immersed in benzyl alcohol. It was eventually concluded that the "milkiness" was probably due to traces of ethyl alcohol remaining in the fibres after scouring. Several experiments had been completed before the extent of the problem was realized and before it was eliminated by changing the fibre scouring procedure. The results of the experiments involving scouring method A have been omitted except where the general trends and conclusions were considered unaffected by the "milkiness" effect.

To avoid the possible effect due to ethyl alcohol, referred to above, it was decided to switch to another scouring method. In this method (coded B) the samples were simply scoured in succession in two aqueous baths containing a non-ionic detergent (0,1% by volume), the temperature being between 55 to 60° C. Two rinses in water completed the scouring. Partial drying of the samples was achieved by means of blotting paper after which drying was completed in a ventilated oven at 50° C for 6 hours. Tests were carried out after the vegetable matter had been removed and after conditioning overnight at 65% RH and 20° C. Although a slight degree of "milkiness" was still observed in some samples after this scouring procedure this was assumed to be due to natural variations in the refractive indices of the different samples.

Relationship Between Medullameter Reading and Certain Other Measures of Medullation

It was considered important to determine the relationship between the Medullameter reading and various other measures of medullation so that its results could be compared with those obtained in other studies. In addition, it was also necessary to determine whether mohair in general differed in any way from the WRONZ wool samples and, if so, what the relevance of this was. Therefore the following measures of medullation were also obtained.

1. **Area medullation** was determined as recommended by WRONZ[31], using the basic methods described in IWTO-8-61(E) (Reprinted 1966) and IWTO-12-64(E). It is important to note that this method produces a length-biased result which represents an estimate of the length of medullated fibres as a percentage of the total length of all fibres, allowance also being made for the cross-sectional area of medullation.

To reduce the effect of sampling errors on the relationship between the Medullameter reading and the area medullation, the sub-samples measured on the Medullameter were filtered and rinsed in alcohol and DCM to remove the benzyl alcohol, after which the area medullation of these samples was determined microscopically.

$$\% \text{ area medullation} = \frac{\Sigma d_m + 0{,}8\,\Sigma d_b + 0{,}2\,\Sigma d_f}{\Sigma d} \times 100$$

Where Σd = sum of external diameter of all fibres examined

d_m = diameter of medulla of wholly medullated fibres

d_b = diameter of medulla of broken medullated fibres

d_f = diameter of medulla of fragmentally medullated fibres

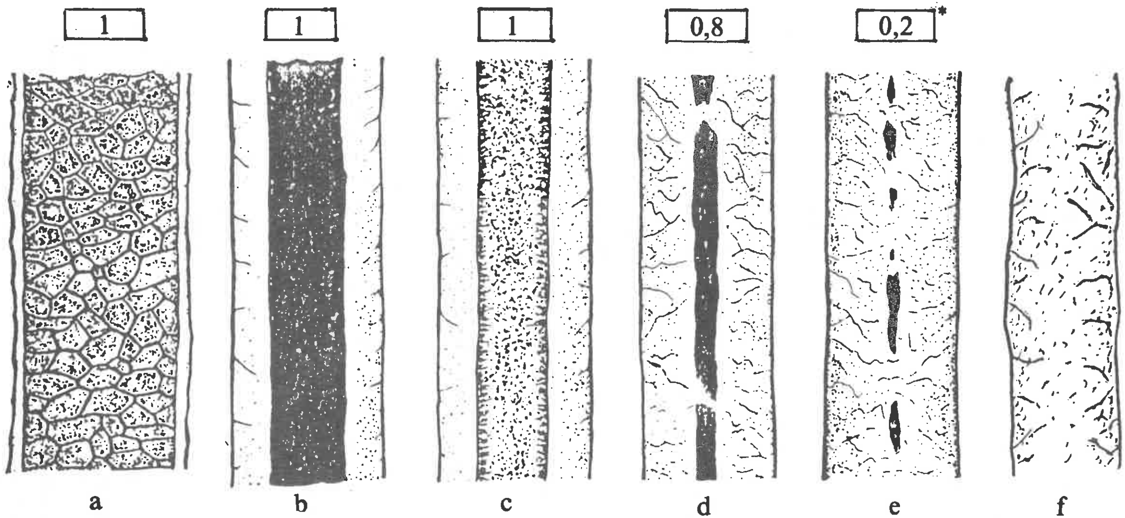


Fig. 3[8] – Simple classifaction of medullae according to their appearance in whole fibre mounts

(a) Unbroken (wide) lattice. (Usual appearance when not infilled by mounting medium).
(b) Simple unbroken. Medium width. (Usual appearance.)
(c) Simple unbroken. Medium width. (Appearance when infilled by mounting medium.)
(d) Interrupted (broken.)
(e) Fragmental
(f) Non-medullated

* — Correction factors which are to be applied to the medulla diameter measurement when calculating the percentage area medullation.

TABLE 5

DIFFERENT MEASURES OF MEDULLATION FOR SOME MOHAIR AND WOOL SAMPLES*

SAMPLE PARTICULARS					DEGREE OF MEDULLATION					
					Photo-Electric	Microscopic**			Visual Sorting	
		Fibre Diameter								
SAMPLE NUMBER	CAPE CLASSING SYMBOL	ALL FIBRES		unmeddulated Fibres Only	Medullameter Reading	% Area Medullation	% By Number	Volume % of Medullation (P_1)	% Medullation by Mass	Number of Medullated Fibres per Gram
		Mean (μm)	CV (%)	Mean (μm)						
WRONZ WOOLS										
OD/100AO		33,6			12,4 (1,1)	0,5 (0,2)	2,88 (0,4)	0,23	7,6 •	—
20D/80AO	—	34,1			26,6 (1,4)	2,9 (0,8)	6,12 (0,6)	1,86	14,3 •	—
50D/50AO	—	37,2			50,5 (2,9)	7,5 (1,1)	13,5 (0,8)	4,98	27,5 •	—
80D/20AO	—	39,6			64,6 (1,3)	10,6 (1,4)	20,0 (1,0)	6,40	41,2 •	—
100D/OAO	—	43,6			77,4 (3,0)	16,0 (5,1)	28,7 (1,1)	8,81	50,2 •	—
MOHAIR SAMPLES										
A	XFK	29,1	65	28,6	15 • —	1,7 • —	—	—	3,2 •	360 •
B	BSH	37,5	49	37,4	10 • —	0,5 • —	—	—	3,5 •	440 •
C	BR	39,5	57	38,9	7 •	1,2 • —	—	—	5,7 •	479 •
D	BSYG	33,0	40	32,6	8,9 • (1,0)	0,5 (0,4)	0,41 (0,2)	0,37	1,4 •	178 •
E	XFH	36,6	65	35,5	20,0 (1,6)	3,6 (2,3)	3,00 (0,4)	4,67	7,0 •	621 •
F	BSFK	25,9	62	25,7	7 • —	0,6 • —	—	—	1,1 •	273 •
G	BH	34,9	53	34,2	10,3 (1,3)	2,0 (0,8)	2,04 (0,3)	1,73	4,8 •	340 •
H	XK	29,3	98	26,9	48,3 (2,3)	7,4 (3,0)	3,06 (0,4)	15,08	20,1 •	1943 •
I	XH	24,3	103	22,3	51 • —	7,8 • —	—	—	19,1 •	3510 •
J	BSFH	30,5	67	30,0	10 • —	1,8 • —	—	—	2,0 •	255 •
K	AUSTR.	33,6	52	33,0	17 (1,4)	2,2 (1,9)	1,61 (0,3)	3,75	5,3 •	701 •
L	—	26,4	38	26,0	13,8 (1,6)	1,6 (0,5)	1,64 (0,3)	1,51	—	—
M	—	47,6	28	46,9	10,6 (0,8)	1,7 (0,9)	1,95 (0,3)	0,80	—	—
N	BAS	28,1	56	25,3	46,4 (2,6)	8,4 (0,5)	5,57 (0,5)	25,02	—	—
O	XFH	35,7	33	34,9	12,8 (1,0)	2,3 (0,3)	2,60 (0,3)	0,94	—	—
P	—	29,4	54	29,0	41,9 (5,4)	10,0 (2,5)	6,03 (0,5)	41,87	—	—
Q	XH	27,6	50	—	28,3 • (1,1)	5,8 (2,4)	—	—	—	—
R	—	25,2	32	—	30,0 • (1,4)	5,1 (0,8)	—	—	—	—
W +	—	29,1	—	25,2	64,0 (1,4)	12,2 (1,2)	6,81 (0,6)	22,73	—	—
X +	—	30,3	—	25,7	70,0 (4,2)	14,3 (3,4)	9,18 (0,6)	24,09	—	—
Y +	—	29,7	—	26,5	44,3 (0,4)	9,3 (1,3)	5,14 (0,7)	40,60	—	—
Z +	—	32,4	—	25,7	56,8 (1,9)	11,2 (2,4)	7,42 (0,6)	53,41	—	—

* — Mohair samples scoured according to method A and figures in parenthesis are the respective standard deviations.
Each result represents the average of four determinations except for those marked with a dot (•) which were based upon only one or two measurements.

** — At least 500 snippets were read per slide (giving a total of approximately 2000 readings per sample).

+ — Special blends of mohair and kemp for extending the range.

TABLE 6

SOME PROPERTIES OF MEDULLATED FIBRES TAKEN FROM CERTAIN MOHAIR SAMPLES

SAMPLE NUMBER	RESULTS OBTAINED MICROSCOPICALLY*																	OBTAINED BY VISUAL SORTING					
	% by Number					Average Diameter of medullated fibre (μm)				Average Medulla Diameter (μm)				Average Med.-Ratio				No. of Medullated fibres per gram			% by Mass		
	Kemp	Med	Overall	Lattice type	Medulla > 40 μm	Kemp	Med	Overall	Lattice type	Kemp	Med	Overall	Lattice type	Kemp	Med	Overall	Lattice type	Kemp	Med	Total	Kemp	Med	Total
WRONZ WOOLS																							
OD/100AO	0,05	2,83	2,88	0,35	—	46 (-)	45 (23)	45 (23)	45 (21)	18 (-)	9 (45)	10 (56)	13 (33)	0,78 (-)	0,21 (45)	0,22 (55)	0,32 (43)	—	—	—	4,1	3,5	7,6
20D/80AO	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6,8	7,5	14,3
50D/50AO	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	19,9	7,6	27,5
80D/20AO	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	31,3	9,9	41,2
100D/OAO	3,97	24,68	28,65	8,17	—	87 (28)	53 (27)	58 (34)	68 (33)	63 (39)	17 (67)	23 (88)	37 (68)	0,70 (13)	0,30 (46)	0,36 (54)	0,49 (37)	—	—	—	39,2	11,0	50,2
MOHAIR SAMPLES																							
A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	168	192	360	1,7	1,4	3,2
B	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	179	261	440	0,9	2,5	3,5
C	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	50	429	479	1,9	3,8	5,7
D	0,21	0,21	0,41	0	0,15	68 (29)	45 (36)	56 (36)	—	46 (41)	23 (59)	34 (58)	—	0,67 (11)	0,47 (30)	0,57 (26)	—	73	105	178	0,7	0,7	1,4
E	1,40	1,60	3,00	0,21	1,65	92 (25)	62 (23)	78 (32)	87 (30)	71 (31)	(25) (57)	(47) (63)	69 (59)	0,71 (31)	0,37 (42)	0,53 (41)	0,67 (59)	497	124	621	6,0	1,0	7,0
F	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	143	130	273	0,7	0,4	1,1
G	0,64	1,39	2,04	0,11	0,64	73 (24)	58 (26)	63 (27)	81 (30)	52 (33)	24 (40)	33 (55)	59 (41)	0,70 (10)	0,40 (28)	0,50 (34)	0,72 (12)	210	130	340	4,1	0,7	4,8
H	2,09	0,97	3,06	0,24	2,23	107 (35)	66 (33)	95 (40)	102 (39)	82 (40)	30 (39)	67 (55)	78 (38)	0,76 (11)	0,46 (24)	0,67 (25)	0,76 (7)	1818	135	1943	19,1	1,0	20,1
I	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3275	235	3510	18,6	0,5	19,1
J	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	140	115	255	1,3	0,7	2,0
K	1,07	0,54	1,61	0,49	1,07	88 (24)	59 (16)	78 (29)	86 (25)	67 (29)	25 (41)	53 (52)	57 (41)	0,74 (10)	0,42 (36)	0,63 (29)	0,64 (30)	663	38	701	5,2	1,0	5,3
L	0,51	1,14	1,64	0,32	0,25	70 (52)	45 (21)	53 (45)	81 (52)	50 (64)	18 (46)	28 (84)	52 (82)	0,69 (11)	0,40 (31)	0,49 (36)	0,59 (38)	—	—	—	—	—	—
M	0,74	1,20	1,95	0,60	0,88	107 (28)	63 (26)	81 (36)	106 (31)	77 (34)	21 (63)	42 (79)	76 (37)	0,71 (11)	0,32 (51)	0,47 (50)	0,70 (14)	—	—	—	—	—	—
N	2,25	3,32	5,57	0,51	2,57	98 (24)	61 (27)	76 (35)	79 (42)	72 (31)	24 (53)	43 (67)	48 (63)	0,72 (11)	0,38 (37)	0,52 (39)	0,55 (45)	—	—	—	—	—	—
O	0,75	1,85	2,60	0,31	0,88	95 (28)	57 (28)	68 (39)	97 (19)	70 (36)	19 (72)	33 (87)	72 (25)	0,72 (10)	0,31 (50)	0,43 (54)	0,73 (8)	—	—	—	—	—	—
P	3,67	2,35	6,03	1,19	4,05	102 (21)	62 (24)	86 (36)	96 (22)	75 (37)	25 (48)	56 (60)	65 (38)	0,73 (10)	0,40 (34)	0,60 (32)	0,65 (25)	—	—	—	—	—	—
W+	—	—	—	—	4,23	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
X+	5,12	4,00	9,13	—	5,37	—	—	—	—	68 (35)	25 (54)	50 (59)	—	—	—	—	—	—	—	—	—	—	—
Y+	—	—	—	—	2,67	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Z+	3,33	4,08	7,42	1,14	4,04	97 (25)	66 (27)	80 (32)	94 (24)	71 (31)	27 (47)	46 (59)	68 (32)	0,72 (9)	0,40 (33)	0,54 (36)	0,71 (12)	—	—	—	—	—	—

* — Medullated fibres classed into kemp and med groups as suggested in ASTM D2968-75 (CV values given in parenthesis)

Note: In mohair the lattice type fibres fall mainly in the Kemp group whereas in the wools examined it falls mainly in the med group

Fig 3[8] illustrates the differences between the various types of medullation as seen microscopically and which need to be taken into consideration when calculating the area medullation[31].

2. **Medullation by number** was determined according to the IWTO-12-64(E) method. The proportions of kemp and med fibres were also estimated, classifying the medullated fibres as previously mentioned (ASTM method D2968-75). It was also recorded which of the medullated fibres appeared under the microscope to be of the lattice type (because these probably account for most of the kemp fibres) and the percentage, by number, of lattice types was calculated.

3. **The proportions (in per cent) of total medullated, kemp only and med only fibres** in a sample were determined visually as follows: Kemp was defined as all fibres having a "milky" or chalky appearance when viewed in air against a black background. Med fibres were those which appeared obviously "milky" in benzyl alcohol when viewed under incandescent light after the kemp had been removed in the above manner. Thereafter, the fibres were rinsed first in ethyl alcohol and then in DCM to remove the benzyl alcohol so that the fibres could be weighed. The number of kemp and med fibres, respectively, as well as their total per gram of mohair were obtained and after conditioning the percentage by mass of each component was also determined.

4. **Volume percentage of medullation.** The volume percentage of medullation (P_1) was estimated[23] from the fibre and medulla diameters as determined microscopically rather than from the medulla cross-sectional areas (as recommended in BS 3209:1968). The volume percentage of medullation can be estimated in various ways from diameter measurements and these different estimates are interrelated and can be derived from each other[23].

The results obtained by the various methods are summarised in Tables 5 and 6.

RESULTS AND DISCUSSION

Effect of Fibre Diameter on Medullameter Reading

When the refractive index of fibre and liquid do not match exactly, there is a possibility that fibre diameter can have an effect on the Medullameter readings, particularly at low readings. Mohair samples having a low degree of medullation but differing widely in mean fibre diameter, were selected for the purpose of ascertaining the effect of mean fibre diameter. The samples were freed of medullated fibres following the method described earlier for visually determining the amount of medullated fibres in a sample and then cleansed. The results of this experiment (Tables 7 and 8) indicate that the effect of fibre diameter on the Medullameter values was small and, for all practical purposes, probably negligible.

Effect of Liquid and Scouring Method

Results obtained in two different liquids, each having a different refractive index but close to that of mohair, are shown in Table 9 for mohair samples scoured according to method B. At the same area medullation, lower Medullameter readings were obtained in o-dichlorobenzene than in benzyl alcohol (see also Figs 4 and 5). Figure 4 also shows that the readings obtained in the different liquids correlate well, indicating that the Medullameter reading is reproducible and that, although the liquid affects the absolute values it should not affect the ranking of samples. The line of area medullation vs Medullameter reading of mohair scoured by method B (Fig 5) for o-dichlorobenzene very nearly passes through the zero point which indicates that, were it not for its pungent odour and possible health hazard, this liquid would be more suitable than benzyl alcohol. This is because the former has a refractive index which matches that of mohair more closely (see Table 1) than is the case for benzyl alcohol. O-dichlorobenzene also has further advantages in that it causes no problems with air-bubbles and it filters more easily than benzyl alcohol.

At the same level of area medullation, scouring method B produced lower Medullameter readings than scouring method A (see Table 9 and Fig 5) due to the milkiness previously referred to.

Relationship Between Medullameter Reading and Percentage Area Medullation

A preliminary experiment, to obtain an estimate of the approximate ranges of medullation for mohair (and certain wools) as well as the magnitude of the relative values for kemp and med fibres from various origins, was carried out. Figure 6 illustrates the results obtained and indicates that, over such a wide range, there is a non-linear relationship between the Medullameter readings and the area medullation. Fibre elepticity together with the method used to measure the area medullation could partly account for this non-linearity. In general, all the results appear to lie on the same curve. The scatter of the results is probably mainly due to random errors in the estimates of the area medullation, the latter in most cases being based upon the results obtained on only one microscope slide, involving about 500 snippet readings.

Because the main objective of this work was the measurement of medullation in mohair and because mohair in general, and South African

TABLE 7

EFFECT OF FIBRE DIAMETER ON MEDULLAMETER READINGS (MEDULLATION-FREE SAMPLES DRIED IN VARIOUS WAYS)*

Sample	Mean Fibre Diameter (μm)	MEDULLAMETER READING Pre-drying time (min)**				Mean
		0	15	30	60	
Mohair						
MOH 1	25,9	15	16	17	21	17,3
MOH 15	45,6	13	15	15	24	16,8
Wool						
BR 50	18,1	9	13	12,5	12	11,6
BR 46	29,2	10	10	11,5	11	10,6
Mean		11,8	13,5	14,0	17,0	

* — Tops which were free of medullated fibres were used and tests were carried out in benzyl alcohol.

** — Dried in oven at 80° C for the periods indicated before overnight conditioning at 65% RH and 20° C.

TABLE 8

EFFECT OF FIBRE DIAMETER ON THE MEDULLAMETER READING (MEDULLATION-FREE SAMPLES)*

Sample	Mean Fibre Diameter (μm)	CV of Fibre Diameter (%)	% Area Medullation Before Removing Medullated Fibres	% Area Medullation After Removing Medullated Fibres	Medulla-meter Reading
F	24,2	29,4	0,64	0,05	4
MOH 1	25,7	30,9	1,64	0,06	4
B	38,6	23,1	0,47	0,01	6,5
MOH 15	45,8	25,3	1,65	0,00	5
MEAN MEDULLAMETER READING					4,9

* — Greasy mohair samples, virtually free of medullated fibres and cleansed according to method B, were tested in benzyl alcohol.

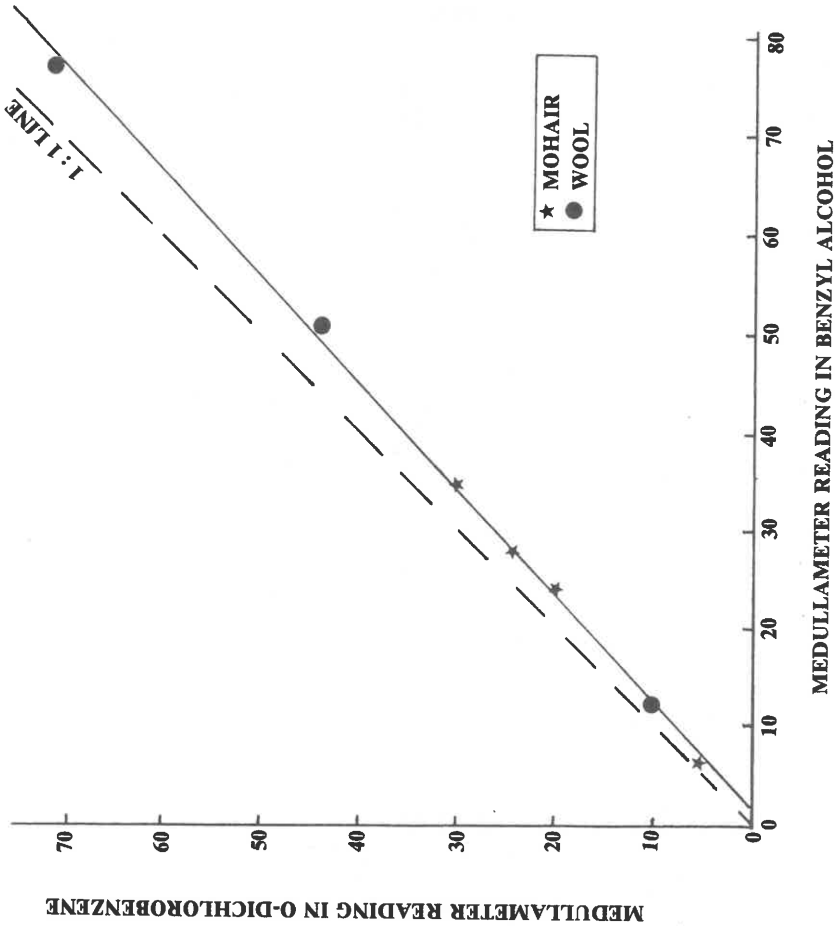


Fig. 4 – The relationship between Medullameter readings obtained in two different liquids

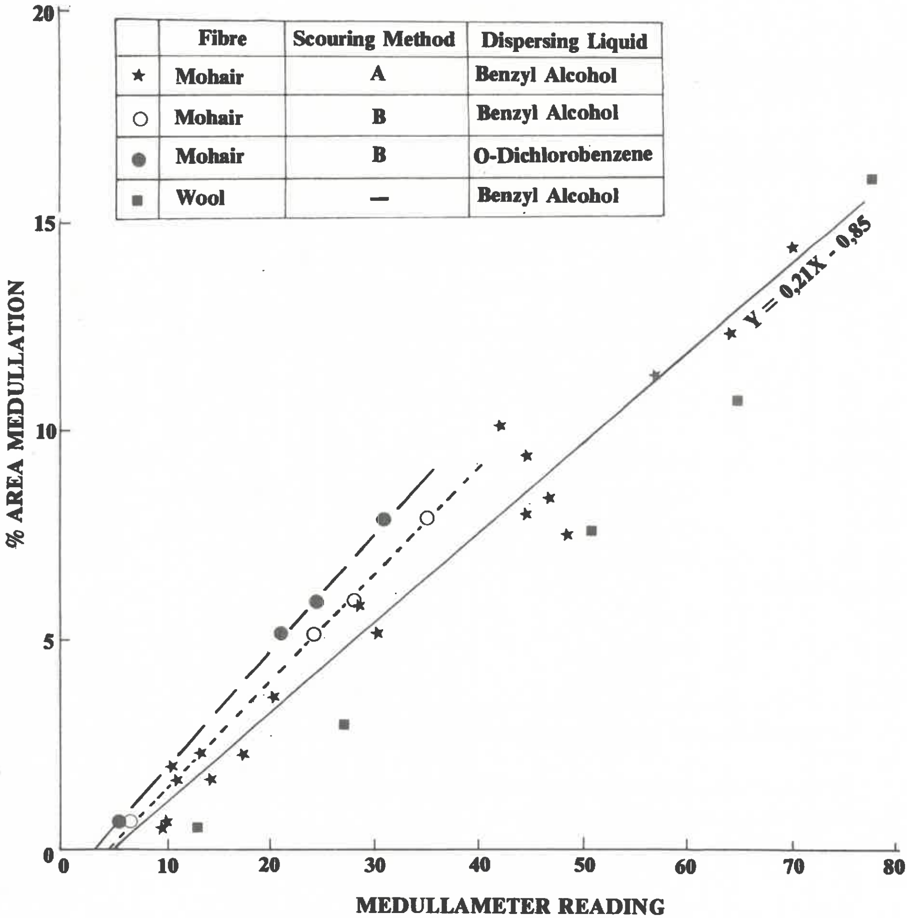


Fig. 5 – The relationship between area medullation and Medullameter reading

TABLE 9

COMPARISONS BETWEEN DIFFERENT SCOURING METHODS AND DIFFERENT DISPERSING LIQUIDS*

Sample	Mean Diameter For All Fibres (μ m)	Medullameter Reading			% Area Medulla-tion
		Scouring Method B		Scouring Method A	
		Fibres dispersed in			
		Benzyl Alcohol	O-dichloro-benzene	Benzyl Alcohol	
Mohair					
MOH 15	43,9 (31)	6,1 (10)	5,3 (7)+	9,5 (7)	0,6 (74)
50/50	25,2 (32)	23,8 (4)	20,5 (3)+	30,0 (5)+	5,1 (16)
XH	27,6 (50)	27,9 (5)	24,3 (7)+	28,3 (4)+	5,8 (41)
Bas Sw	28,4 (56)	34,8 (10)	30,5 (7)+	44,3 (9)	7,9 (23)
Wronz Wools**					
0 D	34,0 (51)	—	10 (0)+	12,4 (9)	0,5 (36)
50 D	37,9 (72)	—	43,8 (2)+	50,5 (6)	7,5 (15)
100 D	41,8 (75)	—	70,5 (5)+	77,4 (4)	15,9 (32)

* — Calibrating ring = 42 Medullameter units and the figures in parenthesis are the respective CV's in %.

\+ — Average of only 2 determinations, all other figures are the averages of four determinations.

** — Tested as received (i.e. not scoured).

mohair in particular, has a low degree of medullation (see Fig 6) it was decided that a range of 0-20% area medullation would cover the entire range of medullation encountered in practice in mohair (in fact a range of 0 to 10% may even suffice). As has already been mentioned, such a restricted range made it possible to increase the sensitivity of the instrument so that each Medullameter unit was equivalent to a fraction of one per cent of area medullation (very approximately equal to about 0,25% area medullation). A selected range of wool and mohair samples was measured on this more sensitive scale and their area medullation also determined so as to establish the following:

1. The relationship between the Medullameter reading and the area medullation for the limited range chosen;
2. The accuracy to which the area medullation could be estimated by means of the Medullameter reading;
3. To ascertain whether the WRONZ calibration wools could be used for general calibration purposes, and
4. To determine the reproducibility of the Medullameter readings.

The results discussed here were obtained on samples cleansed by method A and were thus affected, to some extent, by milkiness as mentioned earlier. Nevertheless, the within-sample variation of both the Medullameter readings and area medullation results obtained on samples scoured by method B (the recommended method) was similar to those obtained on samples scoured by method A (see Tables 5 and 9). It can therefore be assumed with safety that the trends observed for the samples scoured according to method A will also apply to results obtained on samples scoured by method B.

A linear regression analysis, when both X (Medullameter reading) and Y (area medullation) are assumed to be subject to error, was carried out on the pooled results (see Table 5) and the following relationship was obtained:

$$Y = 0,21X - 0,85 \qquad (1)$$

The curve corresponding to the above relationship has been superimposed onto the points in Fig 5. When the usual "least squares" regression (i.e. when only X is assumed to be subject to error) was carried out a similar equation resulted, viz:

$$Y = 0,22X - 1,31 \qquad (2)$$

where n = 14 and r = 0,97.

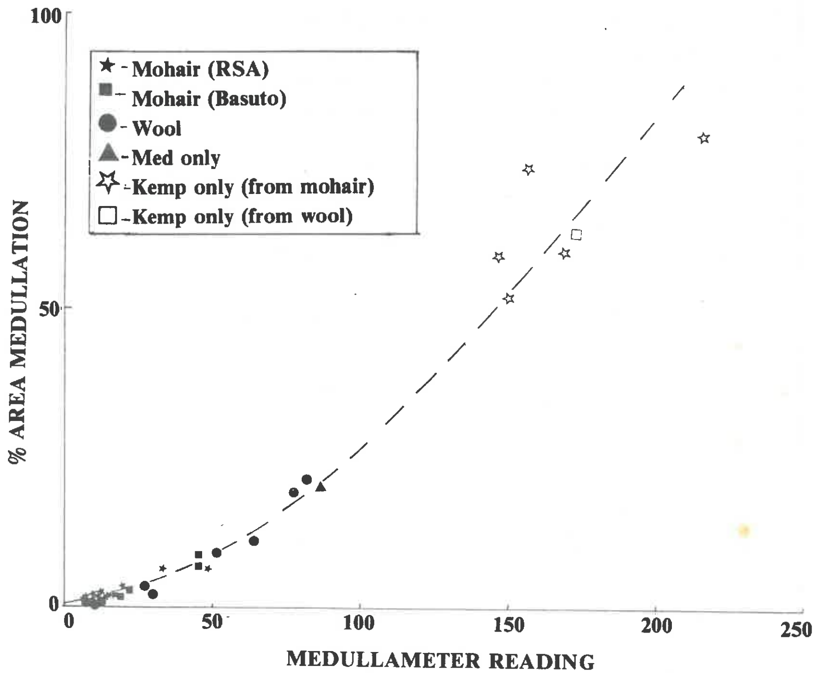


Fig. 6 – The relationship between area medullation and Medullameter readir for some mohair, wool, kemp and med fibres

Ross[28] found approximately the same correlation between the medui area per unit mass and a photoelectric measure of medullation.

According to the first analysis, for a given X, the confidence limit of a future prediction of Y was about 3% area medullation, where the X-value is obtained by averaging the readings of four sub-samples. Therefore, although the parameters are highly correlated, the Medullameter readings cannot be used for accurate prediction of area medullation and vice versa.

There could be various reasons for the scatter in the results, including:

1. Inaccuracies in the area medullation reading.
2. Sampling errors.
3. Slight errors due to the distribution of fibre snippets in the benzyl alcohol.
4. The presence of vacuoles which can vary greatly in frequency and appearance between samples[26].

5. The effect of cell membranes such as those in lattice type medullated fibres which mainly occur in kemp. For this reason the number of lattice type fibres present in a sample may be important.
6. Fibre surface differences (especially when refractive indices do not match).
7. Possible variations in fibre colour (e.g. stains, weathering yellowness and pigmentation).
8. Differences in milkiness due to varying traces of alcohol in the fibre when using scouring method A.
9. The distorting effect of apparent diameter, due to the cortex acting as a lens.
10. Reflection from ends of small sections when the medulla is discontinuous.

According to the CV's given in Table 10, the Medullameter values were far more reproducible than the percentage area medullation values, particularly when the latter was based upon one slide only.

The difficulty in obtaining accurate and reproducible estimates of the percentage area medullation is clear from the results presented in Tables 10 to 12. If the number of medullated fibres per slide varies as much as shown in Table 12 then this, together with the fact that the medulla size can vary greatly, could clearly be the source of large variations.

Another reason for the poor fit may be fibre ellipticity, more particularly if the elipticity varies from sample to sample in such a way that it is not related to the degree of medullation. The ellipticity can lead to an overestimate of the area medullation because flat or oval fibres will tend to lie with their major (long) axis in the plane of the slide. It is generally accepted that course fibres tend to have oval or elliptical cross-sections, with coarser kemp fibres probably more elliptical and even tending towards a "flattened" shape. Another point to bear in mind is that the CV's of both the Medullameter reading and area medullation are larger at the lower end of the scale, where most mohair samples may lie.

In conclusion, the Medullameter gives an acceptable and reproducible estimate of the medullation of mohair. For accurate estimates of both the Medullameter reading and area medullation the most critical factor is probably one of sampling. Perhaps it should be emphasized that the Medullameter provides *another* measure of medullation which is fairly highly correlated to area medullation but which it does not necessarily predict accurately.

Relationship between the Medullameter Reading and Some Other Measures of Medullation

Some other measures of medullation are summarised in Table 5 together

TABLE 10

A COMPARISON OF THE VARIABILITY OF RESULTS OBTAINED WITH DIFFERENT METHODS OF MEASURING MEDULLATION*

Sample Number	Medullameter Reading**			% Area Medullation***		
	Mean	SD	CV %	Mean	SD	CV %
D	8,9	1,03	11,6	0,48	0,41	85
G	10,3	1,26	12,2	1,97	0,84	43
MOH 15	10,6	0,75	7,1	1,65	0,90	55
XFH	12,8	0,96	7,5	2,27	0,33	15
MOH 1	13,8	1,55	11,2	1,64	0,53	32
K	17,0	1,41	8,3	2,22	1,86	84
E	20,0	1,63	8,2	3,60	2,25	63
Kempy Mohair	41,9	5,41	12,9	10,04	2,49	25
Y	44,3	0,35	0,8	9,31	1,34	14
Bas Sw.	46,4	2,59	5,6	8,36	0,54	6
H	48,3	2,29	4,7	7,33	3,05	41
Z	56,8	1,85	3,3	11,22	2,37	21
W	64,0	1,41	2,2	12,22	1,22	10
X	70,0	4,24	6,1	14,30	3,38	24
Average CV %			7,26	Average CV %		35,6

* — *each* result based on determinations obtained on 4 different sub-samples.

** — using benzyl alcohol and calibrating ring = 42 Medullameter units.

*** — one determination (result) was based on readings obtained on one slide (i.e. about 500 snippets per slide were read).

with the Medullameter and area medullation results. Table 13 is a summary of the statistical relationships between the Medullameter reading and the various other measures of medullation and Fig 7 illustrates certain of the trends.

Generally, within a fibre type, the Medullameter reading was fairly closely related to the other measures of medullation except in the case of the volume medullation (results not shown). Nevertheless, in practice the relationship will greatly depend upon the number of medullated fibres, the size of the medulla and how these two factors are combined in a sample. Rough estimates of the other measures of medullation may therefore be obtained from Medullameter readings.

Generally, good relationships were obtained between the different measures of medullation for the WRONZ standard tops. This is probably due mainly to the fact that these tops were all a blend of only two different samples and therefore the effects of other disturbing factors were minimized.

TABLE 11

THE REPRODUCIBILITY OF % AREA MEDULLATION ESTIMATES

Sample Number	% AREA MEDULLATION	
	1st Trial	2nd Trial
MOH 15	1,08 2,80 0,80 1,90	0,88 0,46 0,02 0,07
Mean SD CV %	1,65 0,90 55	0,57 0,42 74
Bas Sw	8,27 7,96 8,07 9,14	9,37 8,66 5,25 8,29
Mean SD CV %	8,36 0,45 6,4	7,89 1,82 23,0

TABLE 12

THE VARIATION IN THE NUMBER OF MEDULLATED FIBRES PER SLIDE (500 READINGS)*

Sample Number	NUMBER OF MEDULLATED FIBRES PER SLIDE**				Mean	SD	CV %
	Slide Number						
	1	2	3	4			
D	3,0	1,0	3,7	0,9	2,2	1,4	66
E	14,9	23,2	9,1	13,6	15,2	5,9	39
G	13,4	7,1	8,8	12,5	10,4	3,0	29
H	22,2	19,0	11,2	12,3	16,2	5,3	33
K	3,3	14,7	5,8	6,3	7,5	5,0	66
MOH 1	8,1	5,2	8,3	11,6	8,3	2,6	32
MOH 15	8,5	11,4	6,2	13,0	9,8	3,0	31
Bas Sw	28,7	29,2	29,7	24,2	28,0	2,5	9
XFH	12,3	14,1	11,3	15,3	13,3	1,8	14
Kempy Mohair	32,4	29,4	32,8	25,3	30,0	3,5	12

* — only samples with naturally occurring medullated fibres were used.

** — adjusted to represent the number of medullated fibres per 500 snippets.

TABLE 13

THE RELATIONSHIPS BETWEEN MEDULLAMETER READING AND VARIOUS OTHER MEASURES OF MEDULLATION FOR SOME MOHAIR SAMPLES*

Medullameter Reading = $0{,}104\ X_1^2 + 9{,}815$; n = 11 and r = 0,97

Medullameter Reading = $0{,}170\ X_2^{0{,}708}$; n = 11 and r = 0,90

Medullameter Reading = $7{,}741\ X_3 + 2{,}003$; n = 14 and r = 0,93

Medullameter Reading = $-0{,}042\ X_4^2 + 2{,}911\ X_4 + 8{,}965$; n = 14 and r = 0,91

where X_1 = percentage medullation by mass,

X_2 = total number of medullated fibres per gram of fibre,

X_3 = percentage by number of medullated fibre and

X_4 = volume per cent of medullation

* All regression equations are significant at the 95% level or better.

From Fig 7 it appears that the relationship between Medullameter reading and the other measures of Medullation was different for the WRONZ calibration wool samples and the mohair. At the same Medullameter reading the WRONZ samples appeared to have a lower area medullation than mohair. The average medulla diameter of these fibres was generally much smaller than that of the mohair (see Table 6) and therefore the medullae were probably more circular compared to that of mohair. This, if so, would lead to more precise estimates of area medullation for these wools, whereas in mohair the area medullation is probably overestimated due to the ellipticity of the fibres. The WRONZ samples also have a higher percentage by number of lattice type medullated fibres which could also contribute towards the discrepancy observed.

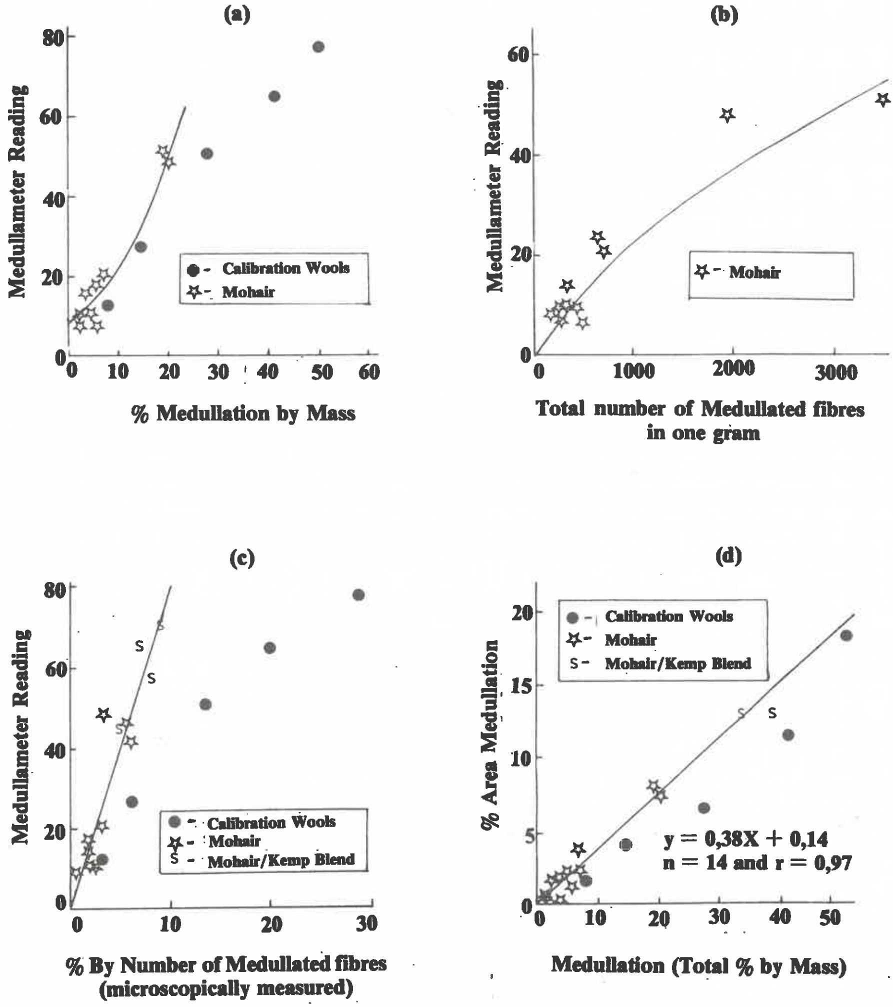


Fig 7 – The relationships between various measures of medullation

Some Distribution Curves and Other Information for Medullated Fibres

The Medullameter reading is mainly a function of the percentage area medullation of a sample. To a lesser degree, however, it is also a function of certain other factors which cannot be determined easily.

As mentioned earlier, it is probably the amount of kemp fibres, rather than the overall degree of medullation, which is important in practice. Further examination of the Medullameter readings, to determine their dependence upon *kempiness* in particular, is therefore warranted. For this purpose it must be possible to class the medullated fibres, as seen microscopically (or otherwise — see later), into kemp (i.e. medullated fibres which are undesirable) and other medullated fibres (termed med fibres) which may not be a problem in practice. To do so it is important to look at the different characteristics of kemp and other medullated fibres. The criterion used in ASTM method D2968-75 for classifying medullated fibres into two such groups seems to be the only practical option. According to this method, those fibres having a medulla diameter to fibre diameter ratio greater than 0,6 are classified as "kemp" while those which have a ratio less than 0,6 are classified as "med" fibres. This method of classifying medullated fibres appears to be rather arbitrary and will be referred to again a little later.

As expected, kemp and med fibre are generally coarser than the normal (solid) fibres in a sample (Fig 8 and Tables 6 and 14), with the medulla diameter increasing as the medullated fibres become coarser (Fig 9).

For the particular samples covered here there was no relationship between degree of medullation and mean fibre diameter. This contrasts with the findings of other workers on wool[32] and mohair[5], who found medullation generally tending to increase as mean fibre diameter increased. There was also a tendency for a higher CV of fibre diameter to be associated with a higher degree of medullation although the correlation was not very good (Fig 10).

Aside from the problem with colour, kemp and medullated fibres, being so coarse, are stiff and prickly (out of proportion to their linear density because they are hollow), which will also make them undesirable in many end-uses. An indication of how much the medullated fibres affect the overall mean fibre diameter of the sample and therefore, probably, the overall stiffness and prickliness of a sample, can be gained from Fig. 11.

To illustrate the distribution of some of the properties of medullated fibres, various histograms (Fig 12) were drawn for medullated fibres which had been pooled from various sources. These clearly illustrate the variability of the measured characteristics of medullated fibres. Fig 12a, which is based upon results obtained on fibres from various sources sorted visually (in air and benzyl alcohol), as described in the experimental section, lends only limited support to the ASTM criterion (ratio of 0,6) used to distinguish between kemp and med

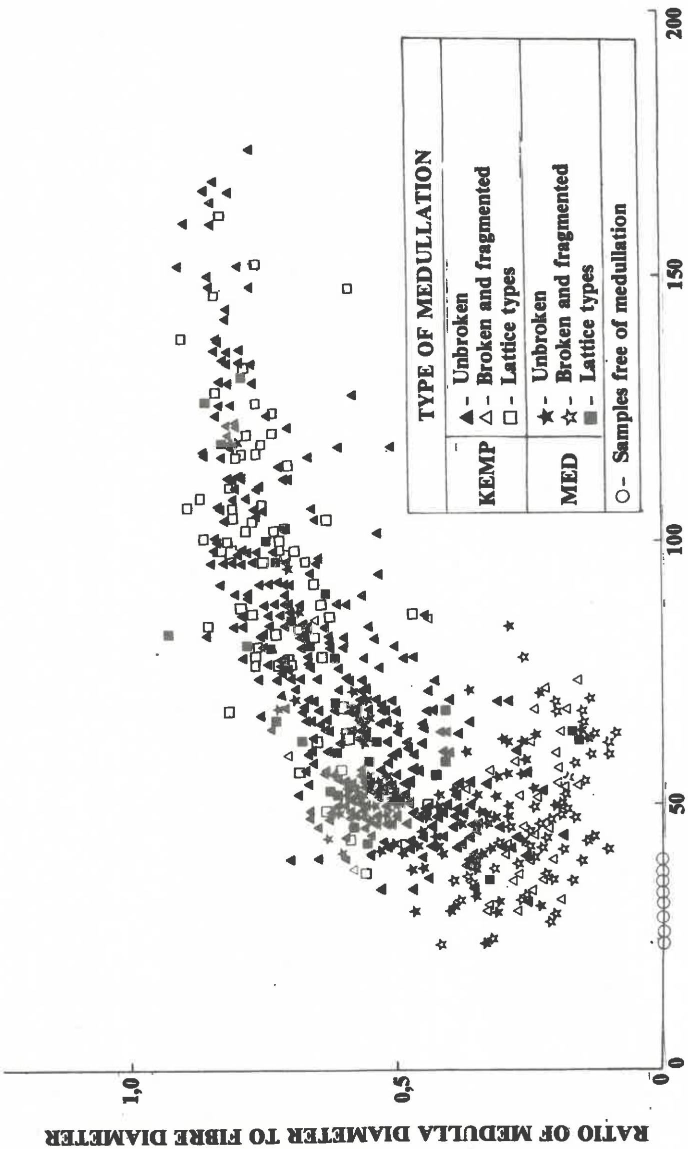


Fig. 8 – The relationship between the medulla diameter to fibre diameter ratio and fibre diameter for all medullated (pooled) fibres.

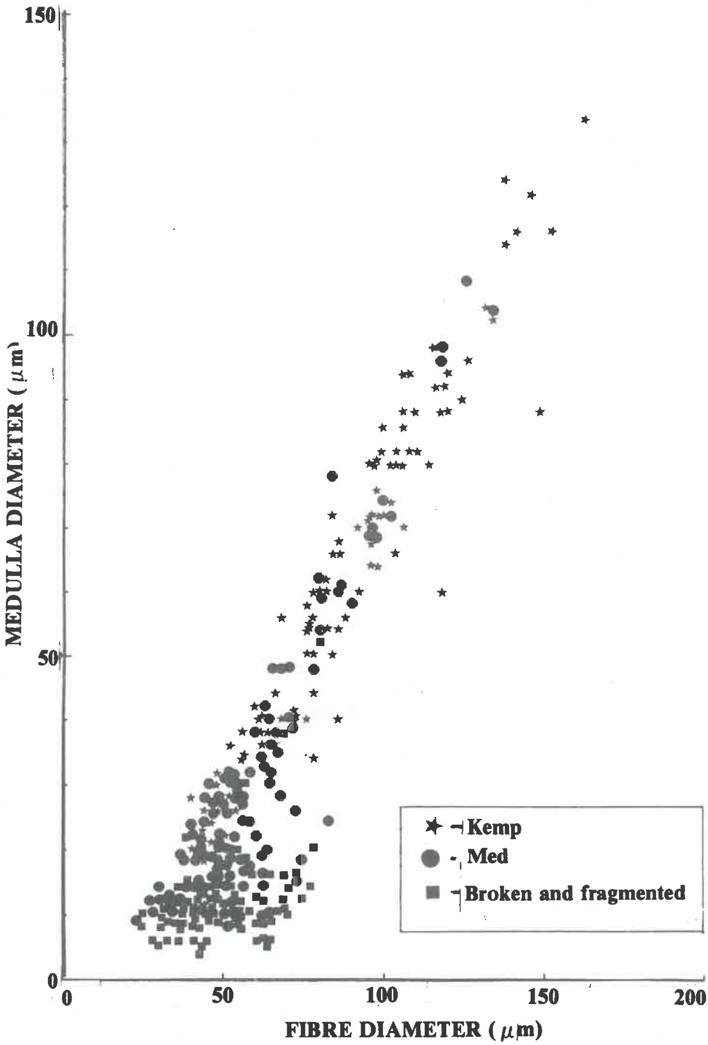


Fig. 9 – The relationship between medulla diameter and fibre diameter for medullated fibres (pooled)

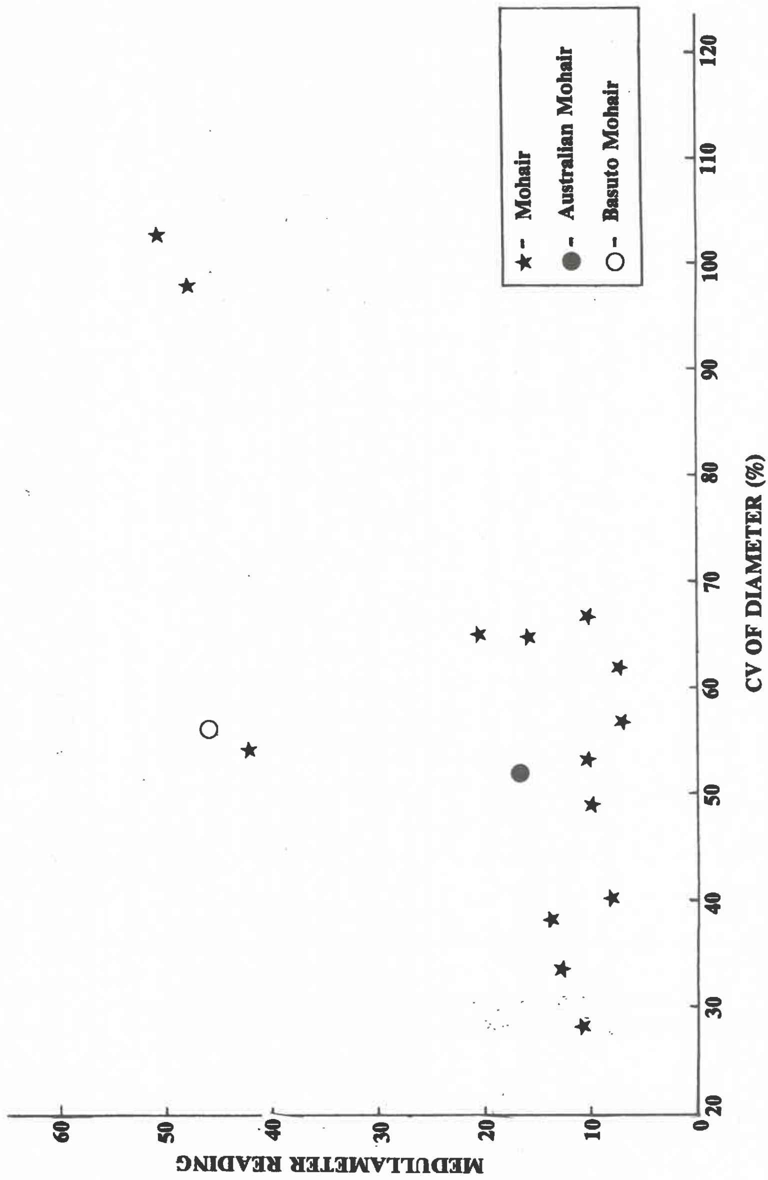


Fig. 10 – The relationship between medullameter reading and CV of fibre diameter

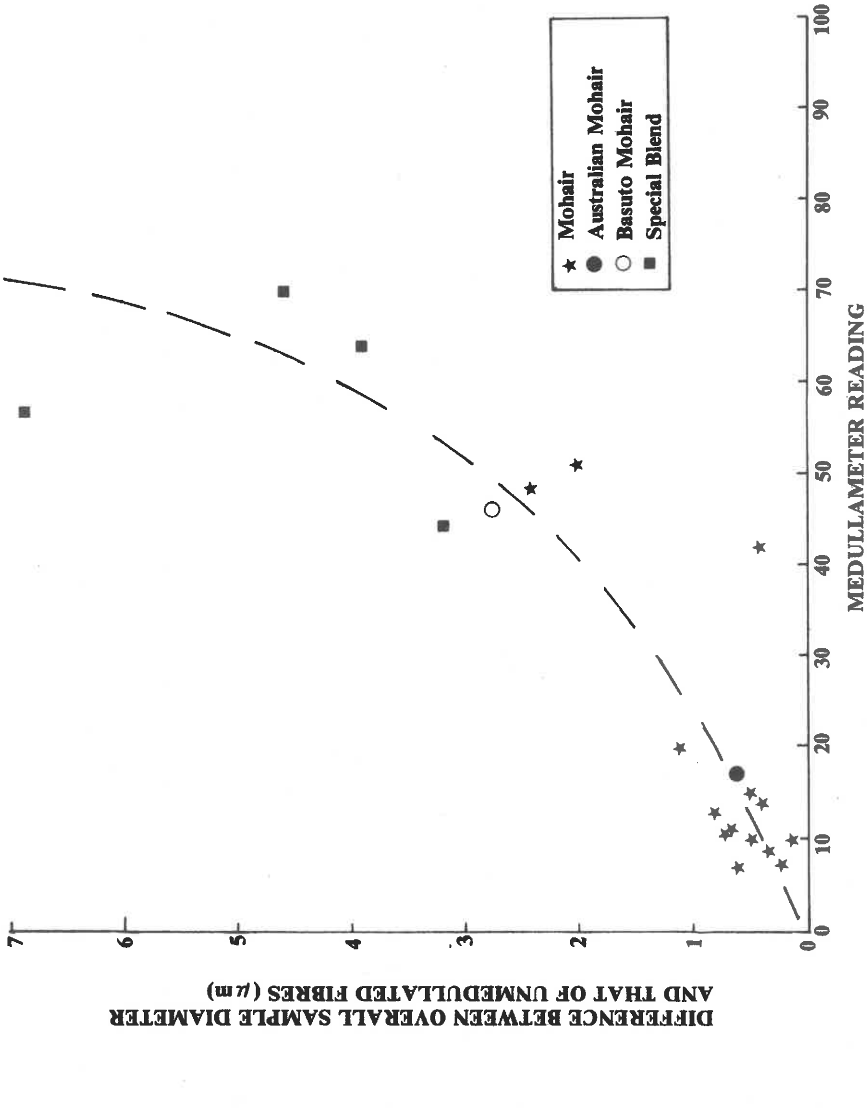


Fig. 11 – The effect of different degrees of medullation on mean fibre diameter

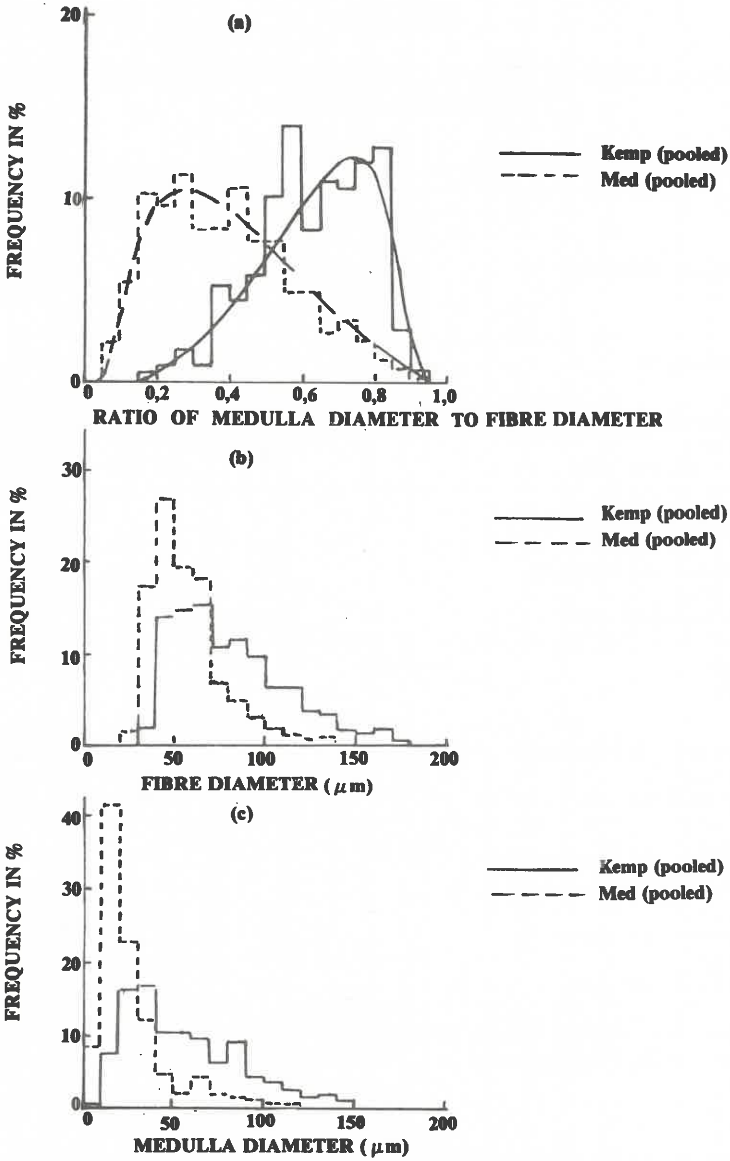


Fig. 12 – Some distribution curves for various properties of medullated fibres (fibres classified visually)

TABLE 14

SOME PROPERTIES OF MEDULLATED FIBRES TAKEN FROM SOME MOHAIR SAMPLES*

Sample Number	Normal Sample mfd (μm)	Medullated Fibres		
		n	Mean fibre diameter (μm)	Mean ratio
Pooled-Medullated**	—			
Overall		424	53 (34)	0,39 (49)
Excluding broken and fragmented		337	55 (34)	0,44 (40)
Lattice type only		68	74 (39)	0,63 (25)
Broken and fragmented only		87	47 (28)	0,20 (47)
Pooled-Kemp**	—			
Overall		446	77 (39)	0,60 (30)
Excluding broken and fragmented		406	80 (38)	0,63 (24)
Lattice type only		66	95 (28)	0,72 (14)
Broken and fragmented only		40	51 (28)	0,28 (46)
I - as received	24,3 (103)			
I-Kemp				
Overall		332	78 (34)	0,64 (25)
Excluding broken and fragmented		324	79 (33)	0,65 (23)
Lattice type only		32	102 (18)	0,74 (9)
Broken and fragmented only		8	55 (36)	0,30 (58)
H - as received	29,0 (98)			
H-Kemp				
Overall		307	120 (28)	0,73 (21)
Excluding broken and fragmented		294	122 (25)	0,75 (16)
Lattice type only		58	136 (18)	0,79 (7)
Broken and fragmented only		13	55 (33)	0,29 (50)

* — Figures in parenthesis are the respective CV's in %

** — All med and kemp fibres removed from 1 g of fibre for each of about 15 different samples and pooled.

fibres. According to Fig 12a there is considerable overlap between the medulla to diameter ratio frequency distribution curves for kemp and med fibres as separated visually. Had the fibres in each group possibly been prepared into parallel bundles before making the slide, the overlap possibly may have been less because the taper of the fibres could have been avoided. It appears almost certain that not all fibres with a medulla to diameter ratio greater than 0,6 are kemp as traditionally defined, although it is possible that such fibres will be the source of problems in practice. According to Figs 12b and 12c, kemp and other med fibres do not differ consistently in either their overall diameters or in the diameters of their medullae. When the medulla diameter to fibre diameter ratio is plotted against the medulla diameter (Fig 13) it appears that at a ratio of 0,6 the medulla diameter is generally of the order of 40 μm.

According to Fig 14 there is a very good correlation between the percentage by number of fibres with medullae greater than 40 μm and the percentage by number having a medulla-ratio greater than 0,6.

The relationships between either the Medullameter reading (or the area medullation) and the various suggested measures of kemp, med and medullated fibres, respectively, are illustrated in Figs 7 and 15 from which it can be seen that in most cases the different measures of kemp are highly correlated to total medullation. Certain of the good correlations can be ascribed to the fact that (for these samples) certain factors, such as average medulla diameter, do not vary greatly between samples and because kemp- and med-fractions are generally related to each other. The fact that the Medullameter reading (or % area medullation) is related to the percentage by number of all medullated fibres is reassuring since it means that, in practice, the Medullameter reading should provide an approximate measure of the number of "defects" (light fibres) in the finished fabric.

Ross[28] found that, for the wools he examined, the photoelectric measure of medullation was not a reliable measure of the percentage of medullated fibres owing to the disproportionate effect of a few large medullated fibres on the photoelectric measure of medullation. He found that the percentage of fibres having a medulla diameter greater than 20 μm was highly correlated with the photoelectric index.

For the samples tested in this study the percentage by number of all the medullated fibres in a sample was highly correlated with each of the following parameters:

1. Percentage by number of fibres with medulla diameter greater than 40 μm (Fig 16a).

2. Percentage by number of fibres with a medulla diameter to fibre diameter ratio greater than 0,6 (Fig 16b), and

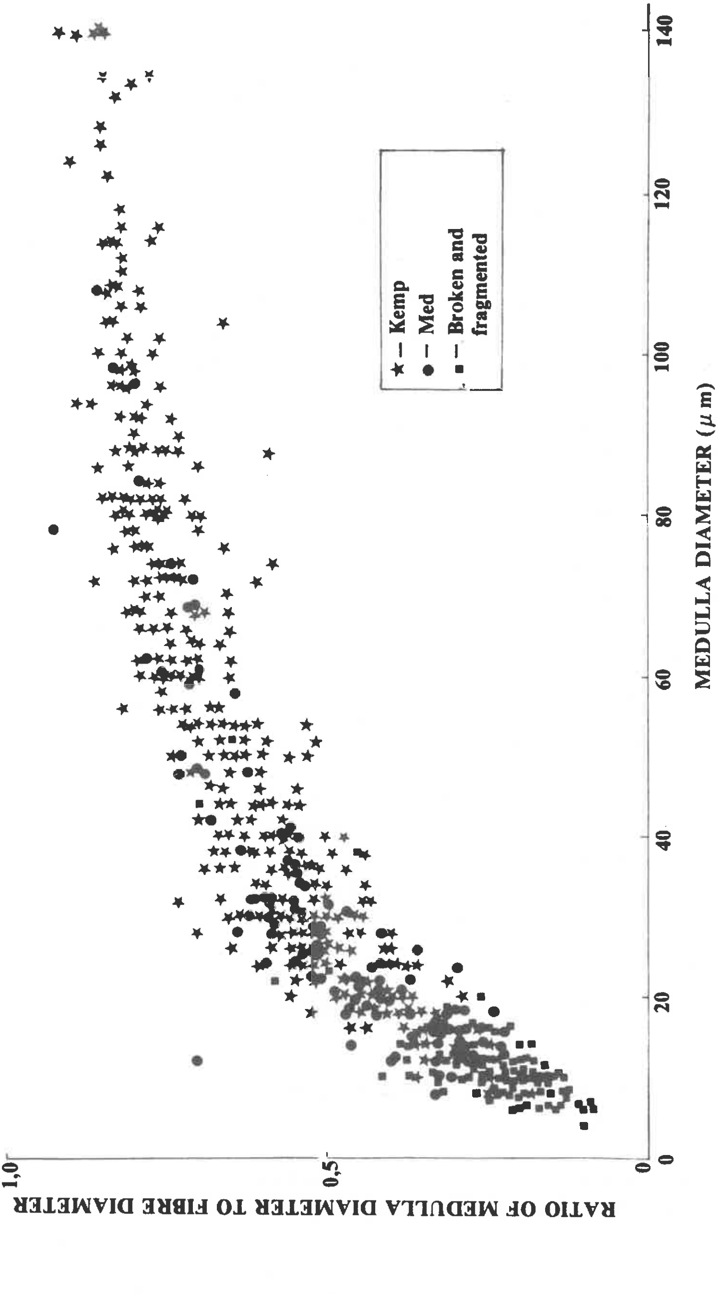


Fig. 13 – The relationship between the medulla diameter to fibre diameter ratio and medulla diameter for different types of medullated fibre

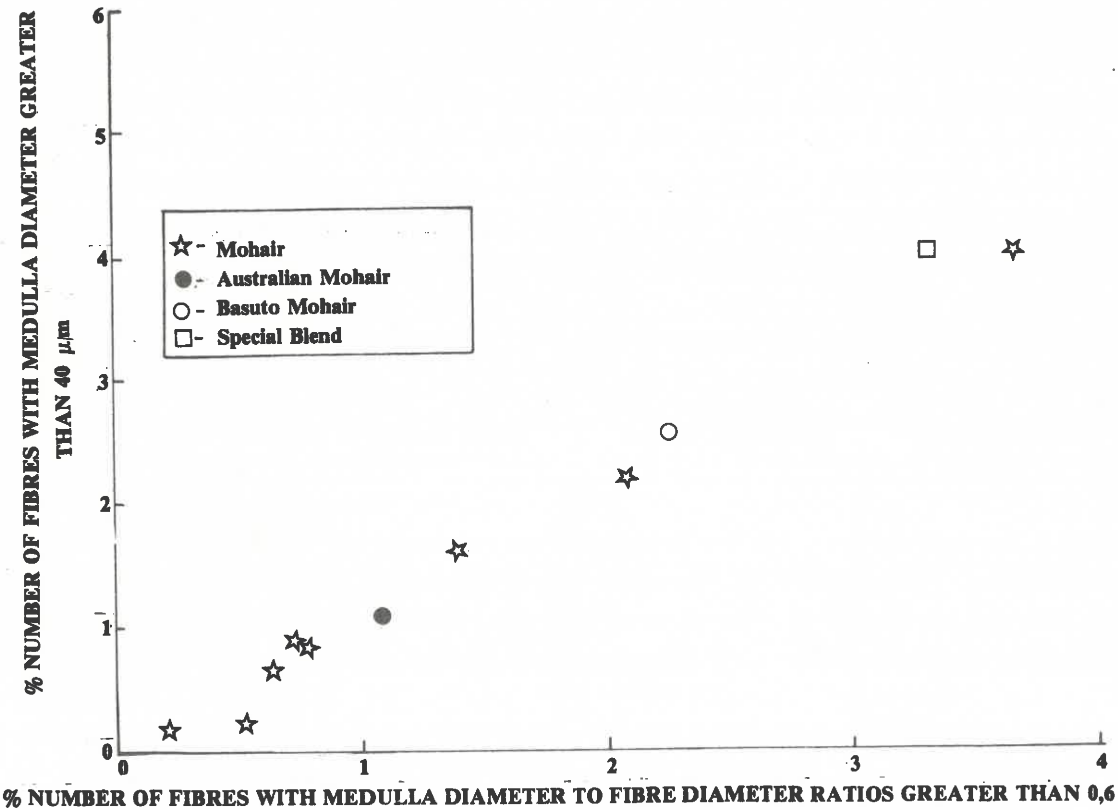


Fig. 14 – The relationship between the number of medullated fibres with medulla greater than 40 μm and the number of fibres with medulla diameter to fibre diameter ratios greater than 0,6

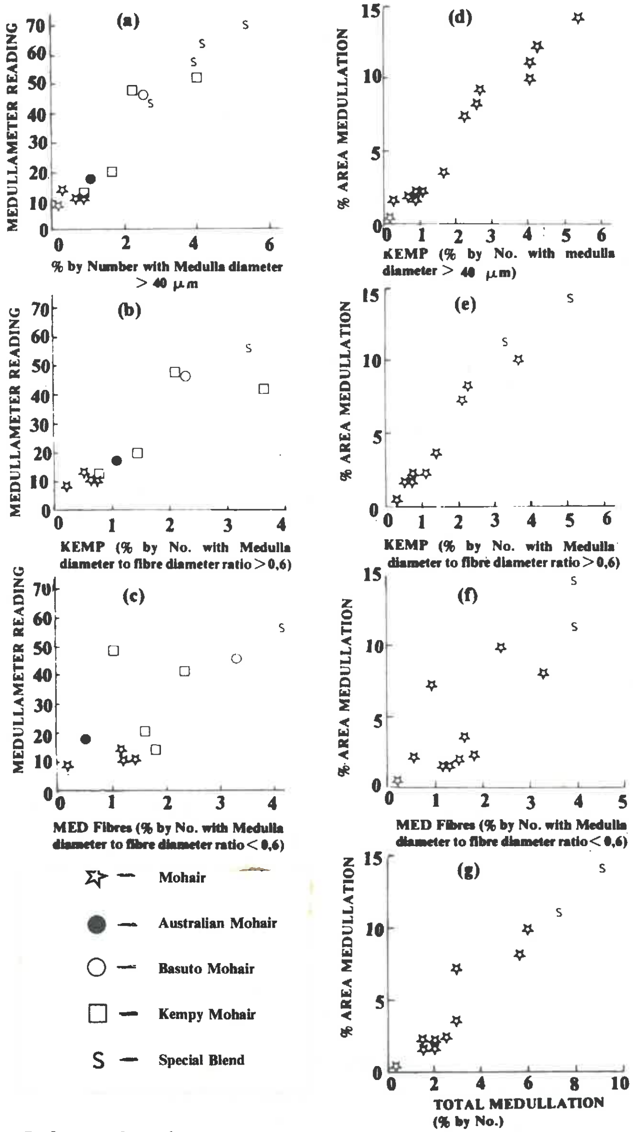


Fig. 15 – Relationships between Medullameter readings (or % area medullation) and the different components of medullation

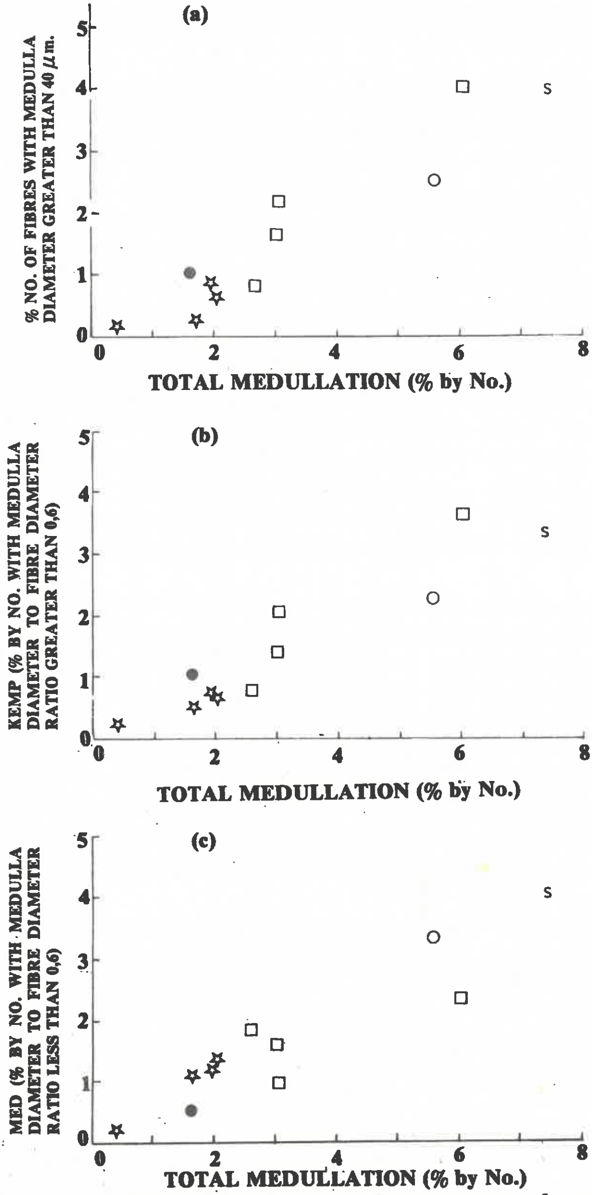


Fig 16 – Interrelationships between the percentage by number of Med, Kemp and all medullated (total medullated) fibres

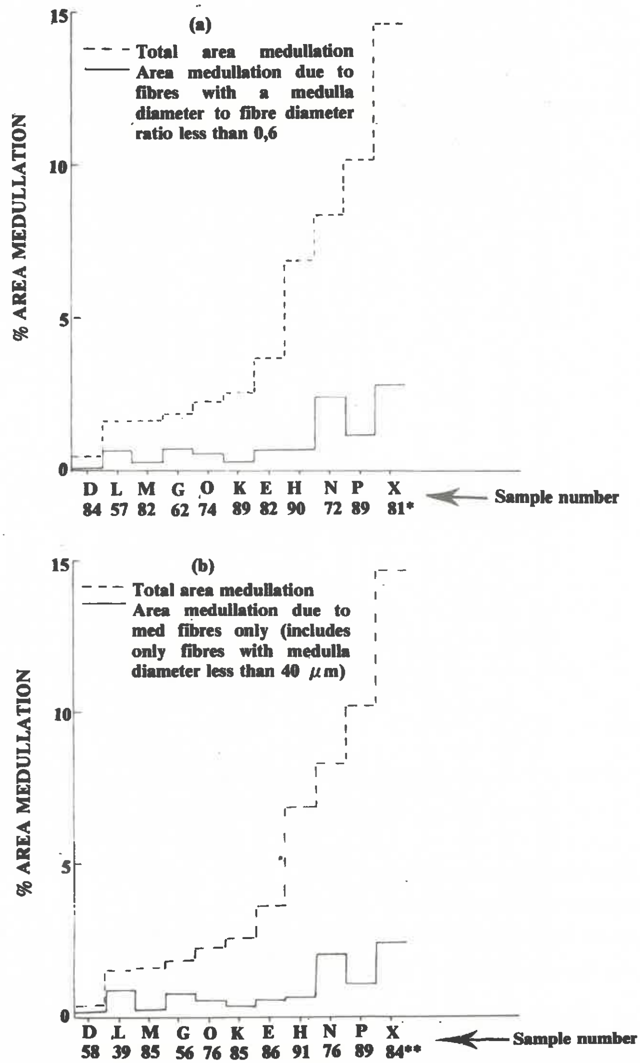
3. Percentage by number of fibres with a medulla diameter to fibre diameter ratio less than 0,6 (Fig 16c).

Generally, the mohair samples studied here appeared to have a similar number of kemp and med fibres although the percentage by number of med and percentage by number of kemp were not very highly correlated.

Classing fibres according to the ASTM procedure (as described previously) and allowing for the medulla diameter, and degree of brokenness or fragmentation of the medulla, the contribution which each of the two medullated components (viz. kemp and med fibres) makes towards the area medullation was estimated for some of the mohair samples used in the foregoing work. This is illustrated in Figs 17a and b. Clearly, kemp (defined as those fibres with a medulla ratio greater than 0,6) contributed most to the area medullation. On average, approximately 78% of the area medullation value was attributable to the kemp fibres in the population of medullated fibres, and the remaining 22% to the med fibres. Generally, therefore, the area medullation reading seems to be mainly a function of the degree of kempiness although there may be exceptions where the proportion of med fibres is greater and contributes more towards the area medullation value. This aspect will be studied in greater depth later.

From the foregoing, and taking into account that the Medullameter reading for all practical purposes was linearly related to the percentage area medullation over the practical range of medullation, another diagram (Fig 18) has been drawn which gives an estimate of the contributions to the Medullameter reading of some of the factors which can affect it. Once again, it is apparent that the "kemp" fibres contributed the most, by far, to the Medullameter reading. By using the mass proportions of kemp and med fibres (see Table 6) and Medullameter readings obtained on 500 mg samples of kemp or med fibres (see Table 4), it was confirmed that kemp was, for the samples examined, the main contributor to the percentage area medullation or Medullameter readings (see Table 15).

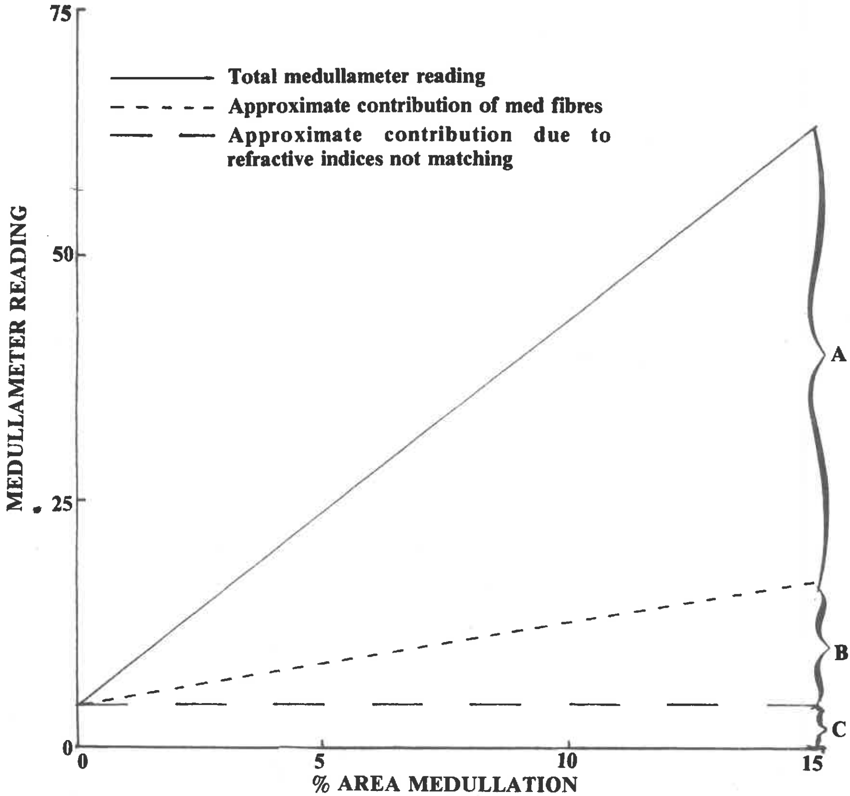
Because the Medullameter reading and the "white spots" noticed on fabrics are due to the same phenomenon, viz. light refraction, and because the Medullameter reading is also related to the number of kempy fibres (in unprocessed mohair) as measured microscopically, it seems that the Medullameter reading will provide a measure of the severity of the medullated fibre problem in a finished fabric, provided consideration is given to other factors which can affect the end result, such as processing conditions, medullated fibre length and mean fibre diameter.



* Percentage contribution to area medullation by fibres with a medulla diameter to fibre diameter ratio greater than 0,6. Average Contribution = 78%.

** Percentage contribution to area medullation by fibres with a medulla diameter greater than 40 μm. Average contribution = 75%.

Fig 17 – The relative contributions to the % area medullation by the main components of medullation



A — Approximate contribution of "Kemp" fibres.

B — Approximate contribution of "Med" fibres.

C — Approximate contribution of (mainly) non-medullated fibres due to refractive indices of mohair and benzyl alcohol not being perfectly matched.

Fig. 18 – A diagram to illustrate the approximate proportions of the Medullameter reading due to the Kemp and Med fractions (for samples scoured according to method B)

TABLE 15

THE AVERAGE PERCENTAGE CONTRIBUTION OF EACH COMPONENT TO THE TOTAL MEDULLATION (USING MASS PROPORTIONS, ETC.)

Medullated Fibre Type	Average Percentage Contribution Towards	
	% Area Medullation	(Medullameter Reading - 5)*
Kemp	92	87
Med	8	13

* — Allowing for the fact that the refractive indices do not match perfectly.

SUMMARY AND CONCLUSIONS

For most end-uses the presence of medullated fibres, or more particularly kemp fibres, is undesirable in high quality mohair and a knowledge of the degree of medullation (preferably kempiness) prior to processing would be most useful. Attention was therefore given to finding a rapid and reliable method of screening samples for degree of medullation and the possibility of using the method to provide a measure of the kemp fibre content explored.

A Medullameter, based on a WRONZ design, was constructed at SAWTRI. This is a photo-electric device designed to measure the amount of light scattered by the medullated fibres present in a sample, 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. It was shown that the medullameter was stable and needed very little re-adjustment over long periods. 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. Modification of the instrument to include an in-built rapid filtration system, as developed by WRONZ, would speed up the procedure and increase its utility.

Sample preparation (i.e. cleaning of greasy mohairs and sampling) was of critical importance 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), is recommended.

At the low levels of medullation generally encountered in mohair, obtaining an accurate measure of the percentage area medullation microscopically requires a careful selection and blending of the sample to obtain a representative sample. It is generally also necessary that more than one slide (500 readings on each) be measured.

The Medullameter reading was shown to be related to various other measures of medullation, in particular to percentage area medullation. The Medullameter reading could, however, not be used for accurate prediction of the percentage area medullation but should rather be regarded as a unique measure of the degree of medullation of a sample.

The Medullameter is considered ideally suited for the purpose of estimating the degree of medullation in mohair because the property it measures and the visual effect due mainly to the kemp fibres in greasy mohair, yarns and finished fabrics depend on the same phenomenon, i.e. light scattering. The usefulness of the Medullameter reading is enhanced because it is related to the number of "kempy" (i.e. those fibres with a medulla diameter to fibre diameter ratio $> 0,6$) fibres in a unit mass, these fibres accounting for something like 80% of the value of the Medullameter reading. It should be mentioned, however, that, although kemp fibres are sometimes defined as those fibres with a medulla diameter to fibre diameter ratio greater than 0,6, this criterion does not always distinguish between kemp and other medullated fibres as separated visually.

A good correlation was found between the number of fibres having a medulla diameter greater than 40 μm and those having a medulla diameter to fibre diameter ratio greater than 0,6.

Frequency distribution curves have been given for various characteristics of kemp and other medullated fibres and the relationships between certain of the characteristics have been illustrated graphically. 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.

It is concluded that, generally, for rapid screening tests aimed at estimating the degree of medullation and perhaps also of kempiness, the Medullameter reading would probably be adequate.

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