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A Summary of SAWTRI's Research on Wool and Wool Blends

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CHAPTER 1

PREAMBLE

The South African Wool and Textile Research Institute (SAWTRI) was established in Grahamstown in the early 1950's upon the initiative of the South African Wool Board. This followed the recommendations of Professor J B Speakman (Professor of Textile Science at Leeds University) who was invited to study the possibilities of organising a wool research facility in South Africa to look after the textile research and development needs of both the wool producers and growing wool textile manufacturing industry of South Africa. After discussions between the various interested parties, the Council for Scientific and Industrial Research (CSIR) entered into an agreement with the South African Wool Board and the two wool textile manufacturing associations (National Textile Manufacturers' Association and the South African Worsted Manufacturers' Trade Association) to establish a co-operative industrial research institute jointly funded by these organisations. In 1953 the Mohair Board added its support and the Institute expanded the scope of its work to include research on mohair. An important milestone was when the Institute was formally incorporated into the CSIR in 1964.
The year 1967 saw an important step when the Institute was moved to its present, more centrally located, accessible and spacious premises in Port Elizabeth which accommodated additional machinery and equipment. The additional facilities enabled the Institute to extend its activities to cover the entire field of wool and mohair research from fibre to fabric.
Another important milestone was in 1971 when the decision was taken that the Institute should extend its activities to include fibres other than wool and mohair, notably cotton;and at this stage the Institute became a National Institute of the CSIR.

Since its inception some 35 years ago, SAWTRI has directed the bulk of its R & D effort to wool and wool-related fields. A large number of technical and scientific publications have ensued from the work of the Institute and it was considered desirable to summarise the work published on wool and wool-related fields so as to provide a record and handy reference of the fields covered and of the contribution the Institute has made to research and development and to the advancement of technical and scientific knowledge in these fields. For the sake of having a complete bibliography, publications dealing with SAWTRI's wool related activities, facilities and reviews have been referred to in Chapter 23. As far as possible, the references have been numbered in chronological order.

CHAPTER 2

WOOL FIBRE STRUCTURE AND CHEMISTRY

2.1 BILATERAL STRUCTURE

Louw[30] compared the bilateral structure of crimped and steely wools and investigated the origin of crimp and verified the existence of a bilateral asymmetry in both normal and steely wools. Weathering damage of the two fibre types tended to eliminate differences in their behaviour towards alkali. Copper deficiency resulted in the production of a relatively uncrimped fibre, because of the fact that keratinization assumed significant proportions at a late stage in fibre formation when the fibre as such had already been stabilized in its steely form. Crimp appeared to be the result of catalyzed keratinization which, proceeding more rapidly in the para- than in the ortho-component and probably resulting in more and/or different cystine linkages in the former segment, resulted in crimp formation while the fibre structure was still relatively unstable and pliable.

Snyman[46] described a suitable embedding method for studying the bilateral structure of Merino wool and used this method to show an increase in percentage para-cortex (and sulphur content) with an increase in wool crimp at a constant fibre diameter[53]. Percentage para-cortex also increased with increasing fibre diameter. Snyman's method was, however, time consuming and tedious and Boshoff and Scheepers[128] developed an improved method which was identical to one developed at about the same time elsewhere. They[128] found no statistically significant effect of crimp on percentage para-cortex which was in contrast to the findings of Snyman[53]. Percentage para-cortex did not appear to be related to fibre diameter either. Snyman subsequently[69] explained the origin and implications of fibre crimp, stating that grazing not only affected diameter but also fibre chemistry and morphology. He concluded that the ratio of the two bilateral segments in Merino wool was determined genetically and not influenced by feeding conditions, confirming the findings of Boshoff & Scheepers[128] on wools derived from a controlled high and low feeding experiment.

Scheepers[209] investigated the influence of age and sex of sheep on the cortical segmentation of Merino wool and found that percentage para-cortex increased with age, diameter also increasing slightly with age but not staple crimp. The percentage para-cortex was higher for the ewes than for the rams and wethers.

Maasdorp[839] used a scanning electron microscope and an energy dispersive X-ray analyser to determine the distribution of sulphur in Merino wool, Lincoln wool and mohair and his results indicated a bilateral structure for the Merino wool and a predominance of ortho-cortex for both the Lincoln and mohair fibres (Fig. 1).

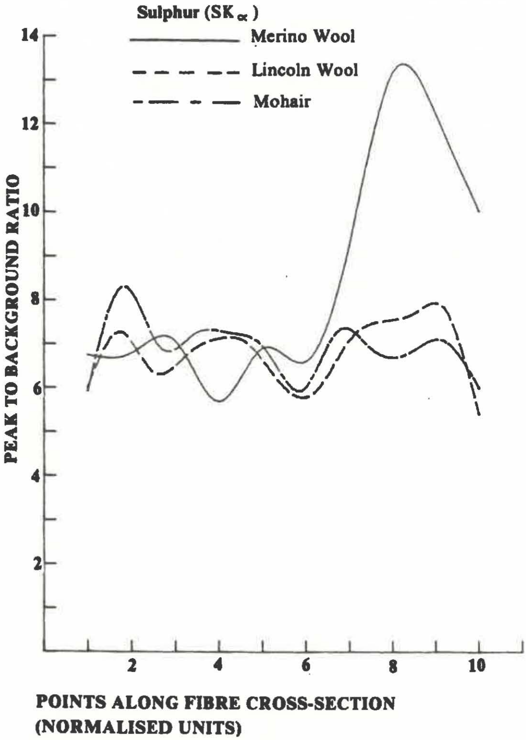


Fig. 1 The distribution of sulphur in the cross-section of Merino wool, Lincoln wool and mohair fibres.(839)

2.2 CHEMICAL STRUCTURE

Van Rensburg[44] investigated the oxidation of cystine and presented his work as an M.Sc. thesis.

Haylett *et al*[48] extracted high-sulphur proteins (γ-keratose) preferentially from performic acid-oxidized wool with pyridine-acetate buffer. They showed that the γ-keratose was heterogenous both on a charge and a molecular size basis by using free electrophoresis, chromatography on DEAE-cellulose and calcium phosphate, and gel filtration on Sephadex. Four sub-fractions of γ-keratose which gave single peaks on electrophoresis and ultracentrifugation were isolated by column electrophoresis, these sub-fractions having very different physical properties and amino-acid compositions.

Swart *et al*[130] compared the soluble proteins of oxidized mohair and reduced mohair with those of wool and found differences in the physical properties and amino-acid compositions. Swart *et al*[274] also reported on the apparent micro-heterogenous nature of the high sulphur proteins of α-keratins (wool and mohair).

Joubert and co-workers[182 201] carried out various studies on the high-sulphur protein fraction, designated SCMKB, of reduced wool. It was shown[182] that SCMKB were heterogenous both on a charge and molecular size basis by free electrophoresis, chromatography on DEAE-cellulose, and gel filtration on Sephadex G-100. A number of sub-fractions of SCMKB were isolated by chromatography on DEAE-cellulose. These fractions were characterised by free electrophoresis, amino-acid analysis and gel filtration. Haylett and co-workers[232] presented evidence that a similar S-carboxymethylated high-sulphur protein fraction (designated SCMK-B2) could be prepared from a number of different types of wool and a related fraction from bovine hair. Significant features of the overall composition were the very high contents of carboxymethyl cysteine, serine, threonine, glutamic acid, proline and glycine, the complete absence of methionine and very low levels of aspartic acid and phenylalanine.

Joubert and Burns[218] fractionated the SCMKB proteins of reduced Merino wool by a combination of gel filtration and DEAE-cellulose chromatography. For most of the sub-fractions single peaks were found on free electrophoresis. Data were presented concerning the electrophoretic mobilities, molecular mass and amino-acid composition of the sub-fractions. The amino-acid analyses revealed the presence of a group of proteins almost devoid of lysine and histidine. Disc electrophoresis, however, indicated that the sub-fractions comprised more than one component.

Haylett *et al*[396] investigated the high-sulphur proteins of reduced and carboxymethylated wool and found that these proteins could be divided into four main groups with a molecular mass of 23 000, 19 000, 17 000 and 11 000 respectively. In spite of considerable differences in amino-acid compositions, these groups still appeared to have certain common features in their primary structures.

Swart *et al*[297] reported on the isolation of a homogenous protein during their studies of the high-sulphur proteins of reduced Merino wool. A re-investigation of a fraction of the high-sulphur proteins SCMKB was made. The proteins were successively fractionated on an eletrophoretic, molecular-size, and chromatographic basis. This work resulted in the isolation of a homogenous protein SCMKB-IIIB2 which had a molecular mass of 11 260, no free amino-terminal group, and contained S-carboxymethyl cysteine as carboxy-terminal residue.

Haylett and Swart[298] presented the first complete amino-acid sequence of a wool protein SCMKB-IIIB2, with a molecular mass of 11 260 and consisting of 97 residues and having an acetylated amino- terminal. The protein had a high- and a low-sulphur region. Haylett *et al*[397] also determined the complete amino-acid sequence of the wool protein SCMKB-IIIB3. Later the complete amino-acid sequence of the protein SCMKB-IIIB4, which was closely related to that of SCMKB-IIIB3, was also established by Haylett and Swart[398].

Lindley *et al*[265] reported on the high-sulphur proteins of ∝-keratins while Lindley and Haylett[202] studied the occurrence of the cys-cys sequence in keratins, reporting on the disulphide interchange reactions involving cyclocystine and their relevance to the ∝-keratin structure[267]. They also described[266] the use of ion exchange cellulose columns in the Autoanalyser for the fractionation of peptides.

Swanepoel and Louw[50] investigated the reduction of the disulphide linkage in wool keratin, cystine and oxidized glutathione by hypophosphite ions (at temperatures up to 85°C) and found that the latter two were reduced by O,1M solutions of hypophosphite buffered at pH 9,3, 5,2 or 2,0, and also by unbuffered 0,1M hypophosphorous acid. The reaction was most rapid at pH 5,2. At room temperature, no significant reduction took place in 3 hours at pH 9,3 or lower. In the case of wool keratin, reduction was only observed in acid media. They also discussed the reaction mechanism. Swanepoel and co-workers[147] studied the electrolytic reduction of proteins.

Van Rensburg *et al*[116] reported on the oxidation of the disulphide bonds in cystine and amino-substituted cystine derivatives with peracetic acid solutions containing sulphuric acid as catalyst and found their results to be consistent with the hypothesis that the S,S-dioxide was the only reasonably stable oxidation product of cystine and its derivatives in which the sulphur-sulphur linkage remained unbroken.

Van Rensburg and Swanepoel[140] studied the asymmetrical disulphides containing cysteine and showed that substantial quantities of the mixed disulphides were formed when 5,5′-dithiobis-(2-nitrobenzoic acid) reacted with cysteine or glutathione. The corresponding sulphinic and sulphonic acids were formed when the mixed disulphides were exposed to alkaline conditions ($pH>11$). They subsequently[203] investigated the reaction of sulfite on fifteen asymmetrical alkyl-alkyl disulfides. In twelve out of the fifteen compounds, substitution took place preferentially at a specific sulphur atom in the disulfide. It was considered that steric hindrance to the approach of the entering group was the predominating influence in determining such preferential substitution. The influence of pH in the range 5 to 9,5 on the nature and magnitude of the preference was not significant. They also investigated[213] the reactions of sulfite on the mixed disulfides of glutathione and cysteine and on those of thiol-proteins and cysteine and found that substitution of the S-S bond of the glutathione-cysteine disulfide took place at random but that a specific sulphur atom (that of the "free" cysteine part of the molecule) in the protein-cysteine mixed disulfides was attacked more frequently than its mate. This directed substitution was eliminated when the reaction was carried out in a concentrated solution of urea.

2.3 SUPERCONTRACTION

Veldsman and co-workers[21] studied the dimensional changes in wool fibres when immersed in 20% caustic potash solution and provided data showing the effects of various chemical pretreatments on supercontraction. They concluded that the results of such a test, as well as those obtained by the conventional Krais-Markert-Viertel (K.M.V.) test for assessing wool damage, should be interpreted with caution.

Swanepoel[36] studied the influence of atmospheric oxidation on supercontraction of wool fibres reduced with thioglycollic acid and concluded that it would be inadvisable to perform supercontraction studies on reduced wool unless precautions were taken to prevent reformation of cross-linkages. He[38] subsequently investigated whether selective iodination of the matrix alone would have any influence on the supercontraction of the fibre and concluded that it did not affect supercontraction whereas total iodination of matrix and micro-fibrils resulted in a marked depression of the second stage supercontraction.

Haly and Swanepoel[40] studied the supercontraction and elongation of modified keratin fibres in LiBr solutions and found that reduced keratin fibres when heated in a 8M LiBr solution at 100°C, first contracted and then lengthened. Reduced and methylated Corriedale wool fibres contracted but did not lengthen under the same conditions. Reduced fibres that had been abraded to remove the cuticle, lengthened less than unabraded fibres. Mechanical, X-ray, and birefringence evidence showed that fibres that had increased to about their natural length were severely degraded and not elastomeric. It was suggested that elongation resulted primarily from a swelling pressure within the fibre produced by dissolution of protein.

Swanepoel[47] also investigated the influence of alkaline media on the configuration of the disulphide linkages in supercontracted wool and concluded that a conversion of disulphides from an intrachain to an interchain configuration was very likely. He also[51] discussed the use of the length modulus (effective Young's modulus for supercontracted wool) of wool, as proposed by other workers in studies on the disulphide cross-linkages.

Subsequent studies by Swanepoel[37], on the supercontraction of sound and weathered wool and mohair fibres, threw further light on the mechanism of this reaction. He concluded that the second stage of supercontraction resulted from the exposure of sterically-protected hydrogen bonds, which could occur through disulfide exchange in the highly cross-linked zones of the microfibrils. Some of the cystine cross-links were stabilized by weathering so that disulfide exchange was inhibited, leading to much less contraction.

2.4 LIGHT-INDUCED CYSTINE/HYPOPHOSPHITE REACTIONS

Swanepoel and Van Rensburg[52] [123] [149] [161] carried out various studies on the light induced reaction between cystine and hypophosphites, both at elevated and low temperatures. The combination of ultraviolet light and hypophosphite was shown to cause a significant degree of reduction of cystine and peptide-bound disulphides[52]. When a solution containing cystine and sodium hypophosphite was irradiated with ultraviolet light, the cystine was rapidly reduced to cysteine but if the reaction was conducted in an acid medium, two intermediary products were formed, namely a quadricovalent phosphoranyl radical and a double salt[123]. In an alkaline medium only the radical was stable, the double salt being decomposed. When irradiation times were extended, alanine was formed in detectable quantities. They showed[161] that the cystine/hypophosphite reaction followed a single mechanism regardless of whether the reaction was induced by ultraviolet irradiation or by free-radical initiators. In the latter event the first stage of the reaction, that of the production of a thiyl radical was the result of a radical transfer mechanism, while the formation of thiyl radical in the former case followed the absorption of light quanta by cystine.

2.5 UREA-BILSULPHITE AND ALKALI SOLUBILITY

Mellet and Swanepoel[148], as well as Mellet in an M.Sc. thesis[151], investigated the modification of native and denatured keratin by alkali, and Mellet[255] investigated the effect of alkali treatment on wool keratin and on silk fibroin in a medium of K_2CO_3 at 50°C. It was found that the denaturing action of LiBr affected the reactivity and reactions of the disulfides differently from those due to stretching of the fibres.

Weideman and Wevers[366] concluded that alkali modification of wool could be detected by determining its urea-bisulphite solubility (UBS) or its alkali-solubility, by dye-exhaustion curves, or by its cystine, lanthionine, lysine or lysinoalanine content. As far as the sensitivity of these tests was concerned, UBS, rate of dye-exhaustion and cystine values were the most sensitive parameters to indicate mild modification of wool. The UBS test was the easiest and therefore the first choice to indicate mild modification.

Weideman and Grabherr[394] found that the UBS of wool samples treated with chlorine at pH 6 decreased at low chlorine levels and increased again at higher chlorine levels, for both sodium hypochlorite and dichloroisocyanuric acid (DCCA) treatments. At pH 5, only DCCA treated wool showed a small decrease in UBS at low concentrations but an increase at higher chlorine values. At high pH values (8 and 10) a decrease in UBS was observed for all chlorine concentrations examined. A difference in solubility characteristics was also found between samples treated by pad and exhaustion methods respectively. It was shown that the time of dechlorination had an effect on the UBS. Crosslinks resulting from chloroamines were suggested to be responsible for the UBS behaviour, but this was not proved.

Weideman[418] also demonstrated the importance of neutralisation on the UBS of chlorinated wool and the effect of storage time on that of alkaline-chlorinated wool, UBS increasing with storage time.

Brinnand[393] showed that alkali solubility, as a measure of the modification of wool by peroxide bleaching, could be replaced by measuring the degree of darkening (reflectance) of wool caused by treatment with lead acetate.

2.6 DETERMINATION OF THIOL, LANTHIONINE AND TRYPTOPHAN CONTENT

Van Rensburg[54] investigated the formation of 2-Iminothiazolidine-4-carboxylic acid in the cyanobromination of lanthionine.

Van Rensburg and Swanepoel[85] described the spectrophotometric determination of thiol groups in wool keratin using 5,5′- dithiobis- (2-nitro-benzoic acid) (DTN) which had advantages over other methods in terms of speed and simplicity. Du Toit *et al*[117] described a relatively rapid and simple method for determining the thiol content of insoluble proteins using DTN reagent after

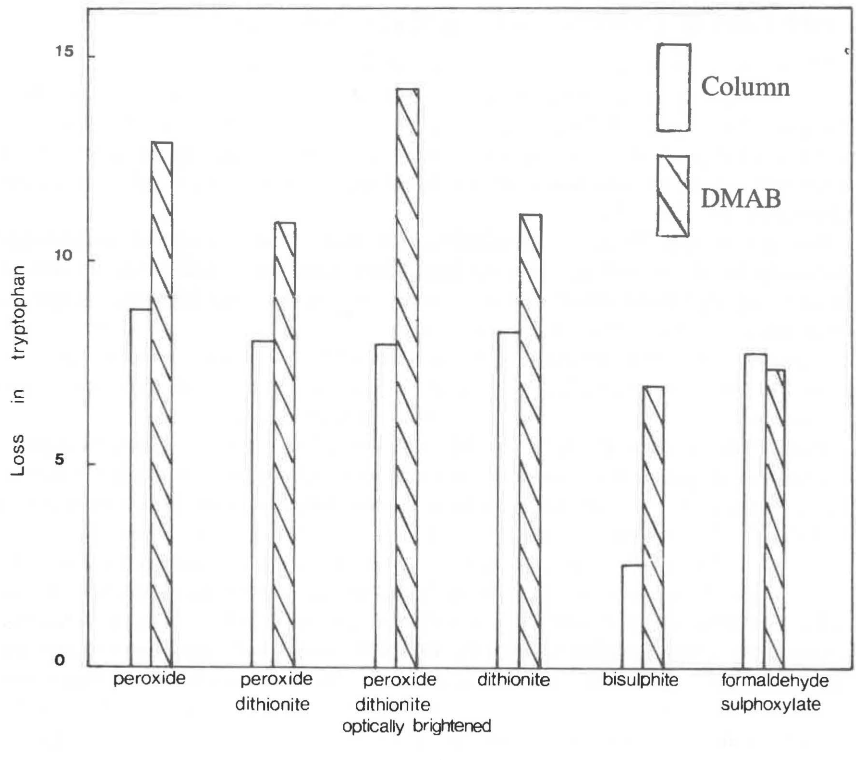


Fig. 2 A comparison of the column and the DMAB methods showing the loss in tryptophan content of various wool samples after exposure to sunlight.(424)

partial hydrolysis of the protein, the concentration of DTN not being critical.

Mellet and Swanepoel[115] described a column chromatographic method for the determination of lanthionine which was readily adaptable to automatic amino-acid analysers.

Weideman and Van Rensburg[424] investigated the determination of tryptophan content of wool using an acid hydrolysis procedure and an automatic amino-acid analyser. Significant differences were found in the tryptophan contents of chemically treated wool samples when determined by a conventional method, using sulphuric acid hydrolysis and p-dimethylaminobenzaldehyde, and when determined with an automatic amino-acid analyser after hydrolysis with p-toluenesulphonic acid. The same effect was observed in the case of wool samples which had been exposed to sunlight (Fig. 2)[424]. It was furthermore possible to determine the tryptophan content of wool containing optical brightening agents by using the amino-acid analyser method, which could not always be done in the case of the conventional method.

2.7 FIBRE SURFACE TENSION

Weideman[434] showed that the critical surface tension (CST) of chlorinated wool fibres, determined by the sink-float technique, varied widely within the same sample, that of chlorinated tips being higher than that of the chlorinated roots. The best wetting agents during the chlorination conditions employed were identified. It was shown that prolonged rinsing in water or alcohol lowered the CST of chlorinated wool fibres. At least 1,3 - 1,4% chlorine was shown to be necessary to raise the CST of the wool to more than 52 dynes/cm which was the CST required for the spreading of R Hercosett 57 on the fibres (that of untreated wool being 30 dyne/cm).

In a subsequent study, Weideman and Grabherr[481] demonstrated the variation in the CST of the fibres in a cross-section of a chlorinated wool top. Different dechlorination media changed the CST of chlorinated wool to different degrees, a higher CST value for chlorinated wool not necessarily implying a reduction in the degree of top shrinkage after R Hercosett application. It was postulated that acidic groups in wool were partly responsible for the increase in CST values.

Weideman[591] subsequently reported on the use of diiodomethane for measuring contact angles and compared results obtained experimentally with those obtained by other workers as well as with a value calculated from parachlor data. The effect of the different surface and interfacial tension values on the calculated polar and dispersion components of the diiodomethane surface tension was examined.

In reviewing the theory and literature on interfacial phenomena and the reanalysing of published data, Weideman *et al*[598] showed that γ_S, the fibre surface free energy or surface tension, was dependent on the values of the dispersion and polar components of the liquid surface tension used in its determination. It appeared that the surface free energy of a solid could be correctly established only when the disperse fractions of the liquid (D_L) and that of the solid (D_S) were equal. The critical surface tension (γ_c) values obtained for polyamide epichlorohydrin (R Hercosett) polymers depended upon the type of liquid used for the determination, polar liquids tending to give significantly higher values than non-polar liquids. Determining γ_c by the sink-float method indicated that it was more sensitive to the type of liquid used in the case of nylon than in the case of wool.

2.8 GENERAL

In an M.Sc. thesis, Bamford[23] studied the sorption of hydrochloric acid and potassium hydroxide by mohair and wool.

Haly and Swanepoel[39] measured the birefringence of Corriedale wool fibres at different relative humidities. After being corrected for swelling, the curve of birefringence against moisture content showed a minimum at a moisture content of 19% of the dry mass of the wool, at which point the birefringence was probably completely intrinsic.

Swanepoel *et al*[32] investigated the hydrogen exchange in aqueous solutions of citric acid, β-methylglutaric acid, β:β-dimethylglutaric acid and α-methylglutaric acid. Swanepoel[60] also studied the reactions and rôle of disulphide cross-links in determining certain physical properties of keratins and presented the results as a D.Sc. thesis.

Swanepoel *et al*[307] partially reduced the disulfide linkages in insulin by irradiating solutions of insulin, also containing sodium hypophosphite, for brief periods with ultraviolet light. The thiols formed were carboxymethylated and the concentrations of S-carboxymethyl cysteine in the separated A- and B-chains were determined. The results showed that photolysis of the three disulfide linkages in the insulin molecule occurred at random.

Scheffer and Van Rensburg[618] determined the heat effect of the interaction between wool and the acid colloid of an aminoplast resin using a micro-calorimeter. The heat of adsorption was found to increase when the level of chlorination of the wool increased.

Swanepoel and van Rensburg[312] described a method of determining the moisture content of minute quantities of protein (single wool and mohair fibres) by means of an automatic elemental analyzer.

CHAPTER 3

WOOL FIBRE PHYSICAL CHARACTERISTICS AND TESTING

3.1 SAMPLING FOR OBJECTIVE MEASUREMENT

Grové and Veldsman[162] briefly reviewed the techniques of core sampling and testing of greasy wool.

Gee and Robie[475] investigated various aspects related to sampling and testing accuracy in the objective measurement of the South African wool clip. In their first study[475], sixteen types of wool, represented by 264 bales, were cored and measured for clean wool content and fibre diameter. Estimates of within-bale ($_{w}$) and between-bale (σ_b)variations were made. Sampling schemes to give a precision of ± 1% for yield and of ± 0,5% μm for diameter were proposed and a measure of the reproducibility of each test method and an estimate of the yield variation from root to tip of the staple were given. Gee[590] obtained estimates for the South African Merino wool clip of the within-bale (σ_w) and between-bale (σ_b) variations of yield and diameter from cores taken by Model T coring machines. The variations in yield were each about 1,6% while the diameter variations for Durban and East London were approximately 1 and 1,5 μm which were higher than the values of 0,5 μm obtained previously for Port Elizabeth wools.

3.2 REGAIN CHANGES IN STORED WOOL

Gee[588] made a theoretical study of the assumed moisture gradients in a bale of greasy wool, resulting from changes in ambient conditions, estimating the bias in yield given by core samples. The average core yield for a bale, having a 50% wool base, when moved from a 40% RH environment (say on the farm) to a 75% RH environment, (in the warehouse, for example,) would theoretically be over-estimated by about 0,4% after 4 weeks and by about 0,05% after 12 weeks.

Gee[562] also measured the rate of regain changes of bone-dry samples of greasy and scoured wool contained in standard sealed polythene bags (film thickness 55 μm) and stored in a constant atmosphere of 21°C and 75% RH and found that equilibrium was attained in about 400 days. After 7 days it was estimated that about one-sixth of the ultimate change would have occurred. For core samples, for the objective measurement of clean wool content, any change in regain during a few days would be completely negligible. Values for the amount of moisture absorbed by clean wool, suint and grease plus dirt were 0,141, 0,327 and 0,035% respectively.

3.3 OPERATOR ERRORS IN PROJECTION MICROSCOPE TESTS

Kritzinger *et al*[86] made a study of the human factors involved in projection microscope measurement of fibre diameter employing a number of different operators. They found that the microscope or the slide, if used and prepared correctly, could not account for the observed variations, but that some operators had significant *constant* and/or *variable bias*. It was shown that a correction, for example through reading a "standard slide" for a variable bias, should preferably not be attempted, but that an operator having such a bias should rather not be used.

3.4 AIR-FLOW MEASUREMENT OF DIAMETER

Kritzinger *et al*[62] found a small, though not consistent, effect of crimp on air-flow measured diameter results while Robie and Slinger[338] showed that the error in air-flow results due to experimental method tended to decrease as the degree of fibre randomisation increased. Hunter *et al*[622, 679] confirmed that there was a significant effect of steam relaxation on the air-flow diameter results for wool, it causing an apparent increase in the fibre diameter results probably due to fibre crimp recovery. It was important that the calibration tops should be in the same state of relaxation as the sample being tested.

3.5 FIBRE LENGTH MEASUREMENT

Van der Westhuyzen and Mandel[84] compared the length results obtained on two Schlumberger Analysers and two WIRA Fibre Diagram machines and found good agreement between their respective results. They stressed the importance of drawing representative samples from several tops.

Faure[120] drew attention to a possible error which could occur in the use of the WIRA Fibre Diagram Tester for determining the average fibre length of tops and suggested a method of correction.

Slinger[185] found the correlation between fibre length values obtained by means of the WIRA Single Fibre Length and Fibre Diagram machines, respectively, to be generally good, the absolute fibre length values obtained on the diagram machine being slightly longer than that obtained on the Single Fibre Length machine. Fibre crimp reduced the length measured on the diagram machine and ageing also had an effect due to its effect on crimp.

Robie[426] also discussed the factors which influenced fibre length measurement on different instruments (Schlumberger Comb Sorter, WIRA Single Fibre Length Tester, WIRA Diagram and Almeter) and concluded that there was fair agreement between the various test methods although differences of up to 5mm could occur. Recognition of such differences and being aware under which circumstances they arise, may assist in cases involving arbitration. Besides these consistent differences, there were also unexplained random differences of the order of 2,5mm probably due to fibre crimp and sample preparation.

Gee[642] derived formulae for the mean and CV of fibre length of a blend of different wools from a knowledge of its component parts in a manner similar to that used for diameter. By considering a range of values for the components,

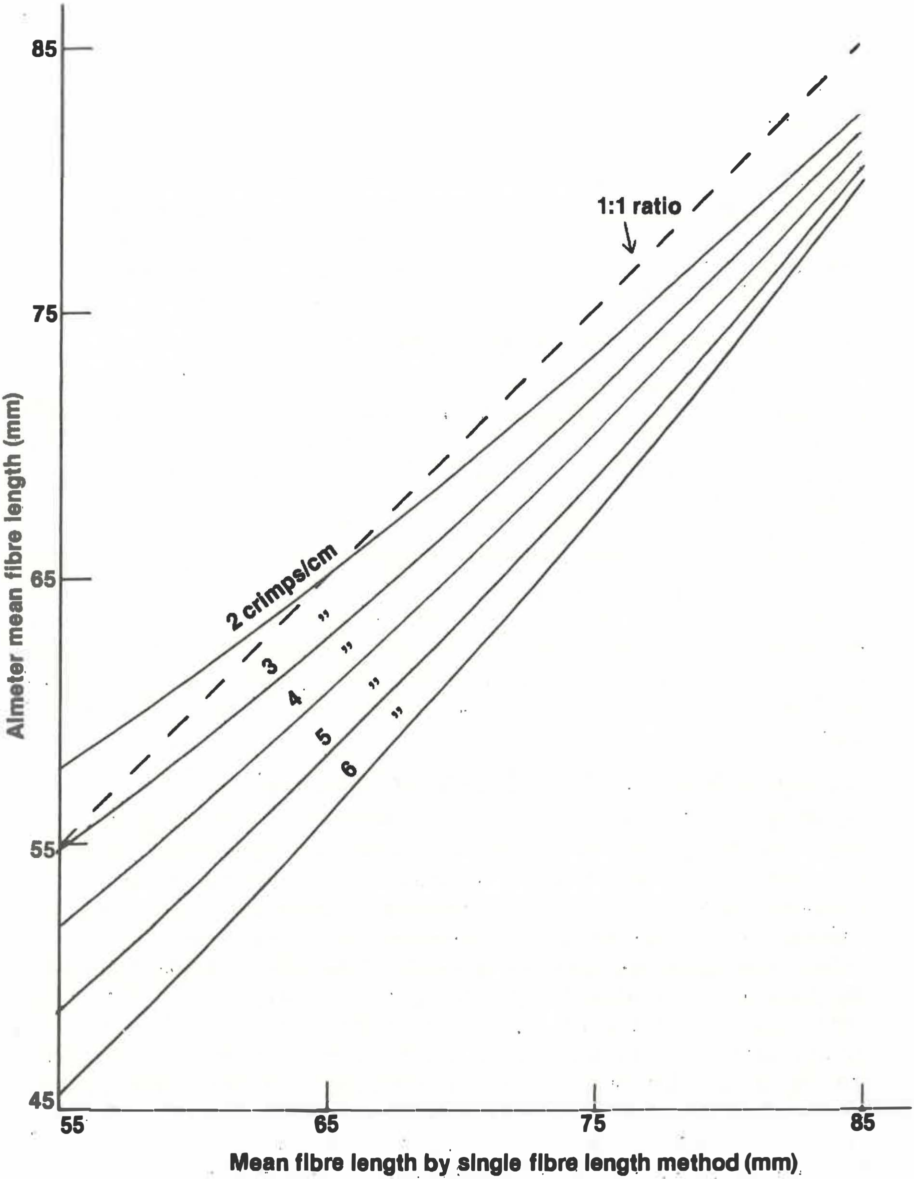


Fig. 3 Regression curves for Almeter mean fibre length versus mean fibre length by single-fibre length method illustrating the effect of crimp (Long Wools and Medium Wools combined).(728)

the calculated values of the blend were compared with those given by the Palmer equation.

Turpie[657 728] showed that staple crimp had a significant effect on Almeter fibre length results, the magnitude of the effect depending on the pre-tensioned state of the top prior to measurement, the effect also appearing to be greater for the shorter wools (Fig. 3).

Kruger[173 269] described a new apparatus and method of determining the mean fibre length of a top or card sliver based upon the force required to withdraw fibres from a sliver inserted in pins, the mean fibre length being calculated from the maximum withdrawal force and the time integral of the total force. Fibre breakage during withdrawal was negligible.

3.6 MEASUREMENT OF SHORT FIBRE CONTENT

Aldrich[468] measured the coefficients of variation of fibre length and short fibre content of tops on an Almeter, WIRA Fibre Diagram Machine and WIRA Single Fibre Length Tester. The Almeter produced, on average, a slightly higher CV-value and the Fibre Diagram Machine a much lower CV-value compared with the Single Fibre Length Tester. The Almeter and Single Fibre Length Tester differed only slightly in respect of short fibre content values. The values obtained on the Fibre Diagram Machine were much lower than those obtained on the Single Fibre Length Tester.

Gee[563] showed that the short fibre content of wool, calculated from the values of mean fibre length and CV by using the properties of the Normal Distribution curve, correlated well with the results obtained from the WIRA Single Fibre Method but not with those from the Almeter or the WIRA Fibre Diagram.

3.7 FIBRE DIAMETER AND LENGTH DISTRIBUTIONS

Linhart and Wilmot[100] described two methods of measuring the bivariate length-diameter distribution in samples of wool fibres while Linhart and Van der Westhuyzen[56] showed that the gamma and log-normal distributions fitted the length-biased diameter distributions of raw South African Merino wools, the log-normal generally giving the better fit.

Gee[635] concluded that, although the mean value and the standard deviation, which characterise a normal distribution, give useful measures of fibre length and fibre diameter distribution, calculation of the third and fourth moments of actual distribution showed that neither length nor diameter had a normal distribution, significant skewness (tails) and kurtosis (peaky or flat-topped varieties) being present. Diameter distribution tended to have positive tails and were peaked, while lengths tended to have negative tails and were also peaked. By quantifying the non-symmetrical distribution of fibre diameter and length of different wool lots, he[852 904 934] showed that the measures of the mode, skewness and kurtosis can play a significant rôle in explaining the behaviour of wool during spinning and in the yarn and fabric. For example, higher values for CV, skewness and kurtosis of fibre diameter tended to give inferior yarns, while higher values for the fibre length properties gave better yarns.

Hunter and Smuts[672] compared the fineness of wool and other fibres determined by means of a vibroscope, with that calculated from the fibre diameter and relative density and found good agreement between them.

3.8 FIBRE DIAMETER AND LENGTH CHARACTERISTICS OF THE SOUTH AFRICAN MERINO CLIP

Uys[64] reported on the geographical distribution of the fineness of Merino wools in South Africa and found that the Merino clip deviated significantly

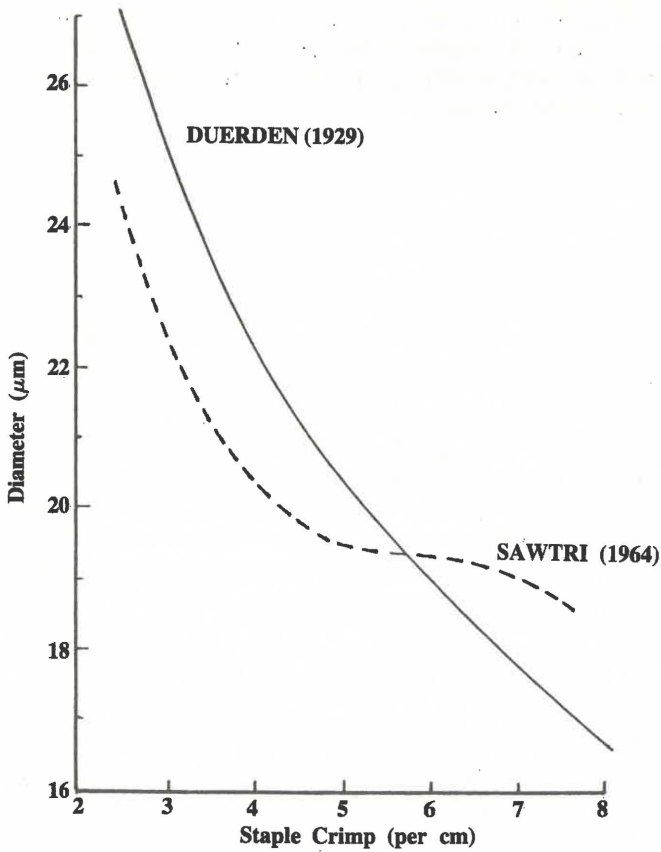


Fig 4. The relationship between staple crimp and mean fibre diameter for South African Merino wools[65]

from the Duerden fineness-crimp relationship derived some 34 years previously. He subsequently[65] presented detailed information on the relationship between staple crimp and fibre diameter which emerged from his results, showing that wools above 19 μm had generally become less crimped than when Duerden carried out his study (Fig. 4)[65].

Venter[81] studied the interrelationship between fleece and fibre properties for Merino wool and presented the results as an M.Sc. thesis.

Strydom and Gee[877] showed that during the period 1967/8 to 1982/3 the average fibre diameter of the South African Merino clip increased by about 1 μm as indicated by a shift in the position of the mode, mean and median values (Fig. 5).

The proportion of the clip finer than 20,0 μm decreased from about 20 to about 5%. Over the same period, no significant trends in staple length distribution were detected. The mode of the length distribution curve was at an appraised length of 10/12 months while 50% of the clip fell in length categories of 9/11 months and shorter.

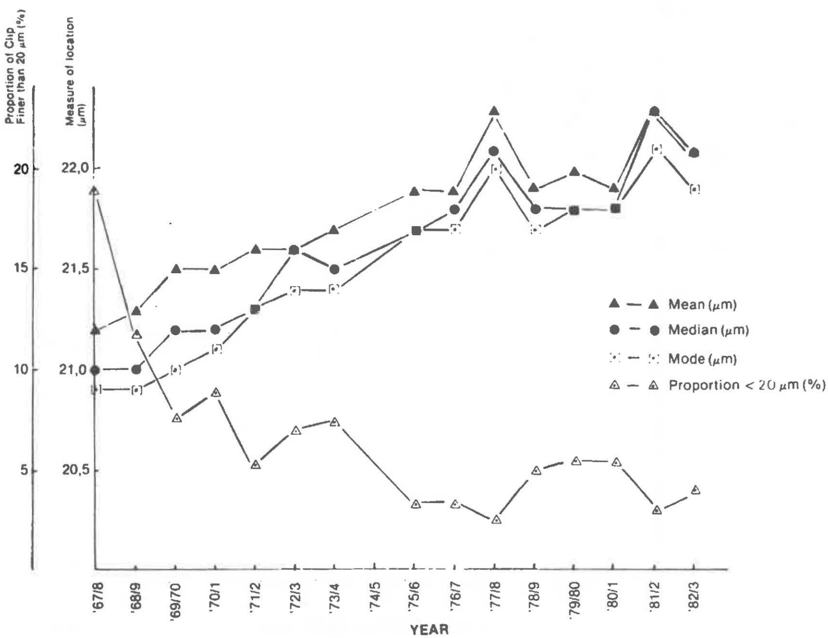


Fig 5. Measures of Location for Fibre Diameter Distribution and Proportion of Merino Clip finer than 20,0μm (1967/8 to 1982/3).[877]

3.9 SINGLE FIBRE TENSILE PROPERTIES

Hunter and Kruger[178 205] and Smuts and Hunter[616] compared the tensile properties of kemp, mohair and wool fibres using the Uster Yarn Evenness tester to measure the linear density of the fibres. This technique indicated the presence of a material in the medulla of the kemp which had dielectric properties similar to the rest of the fibre, but which did not contribute to the fibre strength. The breaking extensions of the different types of fibres were similar, but the tenacities of the wool fibres were lower than those of the mohair and kemp fibres.

Hunter[470] studied the relationship between single fibre tensile properties and diameter, between and within different spinning lots (commercial and laboratory), for a range of *Merino wools*. It was found that, between lots, fibre tenacity was independent of diameter, whereas, within lots, tenacity tended to decrease with an increase in fibre diameter. Single fibre breaking extension was largely independent of fibre diameter. Subsequently Smuts *et al*[802] measured the single fibre tenacity, extension at break and initial (pre-yield) modulus on a large number of wool samples from *different breeds of sheep* and covering a wide range of diameter and crimp to establish "typical" or "average" values for the tensile properties of wools grown in South Africa. It was found that crimp or the quotient of resistance to compression and fibre diameter, (termed bulk/diameter ratio) had a greater effect on the fibre tenacity and initial modulus (pre-yield slope) than diameter, an increase in crimp being associated with a decrease in these properties (Table I). Tables and graphs were given to illustrate the observed trends and for reference purposes. Some values obtained on mohair were included for purposes of comparison.

TABLE I
TYPICAL TENSILE PROPERTIES OF WOOL AT VARIOUS CRIMP LEVELS[802]

Measures of Crimp		Single Fibre Properties		
Staple Crimp (cm^{-1})	Bulk/Diameter Ratio (mm/μm)	Tenacity (cN/tex)	Extension at Break (%)	"Pre-Yield" Modulus (cN/tex)
2,0	0,45	14,2	37	340
2,5	0,53	13,7	37	320
3,0	0,61	13,4	37	310
3,5	0,69	13,0	37	300
4,0	0,76	12,8	37	293
4,5	0,83	12,5	37	285
5,0	0,90	12,3	37	280
5,5	0,97	12,2	37	275
6,0	1,04	12,0	37	270
6,5	1,11	11,9	37	265

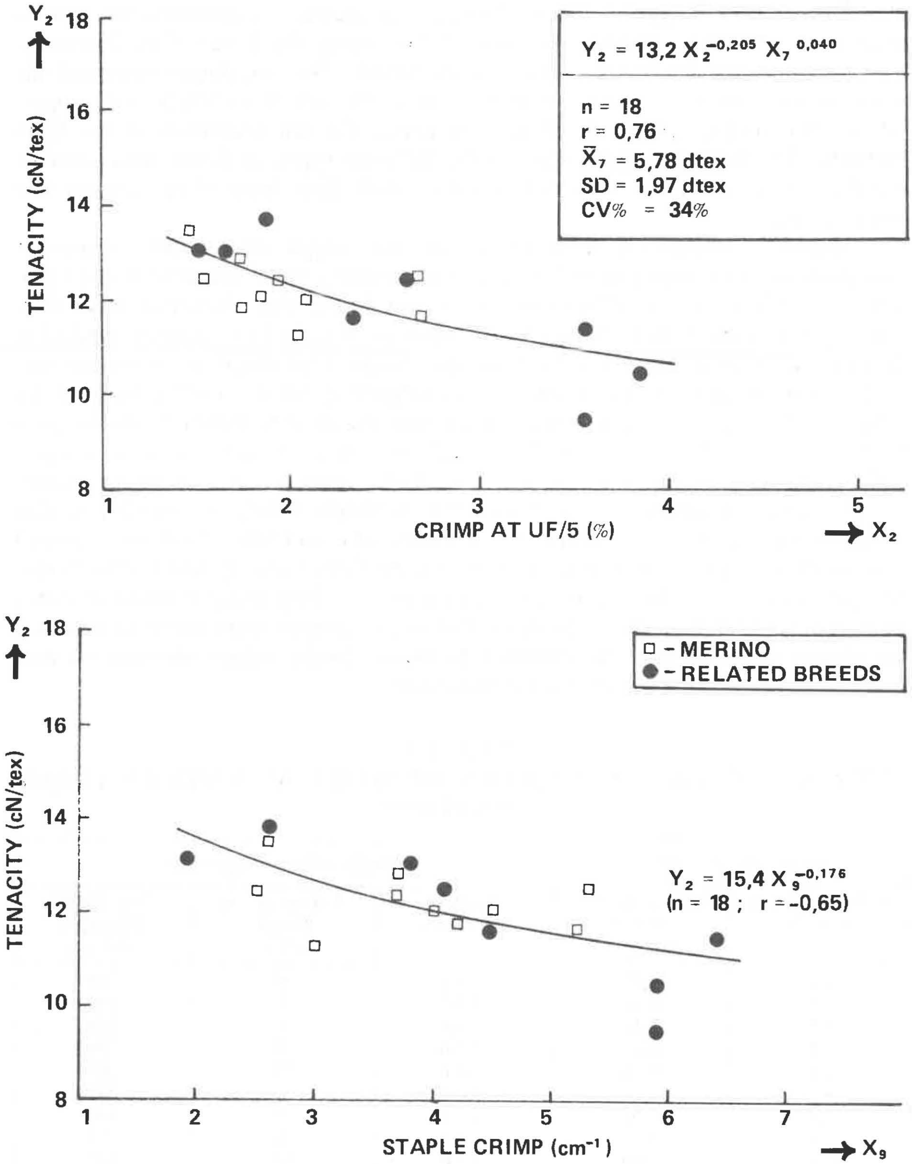


Fig. 6 Effect of Fibre Crimp on Fibre Tensile Properties.(808)

In a follow-up study, Smuts *et al*[808] determined the effect of diameter and crimp on the single fibre tensile properties of wool tops, each of which was produced from a different bale of farm-classed wool. Within such tops there was a tendency for single fibre crimp to increase with fibre diameter, whereas the reverse was true for between tops. Single fibre strength increased approximately linearly with fibre linear density and the latter accounted for about 90% of the variation in strength. For the individual results (both within samples and for all the results pooled), fibre tenacity and extension at break were, for all practical purposes, constant and independent of crimp and fibre fineness. Between samples (i.e. sample means), however, an increase in crimp tended to be associated with a decrease in fibre strength (Fig. 6).

The "initial" (pre-yield) modulus generally decreased with an increase in crimp but was not affected by fibre fineness. The tensile properties of the Merino and related breeds were similar provided their diameter and crimp levels were similar.

3.10 FIBRE BUNDLE TENACITY

The application of the bundle tensile tester for obtaining a relatively rapid measure of wool fibre strength was investigated by De Beer and Slinger[78] who showed that, provided due care was exercised and one operator used, acceptable results could be obtained. It was found that bundle tenacity increased slightly with an increase in diameter or with a decrease in staple crimp and that no difference in tensile strength along the staple was observed when the wool was grown under fairly homogenous feeding conditions. In a later study, Hartley and Slinger[109] used the bundle test to assess the effects of various types of dark shade dyeing on fibre tensile properties. They found metachrome dyeing better than afterchrome dyeing in terms of their effect on fibre strength and found that a pH of 4 produced a smaller drop of ($\simeq$ 10%) strength than a pH of 6 (drop of $\simeq$ 30%). A significant drop in fibre extension was caused by dyeing. A significant correlation between wet single fibre tenacity and dry bundle tenacity was found. A deterioration in fibre tensile properties with an increase in dichromate was observed. A lower liquor to wool ratio (10:1) was also found to be more harmful than a higher liquor to wool ratio (30:1).

Hunter and Grobler[482] applied the fibre bundle test method to fibre still in yarn form using a Stelometer, as did De Beer and Slinger[78], Hunter and Slinger[229] and Hunter *et al*[325] but using a Clemson tester. The mass of the yarn bundles had a profound effect on the extension values obtained, but had only a small effect on the tenacity values[482]. The values obtained on the yarn bundles were found to be significantly correlated with the single fibre tensile values and also with the values obtained when employing the standard bundle test on parallel fibres.

Hunter and Smuts[684] measured the resistance to compression and bundle tenacity of some 200 South African commercial wool tops (dyed and undyed) so as to prepare average or reference values for these two properties. Tenacity increased with increasing fibre diameter (Table II) and decreasing fibre crimp, it being mentioned that the tenacity of a top should preferably exceed 11cN/tex and should not drop below 10cN/tex.

TABLE II

AVERAGE BUNDLE TENACITY VALUES (AT 3,2 mm GAUGE) FOR SOUTH AFRICAN TOPS[684]

Mean Fibre Diameter (μm)	Bundle Tenacity (cN/tex)
18	10,6
20	11,2
22	11,7
24	12,2
26	12,7
28	13,2
30	13,7
32	14,1
34	14,6
36	15,0

Smuts and Hunter[788] investigated the effect of staple crimp, mean fibre diameter and resistance to compression on bundle tenacity and extension of a wide range of unrelaxed and wet-relaxed wool tops and found that they were affected by fibre crimp rather than by fibre diameter. Bundle tenacity decreased and bundle extension increased with an increase in crimp, irrespective of whether the crimp change was due to differences in the original crimp or due to crimp recovery resulting from relaxation of the tops. The quotient of resistance to compression and fibre diameter (i.e. "bulk/diameter ratio"), was taken as a measure of the overall fibre crimp and was better correlated with bundle tenacity than staple crimp or resistance to compression.

3.11 STAPLE LENGTH AND STRENGTH*

Gee[528] carried out a limited investigation of the possible relation between unstretched staple length and mean fibre length and showed that they were very highly correlated (more than 99,9%). Within the limitations of his work, staple length measurements predicted the mean fibre length of the greasy wool within the limits of ± 2,5 mm for a certain set of conditions. His set of data also showed a one to one relation between the staple length and the mean fibre

* See also Chapter 7.8.

length of the top. Turpie *et al*[973a] showed that trapeziums (staple taper) fitted to staple profiles provided by the SAWTRI Staple Length/Strength Tester, were more useful for predicting mean fibre length and fibre length distributions than staple length only.

Gee[710] used the techniques developed by other workers to demonstrate the usefulness of staple strength as a measure of wool soundness, a good topmaking style having a higher strength and a lower variation in strength than an inferior topmaking style. A significant negative correlation was found between the mean strength and its CV. Wools subjectively assessed as tender, gave very low strength values . A high correlation (93%) between the combing tear and staple strength, and lower correlations with decrease in fibre length, were found for the data of seven commercially processed wools. A tentative scale indicated that sound wool had a staple strength greater than 40 N/ktex while an unsound wool yielded less than 23 N/ktex.

Hunter *et al*[853] found a high correlation (0,96) between staple and single fibre tenacity for sound and tender wools. Wools subjectively classified as tender generally had staple tenacity values below about 20 N/ktex, while those of sound wools were generally higher than about 30 N/ktex.

Cizek and Turpie[912 918 924 939 948 973 973a 995] described a staple length/strength measuring instrument developed for the routine automatic measurement of the cross-sectional profile and length (Fig. 7) of a wool staple, the position and cross-sectional area of its thinnest place, its tenacity (Fig. 8) and the work required to break it. Good correlations were found between the lengths mea-

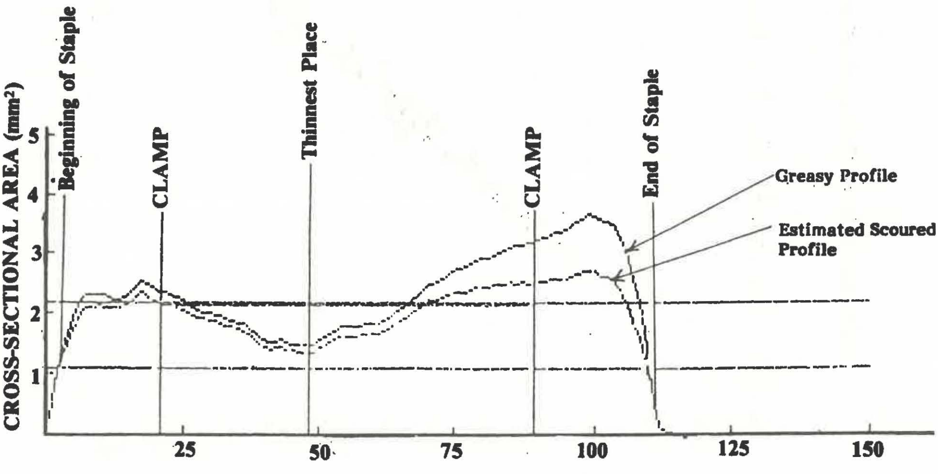


Fig. 7 Example of a raw wool staple profile showing where it was deemed to begin and end, where it was clamped in the machine and also its estimated profile in the scoured state.[918]

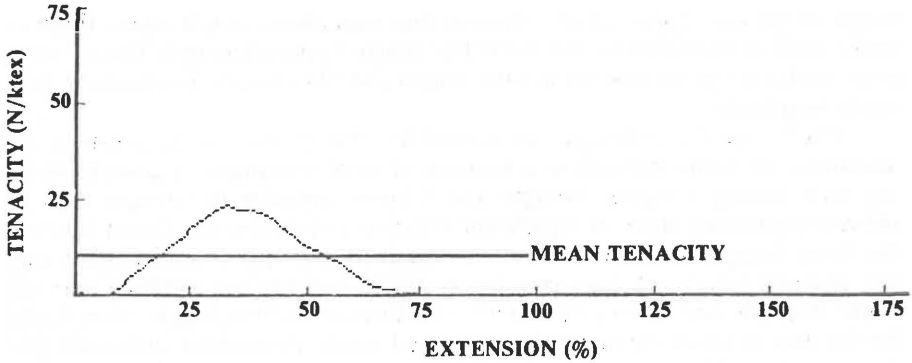


Fig. 8 Example of a force/extension curve obtained from a raw wool staple.(918)

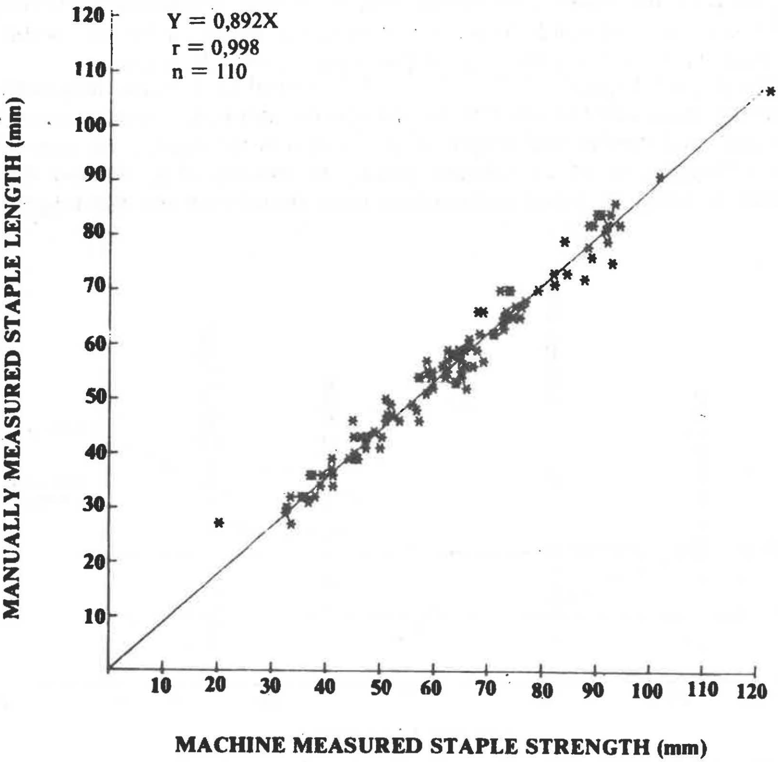


Fig. 9 Machine measured versus manually measured staple length.(918)

sured manually and on the machine (Fig. 9), and between the positions of the thinnest places identified by the instrument and the position of the actual break. Many different staple profiles were encountered, and there were differences between different wool lots in respect of their strength characteristics, but also between different staples within a lot. The results were useful in predicting noil and top fibre length characteristics. In pilot-scale studies it was shown that testing the strength of raw wool staples at a short gauge (20mm), which provided a measure of the intrinsic strength of the wool, in addition to the maximum practical gauge (namely where the staple is clamped 18mm from both root and tip), can be potentially useful in explaining variations in percentage noil during subsequent combing. It was also shown that collective information on the profiles of raw staples could have application in the prediction of the length characteristics of wool and mohair tops.

3.12 STAPLE CRIMP AND RESISTANCE TO COMPRESSION*

Slinger[121] investigated the effects of natural and artificial weathering as well as UV-irradiation on the resitance to compression of wool and found that artificial weathering as well as UV-irradiation increased resistance to compression. He also found that artificially weathered wool felted less than unweathered wool and confirmed that resistance to compression was related to the product of staple crimp and mean fibre diameter.

Slinger and Smuts[188] developed a method and instrument (the SAWTRI Compressibility Tester) for measuring the bulk (compressibility or resistance to compression) of a randomised mass of wool fibres simply, quickly and accurately. They concluded that it was a useful test for selecting wool tops and that it provided a measure of the crimpiness of the original wool. Resistance to compression was also correlated with the cystine content of the wool. Differences in the resistance to compression of different types and breeds of wool could largely be explained by differences in the product of diameter and crimp frequency. Low resistance to compression was observed for stud sheep (rams and ewes) exhibited at an agricultural show, suggesting that softness of handle (associated with low resistance to compression) was considered a desirable attribute for such show wools.

Scheepers and Slinger[230] found that the crimp form was helical for Merino wools relaxed in cold water and more pronounced helical for allied breeds. For the Merino wools, crimp form had a negligible influence on felting propensity (Aachen test) and resistance to compression, with the influence of crimp frequency dominating and with the effect of fibre diameter of secondary importance. Felting propensity and resistance to compression were highly correlated.

Smuts and Slinger[406] found that, in addition to resistance to compression

* The effects of these fibre properties on processing performance and on yarn and fabric properties are covered under the appropriate Chapters.

(or crimp) and fibre diameter, against-scale fibre friction also contributed to the tactile properties (handle) of loose wool and mohair. They proposed that the characteristically low against-scale friction of mohair be used as a criterion for distinguishing between mohair and wools such as Buenos Aires.

Turpie and Gee[692] confirmed that resistance to compression was largely a function of the product of fibre diameter and staple crimp frequency, a better correlation being obtained if felt ball density was included as another independent variable.

Hunter and Smuts[684] measured the resistance to compression of some 200 dyed and undyed commercial tops and prepared "average" or "typical" values for this top characteristic. They confirmed that resistance to compression was largely a function of the product of fibre diameter and staple crimp frequency and that the resistance to compression of a steamed top approximated that of the laboratory scoured raw wool. The resistance to compression of the pilot-plant scoured wools however, was higher both in steamed and unsteamed form.

Hunter[768] presented Fig. 10 as an example of how one can distinguish between over-crimped and under-crimped wools (relative to Duerden values) on the basis of their resistance to compression.

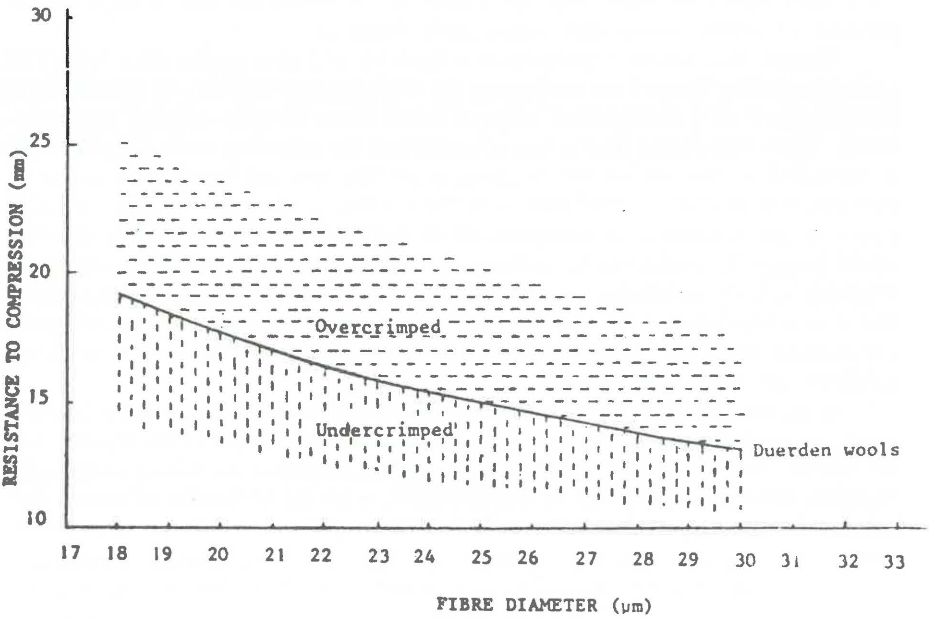
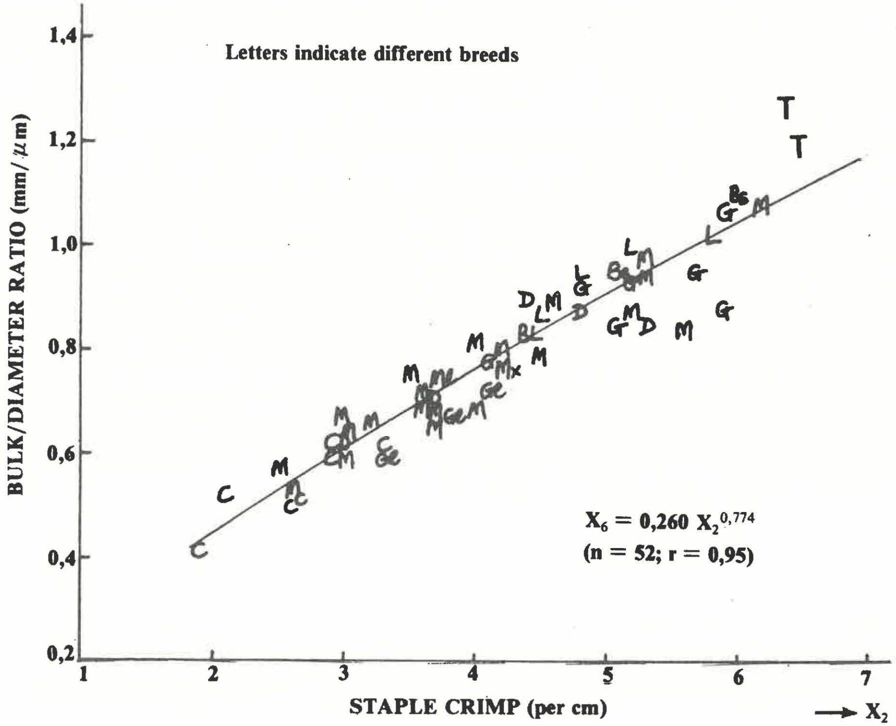


Fig. 10 An example of a reference curve for the resistance to compression of steamed tops or laboratory scoured raw wool based upon wools obeying Duerden's diameter-crimp relationship (SAWTRI test).(768)

Smuts and Hunter[788] showed that the quotient of resistance to compression and fibre diameter, termed the bulk/diameter ratio, was a good measure of the overall fibre crimp (Fig. 11) and was better correlated with bundle tenacity than was either staple crimp or resistance to compression.

Hunter and Smuts[804] measured the resistance to compression of twenty-six wool tops, dyed commercially under identical conditions, both prior to and after steam-relaxation. It was found that such dyeing had little effect on the resistance to compression of the tops measured after steam-relaxation, there being a fairly good correlation between the resistance to compression of the steam-relaxed dyed tops and that of the undyed tops, as well as between the former and the product of staple crimp and mean fibre diameter. In the case of commercial undyed and dyed tops, the resistance to compression of the latter was on average, about 11% lower than the former[684].



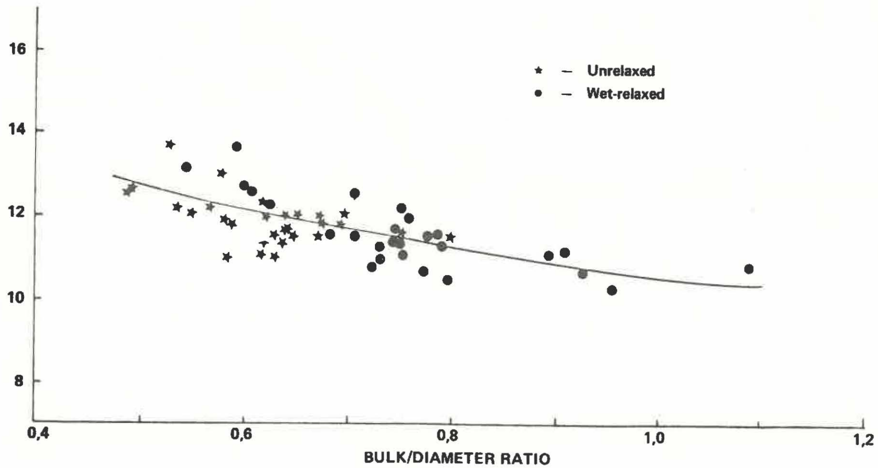
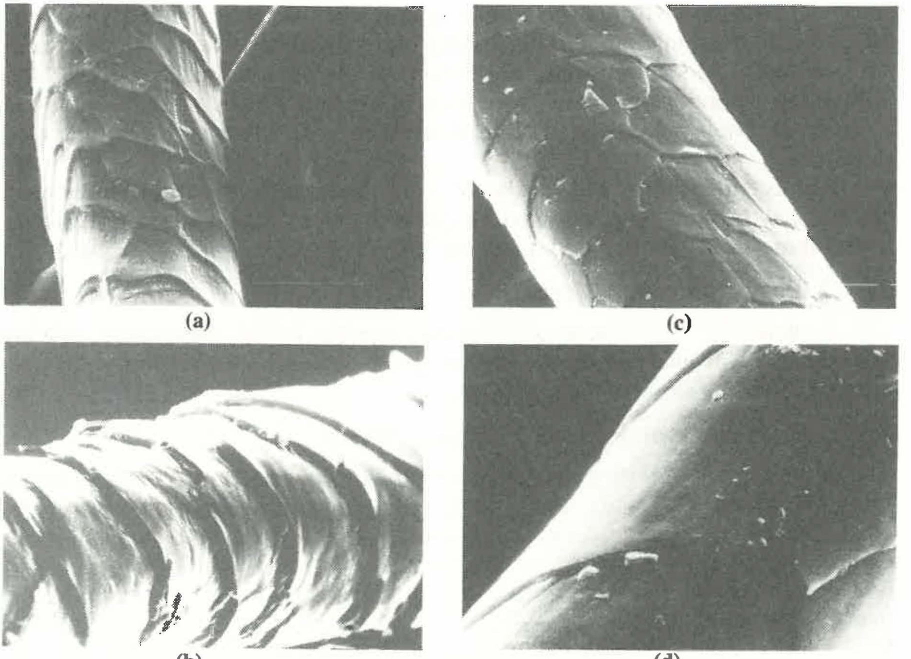


Fig. 11 The relationship between bulk/diameter ratio and staple crimp and bundle tenacity, respectively.(788 802)



(a) (c)

(b) (d)

Wool:
(a) 1400x
(b) 3300x

Mohair:
(c) 1400x
(d) 3300x

Fig. 12 Scanning electron micrographs illustrating wool and mohair fibre scale structures.(985)

3.16 BLACK FIBRE LEVELS

Strydom and Gee[843] tested grab samples from some 209 producer batches of fleece and belly wools for the incidence of naturally pigmented and stained fibres. Excluding abnormally high values which occurred in seven of these samples, it was found that the bellies were slightly more contaminated than the Merino fleece wools and the fleeces from Merino-related breeds. The overall mean count was about 75 dark fibres per kg.

3.17 GENERAL

3.17.1 Detection of Skin Wool

Kerley[89 97] reported on a simple test for detecting the presence of pulled wool in tops which was based upon differences in dye uptake due to fibre damage. A Shirlastain was used which stained the root ends of the fibre differently, according to whether the wool was derived from skins (pulled) or shorn. Microscopic examination could also help to distinguish between painted (sodium sulphide) and sweated (bacterial action) wools. In a subsequent study[109] the processing behaviour and dye absorption of various blends of shorn and skin (depilated) wools were studied. Dye skitteriness was observed for the blended samples.

Kerley[99] also illustrated that wool from sheep suffering from lumpy skin disease may be cemented (gummed) together by an exudate so as to give rise to a problem (fault) in a felted material.

3.17.2 Basic Statistical Techniques

Linhart[25 26 31 35 45 102] dealt with various aspects, mostly theoretical, relating to the statistical analysis of data while Gee[822] discussed the accuracy of measurements on the slope of the regression line.

3.17.3 Properties of Finnish Landrace Wool

Smuts *et al*[427] reported on certain of the physical properties of the Finnish Landrace wool. The characteristic soft handle of this rather coarse wool was attributed to the relatively low against-scale friction and high percentage of ortho-cortex. Felting propensity was high. The 2/2-twill cloths produced from it had a kind handle and the mechanical properties were more or less in accordance with those which could generally be expected from a good all-wool 2/2-twill fabric. The fabric wrinkling equalled that of a good all-wool 2/2-twill fabric.

CHAPTER 4

WEATHERING AND NUTRITIONAL EFFECTS ON WOOL

Van Wyk and Veldsman[18] studied the variation in dye absorption rate (acid milling and premetallised) of different South African wools and found it to be inversely proportional to fibre diameter, deviation from a linear relationship being almost entirely due to weathering damage, open wools showing weathering far down the staple but tar tipped wools only at the tips.

The use of the cross-linking (colour) reaction of ninhydrin with wool protein for estimating wool fibre diameter and weathering damage (dyeing behaviour) was investigated by Veldsman[19] and Louw[20] and optimum conditions were established.

Kritzinger[22] discussed the use of dye absorption and reaction with ninhydrin of wool and mohair as a measure of the weathering and illustrated the importance of fibre diameter, while Veldsman[24] reported on the tryptophane content of weathered wool and mohair and morphologically deviating wool. Snyman[27] studied the effect of environmental factors on weathering of Merino wool and obtained an M.Sc. degree on the results of his work. Swanepoel[37] compared the supercontraction of sound and weathered wool. Van Wyk and Louw[82] investigated the relationship between urea/bisulphite solubility (UBS), suint pH and Ninhydrin Index of South African Merino wool for root, middle and tips separately. Their results supported their contentions that the UBS of weathered wool was influenced by those climatic factors of which the weathering results were assessed in the ninhydrin test and that chemical changes due to alkaline conditions in the fleece tended to decrease UBS.

Mellet[91] investigated the influence of disulphide cross-linkages on the reaction between ninhydrin and wool for wools which had been subjected to artificial weathering (irradiation) and found that the disulphide content of the irradiated wool was associated with its Ninhydrin Index. It appeared that the ninhydrin test could not be used on artificially weathered wool.

Thorpe and Veldsman[76] [94] reported on ways of improving dyeing unlevelness associated with differences in weathering.

Scheepers *et al*[110] showed that the methylene blue absorption test clearly illustrated the tendency of weathered wool staples to give tippy dyeing and studied various factors which affected the use of this method, arriving at a simplified technique. In contrast to the ninhydrin test, the methylene blue absorption for sound wools was independent of fibre diameter, this also applying to artifically weathered wool. The dye absorption test correlated well with visual assessment of weathering damage and with other test results e.g. bundle tenacity, cystine content and the ninhydrin test. There were indications of an effect of storage on dye absorption. The bundle tenacity of the wools ranged from about 13,1 cN/tex for undamaged (unweathered) wool to about 9,1 cN/tex for badly weathered wool.

There were certain complicating factors in the method of Scheepers *et al*[110] and the method was modified in a subsequent study[176] so as to avoid erroneous conclusions due to the influence of chemical changes of a non-permanent (reversible) nature. This involved buffering the wool and dye solution and ensuring that the wool is free of residual grease, detergent and combing oil. The test was not considered suitable for assessing the degree of mechanical damage due to processing the wool into a top since carding and combing tended to remove the weathered fibre tips having the highest dye absorption. The methylene blue absorption of different wools correlated well with their urea-bisulphite solubility values.

Slinger[121] found that natural and artificial weathering and UV-irradiation increased the bulk resistance to compression of wool and that artificially weathered wool felted less than unweathered wool. Veldsman and Swanepoel[34 70 101 259] also reported on the effect of weathering on the felting behaviour of wool and on the efficiency of shrinkproofing.

Louw[28] investigated differences in chemical composition between root, middle, and tip sections of normal crimped and of copper-deficient steely South African Merino wools and their influence on dye absorption and alkali and urea-bisulfite solubility. For normal wools the loss in cystine and tryptophane and increase in cysteic acid revealed the extent of hydrolytic and oxidative weathering damage and explained subsequent changes in solubility and dye absorption. The conclusion was reached that copper deficiency retarded fibre keratinization which could, however, continue during ageing and weathering of steely wools on the animal's back, resulting in increased cross-linking. Variations in amino acid content of root and top sections of normal and steely wools were found. He was able to explain, on the basis of his work on the bilateral structure of crimped and steely (copper-deficient) wools, why copper deficiency resulted in undercrimped wool[30].

Louw *et al*[55] subjected the root, middle and tip sections of staples to artificial weathering in sunlight behind glass. Such artificial weathering attacked cystine and probably formed sulphur-containing compounds which were not amino-acids, in addition to the known decomposition products. Tryptophan underwent serious decomposition, whereas threonine, serine, proline, tyrosine, phenylalanine, lysine and histidine were also affected. Weathering decreased the moisture absorbing capacity of wool. Grease and suint served to restrict penetration of weathering into a fleece on the sheep's back by virtue of their cementing action.

Turpie[453] showed that combing performance deteriorated with deterioration brought about by weathering, particularly when backwashing of the tops occurred at a pH of 10,5.

Snyman[69] suggested that grazing not only affected fibre diameter but also fibre chemistry and morphology. He concluded that the ratio of the two bilateral segments in Merino wool was determined genetically and not by feeding conditions, confirming the findings of Boshoff and Scheepers[128] who found hungerfine wools to be undercrimped while high nutritional level wools tended to be overcrimped.

Slinger *et al*[184] reported on the influence of the nutritional background of sheep on the mechanical properties of the wool and described a relatively easy chemical test for quality control. The ortho-para ratio appeared unaffected by nutritional level while the resistance to compression of the high-nutrition wool was marginally higher than that of the low-nutrition wool, and the bundle tenacity was also higher. It was correlated with cystine and inversely with alkali solubility. Alkali solubility was correlated with cystine content, while alkali solubility and fibre diameter were independent within a nutritional level.

Kruger[343] presented limited results which indicated that a tender portion of a wool fibre, brought about by drought conditions, was intrinsically weaker than the sound part of the same wool fibre.

Scheepers[83] investigated the effect of level of nutrition on the quality of *karakul pelts* and concluded that it had no effect on felt thickness, hair diameter or hair length of newly born karakul lambs.

CHAPTER 5

SCOURING, CARBONISING AND EFFLUENT TREATMENT

5.1 CONVENTIONAL SCOURING AND ASSOCIATED TESTS

5.1.1 Scouring Studies

Early studies[15 16] on scouring dealt with the variability of suint content in South African raw wools and the effects thereof on grease removal and detergent consumption. The benefits of steaming or cold steeping prior to scouring were illustrated as well as the variations in detergent requirements and grease removal due to variations in original grease levels and in the nature of the suint. Subsequent studies[17] showed the beneficial effects of increasing mechanical action and liquor temperature on grease removal.

Snyman and Veldsman[107] investigated the effect of different rinsing conditions on scoured wools containing alkali, hard and soft soaps, a synthetic anionic detergent and a non-ionic detergent. Temperature and mechanical action during rinsing were found to outweigh the effect of time of rinsing on rinsing efficiency. The presence of potassium chloride adversely affected rinsing efficiency, indicating that water of a low electrolyte content was essential for good rinsing.

Grové[57] investigated the effect of variations in the mechanical conditions on the scouring of raw wool and found that both rake and roller speeds could be increased considerably without adversely affecting the appearance of the scoured goods, or detergent consumption. Relatively high rake and roller speeds combined with a high rate of feed gave the optimum running conditions for the plant used. He subsequently[58] showed that detergent consumption could be reduced considerably by employing a suitable rate of backflow. The detergents showed widely divergent reactions to variation in the backflow rate. He also found that the equilibrium solids concentration in the first bowl was inversely proportional to the rate of backflow and described a rapid method for determining the amount of suspended solids by means of a barkometer. Kriel and Veldsman[72] found a 25% backflow optimum for a soap detergent (R Fluidol W100) the build-up of solids showing a similar trend as that observed by Grové[58]. Certain of the above studies were incorporated into his M.Sc. thesis by Grové[59].

When scouring locks (lox) under varying conditions of temperature in the first two bowls of a pilot-scale scouring set, Grové[103] showed that the first bowl temperature was the dominant factor in determining detergent consumption, minimum consumption occurring in the vicinity of 60°C in the first bowl and 62°C in the second. Albertyn and Grové[106] later confirmed that the build-up of solids in the first scouring bowl decreased with an increase in backflow rate but in this study the consumption of an alkyl-aryl polyglycol ether detergent (R Berol Lanco) increased.

In a study on the effect of detergency builders on the scouring of raw wool, Grové[133] found that, in the case of soap, sodium carbonate was the most efficient builder, whereas sodium sulphate and sodium chloride had weaker but very similar effects. Detergent consumption decreased sharply with increasing builder additions in the lower concentration ranges. Excessive amounts of sodium carbonate appeared to have a significant effect on the colour of the scoured wool.

Using the UBS method to determine the modification of wool and mohair by alkali treatment for short periods of time Kriel[137] concluded that scouring at temperatures not exceeding 60°C in a concentration of 0,15% soda ash should have little detrimental effect on the scoured fibres, grease protecting the fibres against alkali modification. Differences in the behaviour of wool and mohair were ascribed to differences in fibre diameter.

Due to inconsistencies in the published literature, Grové and Kriel[189] investigated the sorption of a number of non-ionic detergents by wool and found it to differ for the root (higher) and tip sections of the fibre and to decrease with increasing ethylene oxide chain length. The results indicated that scouring with a non-ionic detergent should be more efficient in the presence of soda ash and this was confirmed in another study by Grové[133]. Sorption was considered to be negligible at 55°C in the case of neutral scouring or scouring in the presence of sodium sulphate, although significant sorption occurred under acidic conditions, for example at the iso-electric point (pH 3,9 to 4,5) of wool.

Swanepoel and Veldsman[288] investigated various factors which can beneficially reduce fibre entanglement during scouring including the use of a fleece breaker, harrow and squeeze roller speeds, and rate of feeding.

Using pilot-scale scouring without backflow, Kriel and Albertyn[237] confirmed the findings of other workers that the grease removed in the first scouring bowl was mainly unoxidised while the more tenacious oxidised grease was removed in the subsequent scouring bowls. An even concentration of detergent over the three bowls was found best for fleece wools, while a relatively higher concentration in bowl 3 was better for locks, probably due to the more oxidised state of the grease on the locks.

Swanepoel *et al*[384] showed that the grease removal efficiency of anionic and non-ionic detergents was adversely affected by relatively high concentrations of sodium sulphate in raw wool scouring liquors. An optimum range of sodium sulphate concentration was found, the effect of sodium sulphate on detergency being dependent upon the presence of suint from the raw wool.

Turpie[456] found that neutral scouring at higher temperatures resulted in noil levels similar to those obtained at lower temperatures in alkaline scouring. Variations in scouring conditions offered some benefit to subsequent mechanical processing, provided they were carefully selected. Turpie[459] also showed that when wool was rinsed in liquors of different pH values following conventional scouring, the entanglement of the wool varied which in turn affected combing. Combing performance depended on the pH of the liquor in which the wool was rinsed, the reagent used to control pH and the residual grease level of the scoured wool. Changes in combing performance were related to changes in entanglement and could be reflected in either the vegetable count or the nep count (sometimes both) of the slivers. The combing performance of wools scoured in an alkaline medium could be improved by a subsequent rinse in an acid medium.

From other studies, Turpie[473] concluded that neither the use of neutral media during scouring nor the use of alkaline or acid media during rinsing, could be expected to reduce the percentage noil by more than 15% and that such treatments may involve slight increases in expenditure on chemicals.

Turpie[493] concluded that, for optimum values of neps and percentage noil and if *soda ash were used,* the pH of the liquor in the *first* bowl must preferably not exceed 9,5 and the temperatures should be below 60°C. If the resulting pH values of the aqueous extract of the scoured wool were too low, however, it appeared preferable, from both an economical as well as a processing point of view, to adjust the pH in the *second* rather than the *first* scouring bowl. If *no soda ash were used,* the temperature of the liquor should preferably be 60/65°C. He found[523] that, for difficult to scour fine Ciskei fleeces, satisfactory neutral scouring and carding and combing could be achieved at temperatures of the liquors in the bowls of 65°, 60°, 50° and 45°C respectively, initial charges of detergent to the first three bowls of about 0,1, 0,02 and 0,02% m/v respectively, and subsequent additions to the first three bowls of about 0,40, 0,15 and 0,05 (total 0,60) kg per 100 kg greasy wool.

Turpie and Gee[566] scoured a range of wools under neutral, slightly alkaline and more severely alkaline conditions, using scouring liquors which varied from slightly dirty to very dirty, to study the effects on the yellowness of the wool. Neutral scouring gave lower yellowness than slightly alkaline or more severely alkaline conditions, although differences present after gilling tended to be reduced after combing. The more inferior styles of wool tended to suffer a greater increase in yellowness.

In a limited study on the reduction in the contaminants of raw wool by desuintage scouring, Turpie and Musmeci[625] showed that the passage of raw wool samples through the first bowl of a pilot scouring plant containing only mains water, effected a significant reduction in all contaminants, i.e. mineral matter, suint and grease. The temperature of the water was shown to be of considerable importance.

Turpie and Gee[660] correlated certain properties of fleece wools with the detergent requirements during scouring and showed that 77% of the variation in detergent requirements could be accounted for by five parameters, viz. solid dirt content, particle size of the dirt, entanglement of the tip portion of the

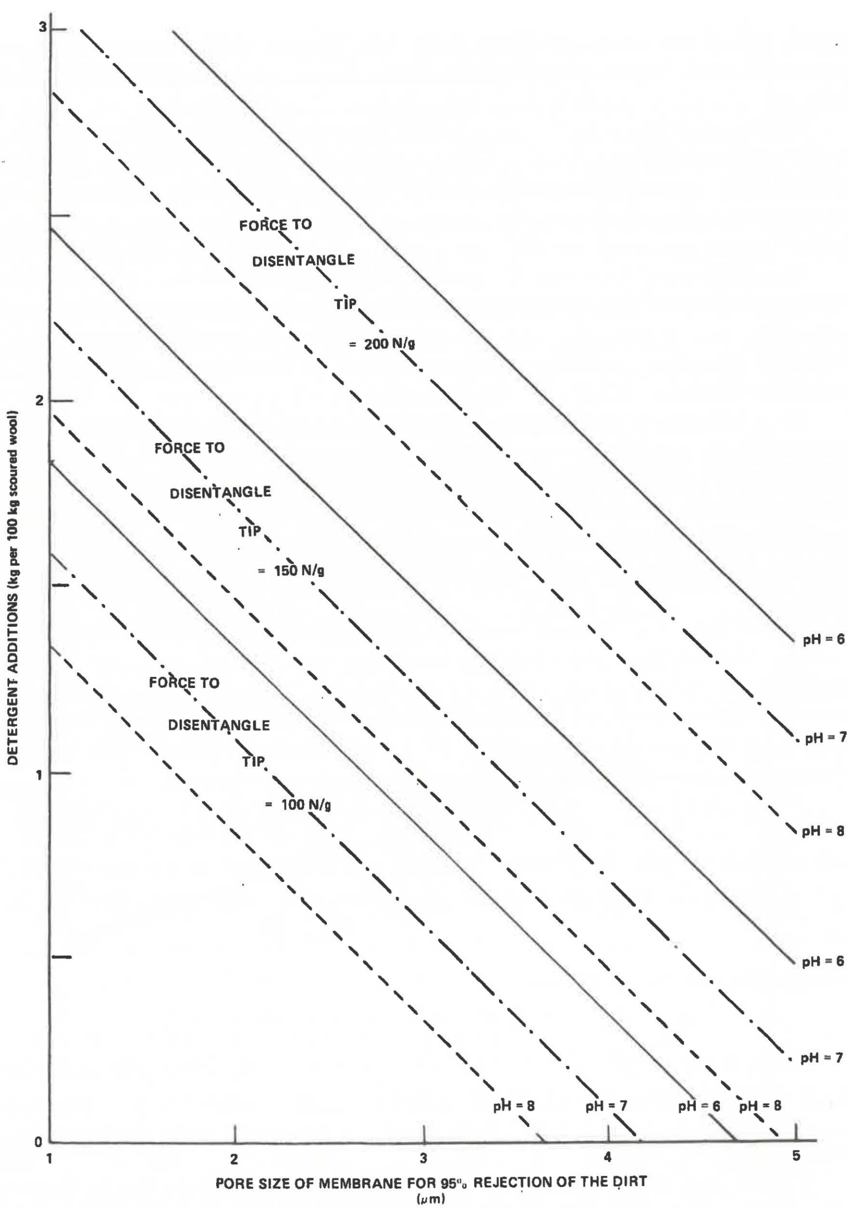


Fig. 13 The effect of the particle size of the dirt, the force to disentangle the tip of the staple and the pH of the suint on the detergent requirements of fleece wools having an average yield of 70% and a dirt content of 10%.(660)

staple, pH of the suint and yield (Fig. 13). Higher staple crimp values were associated with higher entanglement of the staple tip and with finer dirt particles.

Mozes and Pretorius[790] carried out a pilot-scale investigation to assess the sludge removal efficiency of a screw conveyor, bucket elevator and overhead settling tank system. The introduction of this system into the centrifugal effluent treatment system during the scouring of low yielding locks resulted in an overall grease recovery of 60% and a total suspended solids removal of 60%.

In a laboratory study on 20 non-ionic detergents Mozes *et al*[813] showed that scouring efficiency decreased with an increase in the detergent partition coefficient (Fig. 14). It was also found that the scouring efficiency increased and the detergent partition coefficient decreased with an increase in the hydrophilic-lipophilic balance (HLB) of the detergent.

In a laboratory investigation on the effect of a non-ionic type detergent (nonylphenol, octylphenol and linear alkyl polyethoxylate) and HLB (10,9 to 15,0) on both the first bowl and the overall scouring efficiencies in terms of grease removal, Mozes[859] found the first bowl scouring efficiency to be best for the linear alkyl polyethoxy type of detergent and an HLB of 15. The overall scouring efficiency was generally high, independent of the parameters investigated.

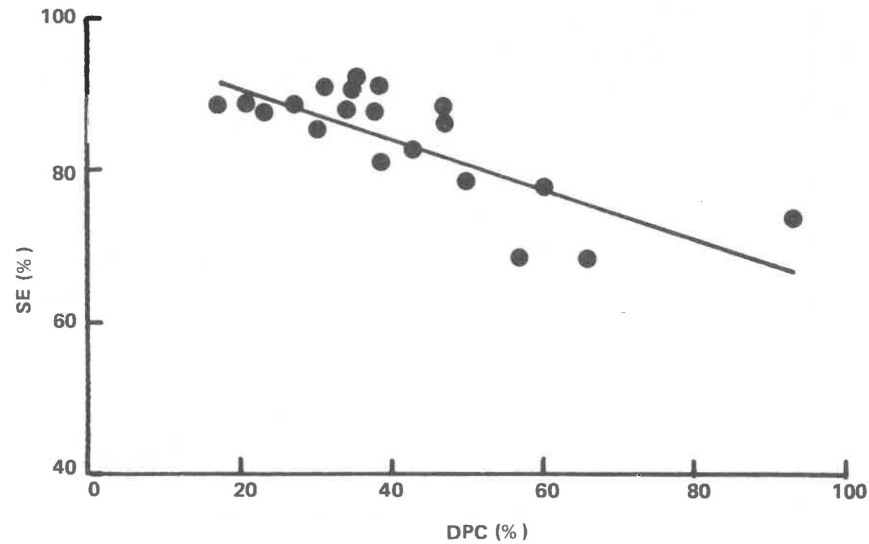


Fig. 14 Interrelationship between scouring efficiency (SE) and detergent partition coefficient (DPC).(813)

5.1.2 **Tests**

Veldsman and Palmer[1] adapted the Column-and-Tray method to provide a rapid method for determining the grease content of scoured wool. Veldsman[2] developed a rapid terephthalic acid method for determining the total alkali in scoured wool, the alkali content being important in respect of fibre damage, yellowing, handle and pH conditions during dyeing. Alkalinity of the wool could also promote microbiological attack of the wool under hot and humid conditions.

Various rapid methods for the industrial control and monitoring of wool scouring, including residual grease, alkali and soap in the wool, and the grease content of the effluent and the moisture content of the grease, were described[8 12 13]. Veldsman and Palmer[9] offered an explanation why different laboratories obtained different results in the ether extraction of wool, suggesting that the ether quickly extracted oil (and residual grease), but also extracted the regain water, though more slowly. As long as there was water present, residual soap on the wool was hydrolysed to free fatty acid, and this was also extracted, making the mass of extract too great.

Veldsman[15] introduced the concept of Washing Improvement Number (WIN) as a rapid method of characterising the scourability of raw wool.

Kritzinger and McHardy[33] carried out a field study on a series of emulsion-type sheep-branding fluids and elucidated the rôle played by various factors which affected the scourability and legibility of such fluids. They showed that, in the preparation and testing thereof, due account must be taken of the effect of the type of wool on which the brand was put, the effect of time upon scourability and legibility, and the type of scouring solution used.

Grové and Albertyn[150] found that irregular packing of the column in the accepted Column-and-Tray method caused channelling when applied to scoured mohair and subsequently[169] developed a rapid method of fibre preparation (laboratory cutting mill) which reduced the problem. Jamison and Musmeci[386] used forced draught evaporation to eliminate sputtering during the Column-and-Tray determination of residual grease on scoured wool. A mixture of dichloromethane and chloroform was used as a grease-extracting non-flammable solvent.

Musmeci and Turpie[484] described the application of a colorimetric method for the determination of synthetic non-ionic detergent of the ethylene oxide type in wool scouring liquors and recovered wool grease. When high dilutions of the samples to be tested were used, a simple relationship between absorbance and the concentration of detergent existed and the test could be completed within about ten minutes.

Turpie and Van der Walt[631] established an improved method for the rapid determination of non-ionic detergent in the cream, effluent and sludge from wool scouring liquors and in recovered wool grease by evaporation of the sample in an oil bath followed by extraction with dichloromethane and appli-

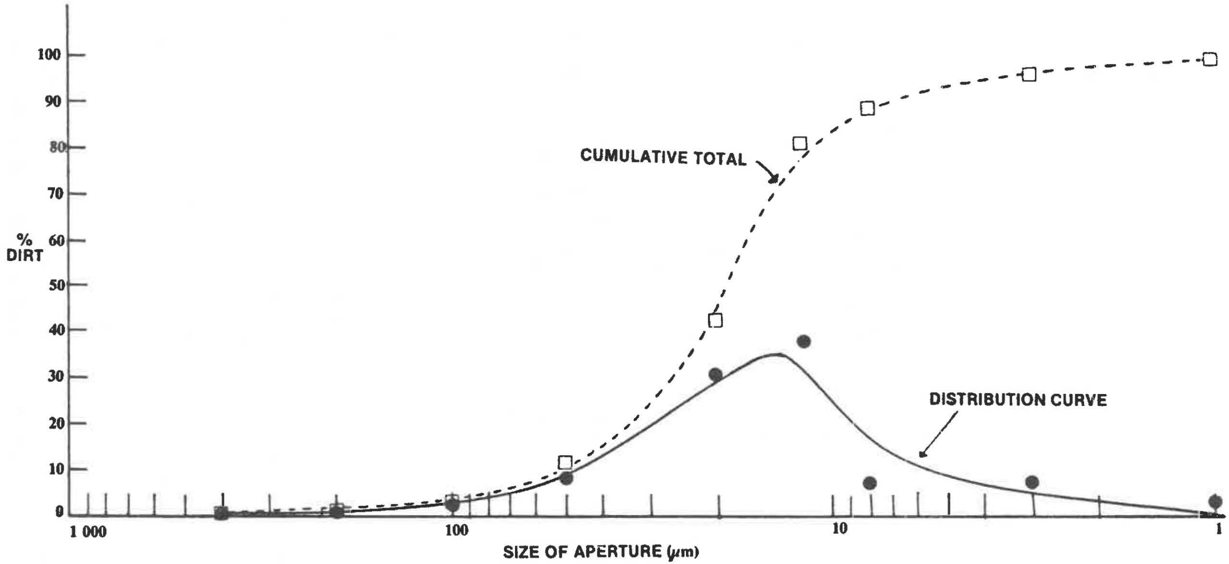


Fig. 15 Mean frequency distribution of dirt particles in 25 samples of fleece wool together with the cumulative total rejected by decreasing aperture size.(741)

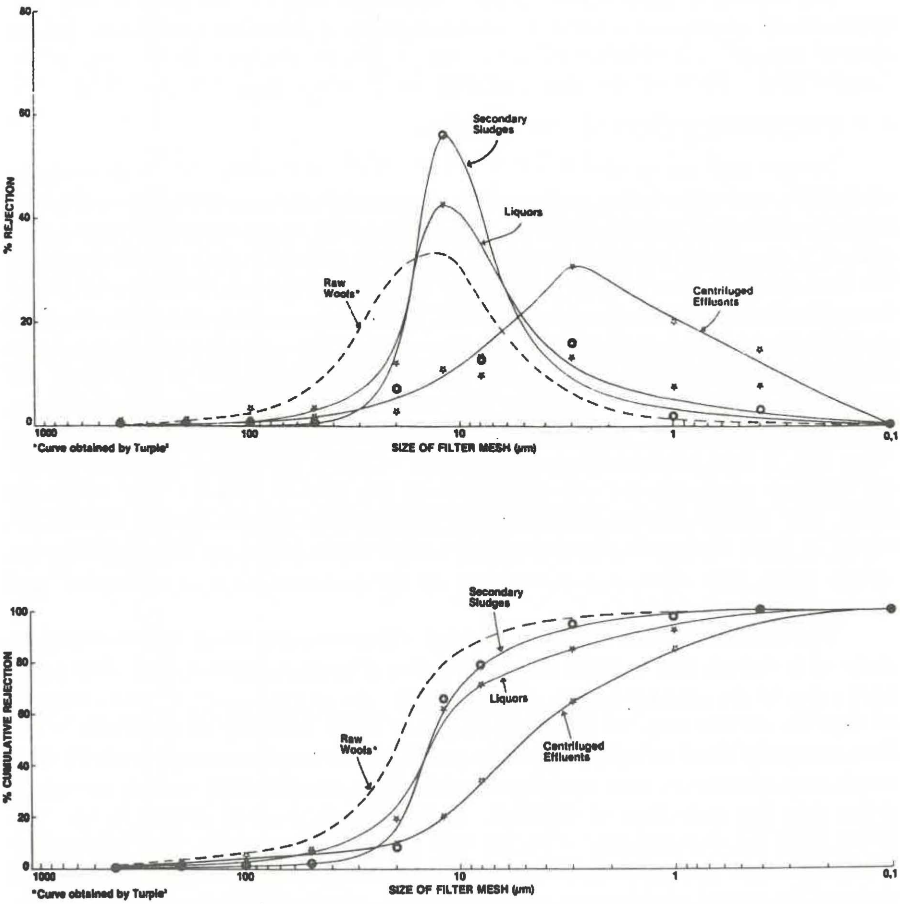


Fig. 16 Mean particle size distribution of suspended solid dirt.(742)

cation of a colorimetric technique. By using radio-active techniques it was concluded that, under suitable conditions of sample dilution and absorbance, the method gave results which in 95 cases out of 100, should be within ± 10% of the true value if three aliquots were tested, or within ± 12,5% of the true value if only one aliquot was tested.

Turpie[741] described a procedure for the routine determination of the distribution of solid dirt particles in raw wool and found the bulk of the dirt to lie between 10 and 30 μm (Fig. 15).

Subsequently Mozes and Turpie[742] presented data on the particle size distribution of suspended solid dirt, determined by a filtration technique, for industrial liquors, centrifuged effluents and secondary sludges. In the case of the liquors about 95% of the dirt particles were larger than 0,5 μm (Fig. 16).

5.2 UNCONVENTIONAL SCOURING

Turpie and co-workers[466, 467, 471, 472, 539, 542, 543, 548] carried out wide-ranging laboratory and pilot-scale studies on the unconventional scouring (in a concentrated wool grease emulsion) of wool and mohair in which the initial concentration of wool grease (sunflower oil being used in certain cases) and detergent in the first scouring bowl was considerably higher than the equilibrium concentrations frequently encountered in practice. It was shown that although the total amount of grease carried forward by the wool to the second bowl was a function of both the amount of grease *and* the amount of detergent in the liquor, the amount of grease *removed* from the fibre was *not* a function of the concentration of wool grease in the liquor, but a function of the concentration of detergent (Fig. 17). It was further shown that, at low (<0,1%) detergent concentrations, the amount of grease not yet scoured from the fibre in bowl 1 was relatively high, very sensitive to the concentration of detergent and changes in wool type, while at high detergent concentrations (<0,5%) it was very low (tending towards zero) and relatively insensitive to the concentration of detergent and changes in wool type.

The unconventional scour was very efficient right from the commencement of scouring, but without a backflow this efficiency deteriorated after a few hours due to the rapid build-up of suspended sand in the liquor. It was concluded that the unconventional scouring of grease wool, utilising an emulsion in the first scouring bowl of relatively high wool grease concentration, may be economically attractive, also making a worthwhile contribution to the saving of water and the reduction of effluent. Variability in residual grease levels was lower than for conventional scouring and combing, tears were also better. The relatively high detergent level present in the recovered wool grease could be reduced by grease purification with the further possibility of re-using the recovered detergent.

Turpie[544] also investigated whether the unconventional conditions previously claimed as producing superior results, could be brought about simply

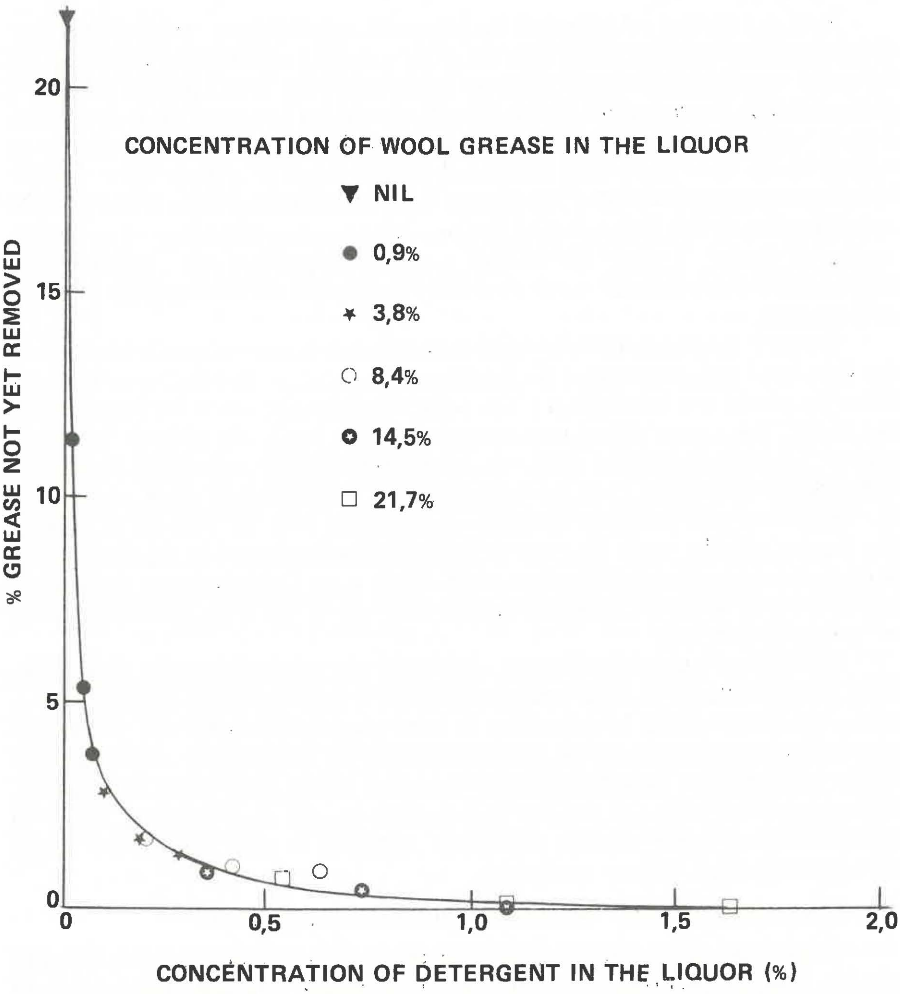


Fig. 17 Percentage grease not yet scoured off the fibre in Bowl 1 versus concentration of detergent in the liquor.(539)

by allowing the grease and detergent contents of the liquor in the first bowl to build up naturally but keeping the proportion of detergent to grease constant. It was shown, however,that this was not so. Consequently, it was considered that the build-up of solids in the liquor might be the key factor which limited scouring efficiency. He also showed[597] that clay adversely affected scouring efficiency by absorbing grease and detergent.

Turpie[633] further investigated the effect of certain liquor 'purification' procedures conducted after every four hours of scouring on scouring efficiency. In all cases scouring efficiency initially improved with time, passed through a peak and then deteriorated. There appeared to be an optimum suint concentration at which maximum scouring efficiency took place, and above which any further build-up of suspended solids and suint resulted in a progressive deterioration in scouring efficiency. In a pilot-scale experiment on the effect of suint concentration in the first scouring bowl on the scouring efficiency of an unconventional liquor, Turpie[653] found that a suitable backflow rate, together with suspended solids removal, were necessary in practice to achieve high scouring efficiencies.

Turpie[654] carried out extended pilot-scale experiments in which liquor from the first bowl was centrifuged for the removal of sludge, and the aqueous phase from the centrifuge treated in a pilot- scale ultrafiltration plant for re-cycling to the bowl. The cream phase was re-cycled to the bowl. An average backflow rate of 2,8 ℓ/kg of scoured wool was used to replace the volume of sludge and concentrate discharged from the centrifuge and ultrafiltration plant, respectively. Efficiency was found to decrease significantly with an increase of suint in the liquor, and the latter also led to higher losses of grease in the concentrate discharged from the ultrafiltration plant. Low suint concentrations and drastic improvements in liquor handling (particularly pumping) were considered to be of prime importance.

Studies by Turpie and Mozes[701] indicated that moderately low, rather than zero, concentrations of suint were desirable for maximum scouring efficiencies, that a backflow would be necessary at some stage to maintain this efficiency, and that de-stabilisation of the emulsion should be reserved for after-treatment of the spent liquor. Destabilisation of the spent liquor with about 4% bitterns, the magnesium-rich waste residue from a common salt recovery plant, followed by centrifuging under suitable conditions, appeared to offer an efficient means of obtaining high grease recoveries.

5.3 TREATMENT OF WOOL SCOURING LIQUORS

Veldsman and Turpie[506] reported on the removal of grease from scouring liquors. During experiments carried out on different, specially prepared wool scouring effluents, Turpie[498] showed that the efficiency of evaporation from evaporation ponds tended to be approximately proportional to the percentage of the surface area of effluent not covered by grease.

Mozes and Turpie[608] investigated flocculation of wool scouring liquors by alum and polyelectrolytes and the variation in flocculation efficiency with pH of the scouring liquor and the effluent produced from the liquor by centrifuging for two polyacrylamide ranges of polyelectrolytes (comprising anionic, nonionic and cationic types). It was found that, in general, flocculation efficiencies increased with decreasing pH values in the approximate range 5 to 8 and with increasing polyelectrolyte concentrations. Mozes and Turpie[624] also studied the ultrafiltration of scouring liquor in a pilot-scale ultrafiltration plant, using a R Romicon hollow fibre cartridge and reported on the decay in the ultrafiltrate flux with time, grease concentration and total solids, and the effects of the concentration of grease and total solids in the feed on the quality of the ultrafiltrate.

Mozes and Turpie[663] investigated the microfiltration of wool scouring liquors and effluents on a specially designed laboratory- scale plant, their results indicating that the microfiltration technique had potential. In further studies on the microfiltration of wool scouring effluents using a pilot-scale plant fitted with one of two long tubular cartridges, they[752] found that an inlet pressure of 500 kPa and a backpressure of 250 kPa gave a good quality microfiltrate. A 24% decay in flux was obtained during 6 hours operation of the plant.

Certain aspects of the above work were incorporated in a Ph.D. thesis[724] by Mozes.

Turpie and Mozes[659] studied the particle size distribution of solid dirt in South African fleece wools from a range of breeds. It appeared that efficient removal of suspended solid dirt from the scouring liquors could be effected by "micro-filtration" of such liquors through pores which were relatively coarse, a pore size of about 3 μm producing a 95% rejection of the dirt.

5.4 DESTABILISATION WITH SEA-WATER, BITTERNS AND MAGNESIUM CHLORIDE

Turpie and Mozes[609 613 724] investigated the destabilisation of wool and mohair scouring liquors by means of sea-water and considered it to have some merit for operations taking place close to the sea or by using the salt constituents of sea-water. Subsequently Mozes[614] showed that three major constituents of sea-water, namely sodium chloride, magnesium chloride and magnesium sulphate were mainly responsible for the destabilising effect of sea-water on wool scouring liquors. When treating industrial slugde with sea-water and then passing it through a horizontal decanter and disc centrifuges in series, Mozes and Turpie found that from 80 to 90% of the grease could be removed in the form of a secondary sludge[636]. Treatment in the same manner after storage for several days at 65°C enhanced grease removal to 95%. Centrifugal treatment was advantageous for all the categories of waste[685]. For centrifugally treated liquors and effluents, it was found that storage (at 65°C) was important for destabilisation efficiency. Residence times during centrifuging of 5 to 10 minutes seemed to be optimal in the case of all three categories of waste. Grease removal after destabilisation was found to be correlated with bacterial activity[707].

Subsequent studies by these and other workers[636 585 702 707 724 773 786 787 821 838] centred on the use and advantages of either magnesium chloride or bitterns (magnesium-rich waste residue from a common-salt recovery plant) in the destabilisation of scouring liquors and industrial sludges. A process called the SAWTRI Bitfloc process was proposed[797] for the treatment of sludge from the wool scouring industry which involved an addition of magnesium chloride or bitterns to liquid sludge, followed by centrifuging in a horizontal decanter centrifuge. The by-products of this process were a centrate of reasonably low residual grease content and a decanter sludge rich in grease and of spadeable consistency.

Mozes and Turpie[702 773] showed that 6% (v/v) of bitterns was optimal for both industrial scouring liquors and effluents. Storage was not required for liquors whereas 5 days were optimum for the effluents. As little as 2% (v/v) bitterns destabilised sludges. In general, grease removal was much higher for bitterns than with sea-water.

In extended pilot-scale studies Mozes and co-workers[786] monitored the performance of a horizontal decanter centrifuge in the treatment of sludge from wool scouring during continuous operation over two months, using bitterns as flocculant. When 5% (v/v) of bitterns was added to the sludge prior to decanter treatment, the decanter sludge contained over 70% of the grease and nearly 90% of the suspended solids originally present. In addition, significant reductions in the levels of bacterial count and chemical oxygen demand were obtained in the aqueous discharge (centrate) from the decanter. In general, the by-products of this treatment were a centrate of reasonably low residual grease content and a decanter sludge rich in grease and of spadeable consistency. About 1% of magnesium chloride was found to give better results than 5% of bitterns[787 838]. In a laboratory study of the centrifugal treatment of industrial wool scouring creams, Mozes[821] showed that the grease content of the grease phase could be increased significantly and an aqueous effluent phase, virtually free from grease, produced by addition of magnesium chloride prior to centrifuging.

In a pilot study[838] to assess the performance of a clarifier disc centrifuge on effluents destabilised with either bitterns or magnesium chloride it was found that the wastes were clarified significantly at a feed flow rate of 500 ℓ/h. Addition of flocculant also reduced the residual grease content of the clarified effluent and increased the solids content of the liquid sludge.

5.5 RECOVERY AND REFINING OF WOOL GREASE

Kriel *et al*[193] investigated the pilot-scale refining of centrifugally recovered wool grease, as well as the reduction of the ash content of the recovered grease, using the sulphuric acid method, and the bleaching of the grease. Kriel and Albertyn[214] carried out a pilot-scale investigation into some factors influencing centrifugal wool grease recovery from wool scouring liquors.

Jamison[413] developed a laboratory-scale method for the extraction of wool grease from raw wool scouring liquors, using perchlorethylene. The solvent was emulsified in the liquor, and then separated from the degreased liquor centrifugally. Other solvents appeared to be potentially effective when used in the same manner. The wool grease was recovered, mixed with solvent and dirt, from which mixture it could be separated by suitable treatment. The grease contained some detergent, however. Subsequent pilot-scale trials[431] revealed that petroleum hydrocarbon solvents had some advantages over chlorinated hydrocarbons in the degreasing of scouring liquors. Further studies[477] dealt with pilot-plant scale scouring of raw wool with recycled liquor degreased and des-ludged by a solvent extraction and centrifugal process. Jamison[478] also investigated the distillation of mixtures of wool grease with white spirit and benzine, both with and without the addition of water. A centrifugal evaporator and a rising-and-falling film evaporator were used. The latter evaporator was preferred for reasons of simplicity and efficiency. Benzine was preferred to white spirit by virtue of its ease of distillation.

According to Turpie and Musmeci[587] pilot-plant studies on the primary centrifugal treatment of wool scouring liquors suggested that the pattern of distribution of detergent, grease and methanol-insoluble matter in the cream, effluent and sludge was affected by the particular non-ionic detergent selected.

In a laboratory study into the solvent extraction of wool grease from wet sludge (water content about 40%) Mozes[889] showed that 50/50 (v/v) mixtures of dichloromethane with either petroleum spirit, n-hexane or benzine yielded grease extraction levels of 84 to 90% on average.

5.6 MILD CARBONISING

Turpie[994, 997] proposed an alternative carbonising treatment, employing milder, "less effective" carbonising conditions which would allow a relatively faulty wool to be carded and combed without the necessity to employ sophisticated deburning devices to produce a clean top. The merits of such an alternative were illustrated by laboratory and pilot-scale work which indicated that excessive loss of fibre substance and excessive damage to the fibres occurred when acid concentrations and immersion times in the acid bath were high, and when associated mechanical treatments were severe. While such conditions were often necessary for total vegetable matter (VM) removal, the proposed milder carbonising treatment together with the subsequent mechanical operations of carding and combing could achieve fairly satisfactory cleanliness of the material (for certain end-uses) while preserving or enhancing other attributes such as mean fibre length, yield, and colour.

CHAPTER 6

WORSTED PROCESSING

6.1 EFFECT OF HIGH DENSITY DUMPING

Strydom[863] studied the effects of high density dumping (baling) on worsted processing. Fleece wools (raw and scoured) and bellies (raw) were dumped in one high density press, and subsequently converted into top. Dumping densities ranged from 500 to 600 kg/m³ for the raw wools and around 300 kg/m³ for the scoureds, the latter being dumped at between 10 and 12% regain. Three months elapsed between dumping and further processing of the raw wool, and six weeks for the scoureds. No conclusive evidence of significant detrimental effects could be detected in terms of either card wastes, percentage noil, top and noil yield or in the Almeter Hauteur fibre length. In a follow-up study[896] two different wools were scoured industrially, pressed to approximately 300 kg/m³ and stored for 6 months before processing. Both were pressed under conditions of either "high" or "low" regain. Compared with "normal" scoured bale densities (175 to 200 kg/m³), regain caused neither large nor significant effects. Storage time was the largest single factor contributing to differences in processing and top properties. As much as 75% fewer neps were counted in the card sliver after storing the scoureds for 6 months. Card rejects, comb noil and top and noil yields were either unaffected by storage or decreased slightly. On average, the tops were as much as 14% shorter after processing scoureds stored for about 6 months.

6.2 POLYETHYLENE CONTAMINATION OF WOOL

Strydom[929] carried out pilot-scale processing trials with wool which had been packed in a new low fibrillating, high density polyethylene (HDPE) material developed by a South African firm. The bales were deliberately excessively damaged during conventional coring and grab sampling to accentuate differences between this material and conventional HDPE pack material. The removal of HDPE remnants during processing was subsequently studied by seeding scoured wool with HDPE strips on the feed lattice of the card and analysing the processing wastes. Compared with the conventional pack, the new pack was found to contaminate the wool to a lesser degree than the conventional pack. The low fibrillating type also appeared to be more readily removed during processing than the conventional type.

6.3 CARDING

Godawa[153] studied the effect of speed variations at the forepart of a worsted card (clothed with flexible clothing) on fibre breakage as well as aspects relating to the entanglement of the scoured wool, residual grease content and addition of lubricant. An optimum surface speed ratio of 105 to 1 between the breast and feed rollers was established, while increasing the speed of the forepart of the card (up to the breast) by 20% effected some further improvements in mean fibre length. An open scour and the addition of lubricant prior to carding (to bring the ether extractable matter to 1%) improved carding.

Aldrich *et al*[336] investigated the carding and combing of 64's quality Merino wools differing in fibre length. Fibre breakage in carding was found to increase almost linearly with increasing fibre length, with more open card settings giving more efficient processing. According to the combing noil and mean fibre lengths of the tops, considerable reductions in fibre length occurred during the processing of long wools due to fibre breakage during carding (Fig. 18)[336].

Turpie *et al*[390] compared the carding performance of fillet and metallic clothing and found that the single-swift metallic card gave results which favoured its use in preference to the double-swift fillet or double-swift metallic cards for a long wool of 64's quality which was free to nearly free of vegetable matter. Fewer neps were produced with metallic clothing but the removal of vegetable matter was poorer. Turpie[447] studied the ability of the card to disentangle wools which had already been carded or combed and concluded that the creation of fibre hooks by the card limited its ability to disentangle fibres and in cases of carded or combed wools an increase in entanglement could actually

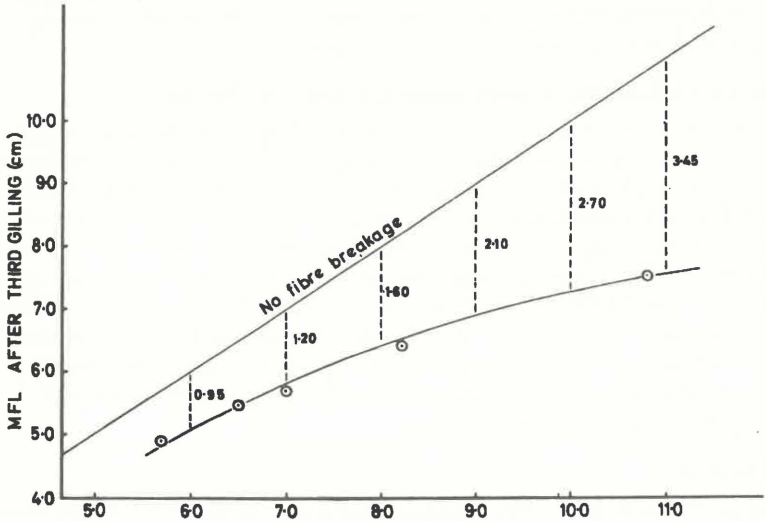


Fig. 18 Mean fibre length after third gilling versus m.f.l. of raw wool (Open card setting)(336)

take place during carding. The use of such materials of low initial entanglement provided an insight into the ultimate disentangling power of a card.

Turpie[651] showed that increases in the card production rate per swift revolution produced a significant deterioration in both carding and combing performance, whereas a reduction in the speed of the main driving pulley to the card produced effects during carding and subsequent combing which were mostly marginal and of little practical consequence.

6.4 NOBLE COMBING

Kruger *et al*[66] investigated the factors which influence the dabbing forces on a Noble Comb using an apparatus which simulated the actual dabbing process, a reduction in dabbing force being related to a reduction in noil. It appeared that the force required to push a brush into a bed of pins, depended primarily on pin density, temperature of the pins, presence and type of oil, pre-gilling operations, sliver thickness, and fibre diameter, in that order. Other factors affecting this force, but which were of a more secondary order, were depth and speed of dabbing, regain, and tautness of the sliver.

Turpie and Kruger[302] investigated the influence of circle temperatures on percentage noil and found that the use of hot small circles produced the least noil. Significant differences in large-circle temperature requirements were found, however, for first and re-combing. In the case of re-combing minimum noil was obtained when the large circle was cold. The percentage noil in the case of re-combing depended to a large degree on the temperature difference between the large and small circles. In the case of first combing the percentage noil was not dependent on the temperature difference but rather on the absolute values of the temperatures of the small and large circles. In a subsequent study Turpie and Kruger[310] used unconventional techniques to separate the combed slivers from the small and large circles (Fig. 19). The regain of the tops, the ratio of sliver weights from the large and small circles, the holding power of the large circle and the percentage noil patterns for different temperature combinations were investigated for both first combing and re-combing (Fig. 20). Some of these factors were also investigated under conventional combing conditions at different outside drawing-off roller (O.D.O.R.) settings. Circle temperature combinations for minimum noil for the different combing conditions were outlined. Different patterns observed in these and the earlier experiments[302] were ascribed to changes in O.D.O.R. setting, ether extractable matter and withdrawal force of the ingoing slivers.

In a further study[318] the effects of changes in the level of ether extractable matter on the percentage noil-temperature patterns were studied at fairly close settings of the O.D.O.R. The temperature requirements of the large circle for minimum noil changed from cold for low ether extractable matter to hot for higher ether extractable matter. It became apparent that at least three factors affected the percentage noil-temperature relationships for different wools and

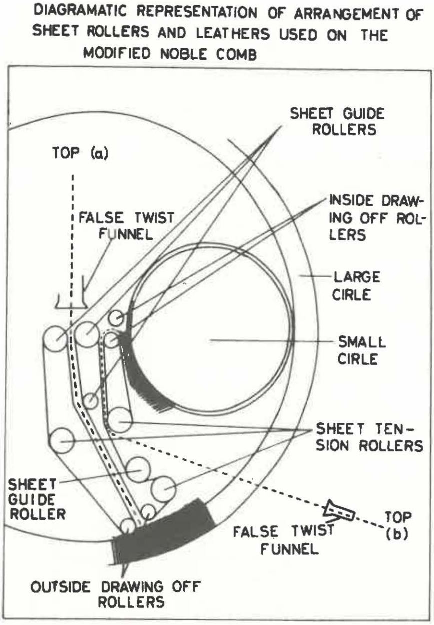


Fig. 19 Diagramatic representation of arrangement of sheet rollers and leathers used on the modified Noble Comb(310)

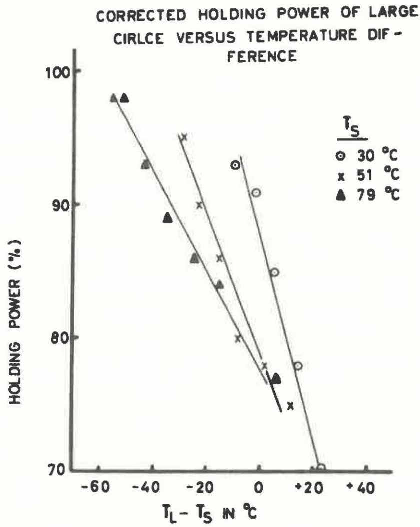


Fig. 20 Corrected holding power of large circle versus temperature difference(310)

different comb settings, namely the O.D.O.R. setting, the level of ether extractable matter and the degree of entanglement of the slivers. This work formed the basis of an M.Sc. thesis[271] by Turpie.

In further studies[329 421] it was found that not only was the withdrawal force of overwhelming importance in its influence on percentage noil, but that this force was also an important factor as regards the choice of temperature for minimum percentage noil at each setting of the outside drawing-off roller. The m.f.l. and noil results obtained could be explained on the basis of the interaction of fibre migration and fibre breakage. There was a general tendency for m.f.l. to increase with increasing large circle temperature and also with increase in O.D.O.R. setting. At low withdrawal forces a significant improvement in m.f.l. was observed as well as a substantial decrease in percentage noil.

The separation of short fine "down" and coarse (beard) karakul hairs on the Noble comb was subsequently investigated by Turpie and Kruger[334 422] and it was found that they could be separated efficiently by using a large circle of high pin density and a small circle of low pin density. The two combed slivers were produced simultaneously and differed significantly in fineness and length. Kruger[337] reviewed the various methods (carding and combing) investigated at SAWTRI for separating fibres of different diameters which could be applied to separate, for example, karakul "down" from its coarse component and kemp from mohair.

Turpie[371] studied the removal of kemp from wool by means of the Noble Comb and found use of wide settings on both the outside and inside drawing-off rollers best for reducing the amount of medullated fibres, lower pin densities on the large circle being recommended for increasing the fibre length and decreasing the fibre diameter of the top. For better removal of medullated fibres by unconventional techniques, whereby the combed slivers from the large and small circles were kept separate, had merit together with the use of low small-circle temperatures and high large-circle temperatures.

6.5 RECTILINEAR COMBING

6.5.1 Effect of Different Lubricants

Kruger[187 206 292] reported on the influence of lubricants in rectilinear combing and found that small additions of lubricants resulted in improved combing conditions, optimum combing performance being obtained in each case at about 2% fatty matter for vegetable and mineral oils and at about 1% for the water-soluble compounds. Oil viscosity affected the efficiency of lubrication. Large amounts of oil present on the fibres resulted in a reduction in the number of neps present in the top, due to an increase in the size of the existing neps. However, the addition of oil up to the optimum value had little influence on the number of neps. Optimum withdrawal force was at about 5% oil (also optimum noil).

Turpie[446] studied differences in performance during carding and rectilinear combing brought about by the application before carding of fourteen different lubricants. It was found that the mean fibre length and short fibre content of the tops and the percentages of noil obtained during combing were more satisfactory with certain lubricants than with others. An application level of 0,3% added active matter was generally found to give optimum results. The active matter content varied widely between lubricants (from 20 to 100%) so that actual optimum levels of application could vary from 0,3 to 1,5%.

Strydom[920] later also compared the effect of various commercial processing additives on the worsted carding and combing performance of two "different" wools under "normal" (65% RH and 20°C) and "adverse" (26°C/55% RH) atmospheric conditions. Differences between products and between the results for the different atmospheric conditions in terms of card waste, comb noil and fibre length distribution in the top were generally small. The processing of the good quality wool appeared to be insensitive to variations in the total extractable matter levels, but in the case of the inferior quality the best results were obtained at a pre-comb level of around 0,9% (omw).

6.5.2 Effects of Machine Settings and Moisture Levels

Godawa *et al*[114] carried out a series of experiments to determine the factors, some of which were identified by other workers, which could affect the combing performance of two rectilinear combs (St. Andrea and Schlumberger). It was found that the percentage noil and the mean fibre length increased with increasing gauge settings. Fibre breakage appeared to follow a complex pattern with gauge setting, and the two combs did not appear to follow the same trend. There was, however, significant fibre breakage even at optimum comb settings. An optimum gill amplitude setting occurred at approximately 6,5mm, minimum fibre breakage occurring at this setting.

Turpie and Kruger[346] investigated the influence of moisture on carding and rectilinear combing performance and found that the performance of rectilinear combing was improved by combing at high regains (at least 22% in Fig. 21). Practical values for relative humidity during gilling and combing appeared to be between 68 and 80%. Carding of scoured wool at increasing regains resulted in larger amounts of noil (Fig. 21). Carding at low regains, with an antistatic agent applied before carding, was found to be beneficial provided water was added during gilling to maintain the optimum regain for combing.

Aldrich[375] investigated the combing performance of three types of comb cylinders on the basis of top cleanliness, mean fibre length of the top and fibre breakage. A comb cylinder with flat pins on the fine segment was found to give only slightly less noil, but produced a top containing many more neps and vegetable particles than one produced by a comb cylinder with round pins throughout. A comb cylinder with saw-tooth type pins gave a performance equal to that of a conventional comb cylinder as far as top cleanliness, m.f.l. and fibre breakage were concerned. The mechanical strength of the former, however, was found to be superior to that of a conventional comb cylinder.

Kruger and Aldrich[399] showed that fibre breakage was linearly related to comb gauge setting. Different types of combs did not produce appreciable differences in percentage fibre breakage, while five preparatory gillings resulted in lower fibre breakage than 3 gillings. Only a moderate increase in the mean fibre length of the top resulted when the gauge setting was increased while the amount of noil increased appreciably. The amount of fibre breakage seemed to be related to the migration of fibres, and consequent disarrangement of fibres behind the top comb, during drawing-off.

Aldrich and Kruger[416] showed that percentage noil depended upon gill-feed, particularly at large gauge settings and a gill-feed giving a minimum percentage noil was found to exist at each gauge setting. The optimum gill-feed value increased linearly with gauge setting.

Percentage fibre breakage decreased slightly with increasing gill-feed at all gauge settings, and increased with increasing gauge setting.

Aldrich and Kruger[210, 433] developed an apparatus for simulating the with-

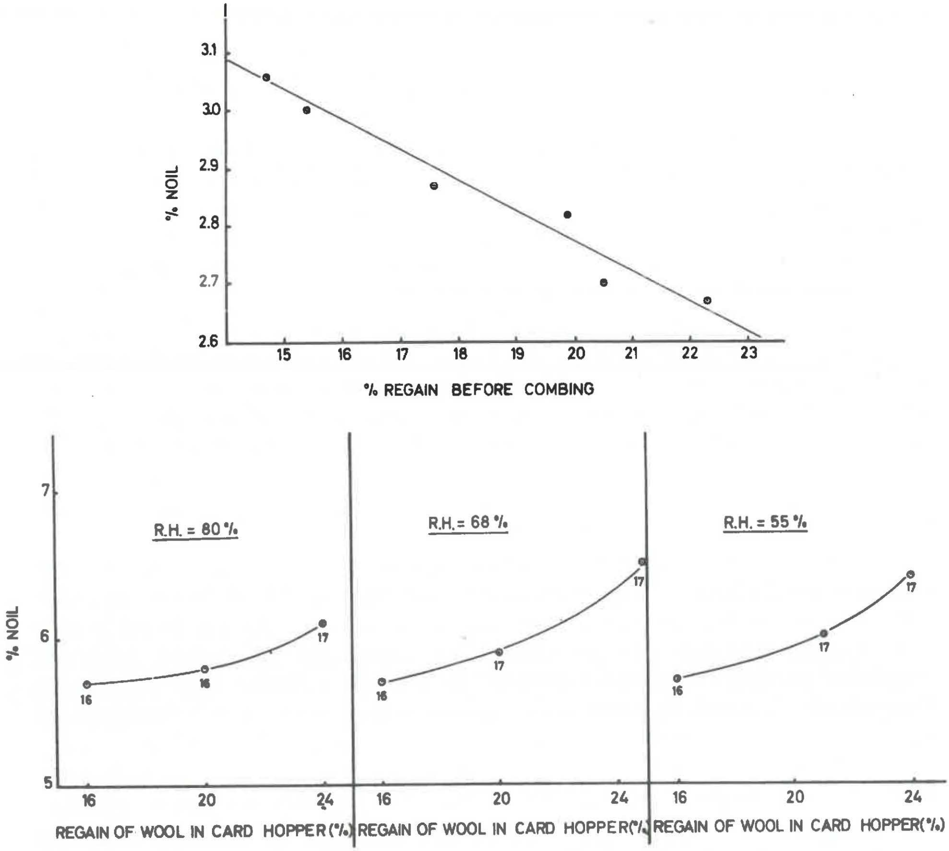
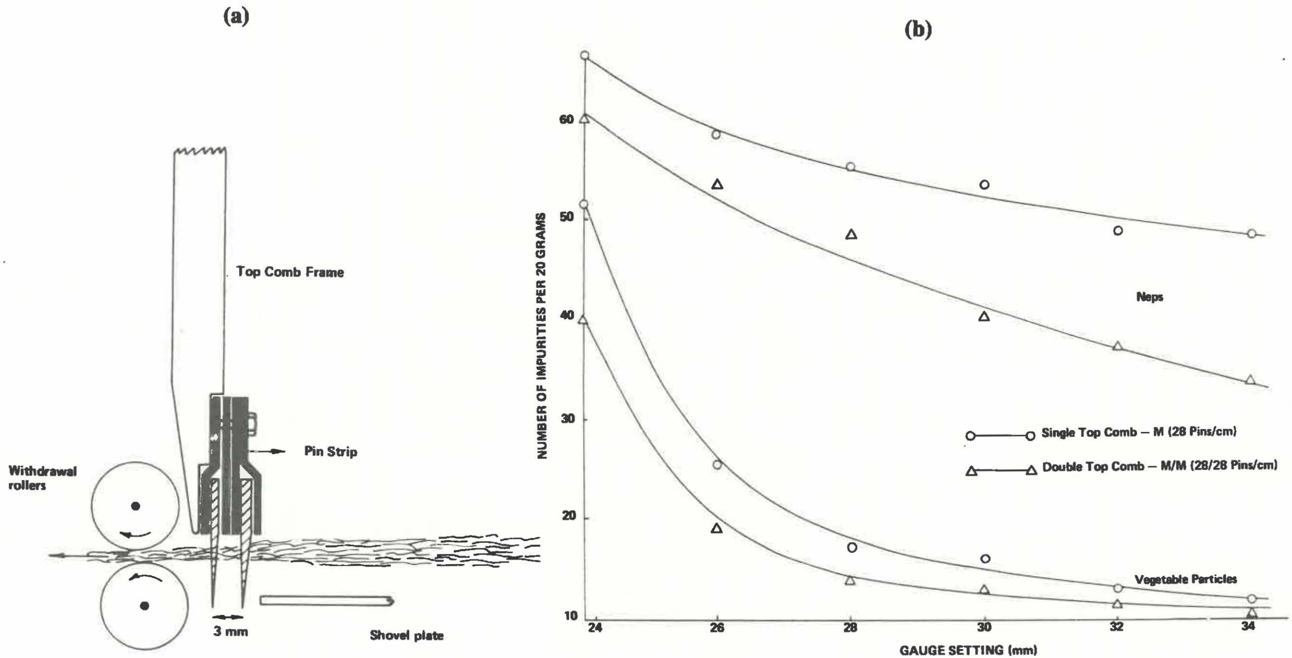


Fig. 21 Effect of regain on combing noil(346)

drawal action of a rectilinear comb, allowing the measurement of the force necessary to withdraw a tuft of fibres from a pin bed at high speed. The average withdrawal force per fibre was well below the breaking strength of the fibres. The contribution of the withdrawal action to the fibre breakage encountered in rectilinear combing should, therefore, be small.

Aldrich and Kruger[436] investigated the influence of gauge setting and gill-feed on the efficiency with which the rectilinear comb removed impurities. The nep content of the top decreased with increasing gauge setting, provided an efficient top comb was used, vegetable particle content decreasing with increasing gauge setting. At very small gauge settings, the nep content of the top increased with increasing gill-feed, while at higher gauge settings it showed a



Cross-section through the Top Comb Frame showing the Double Top Comb Arrangement

Number of Impurities per 20 grams versus Gauge Setting using a Double and a Single Top Comb. (Wool B)

Fig. 22 The effect of a double top comb (a) on the number of impurities in the top (b)[439]

tendency to decrease. The number of vegetable particles in the top increased with increasing gill-feed.

Aldrich and Kruger[438] investigated the influence of the gap between pins, percentage void, pin density and pin thickness on the combing performance of top combs and established values for the gap and percentage void of the top comb, giving a minimum impurity content in the top. No significant influence of top comb characteristics on the mean fibre length and CV of fibre length of the top could be found. The characteristics of the top comb appeared to be relatively more critical than those of the cylinder in respect of the removal of impurities. In a subsequent study[439] they compared the combing performance of a double top comb (Fig. 22) with that of the single top comb. For equal gauge settings, the double top comb produced more noil but a top having fewer impurities and a longer mean fibre length than the single top comb. The use of the burr beater resulted in a small improvement in top cleanliness. Certain of the above work on the rectilinear comb formed the basis of a Ph.D. thesis by Aldrich[359].

Turpie[440] investigated the effect of applying water to wool slivers during gilling on rectilinear combing. Optimum percentage noil was obtained when the combed sliver emerged with a regain of 22%, while production rates decreased with increasing regain.

Godawa and Turpie[504] fitted the top comb of a rectilinear comb with a thermostatically controlled heating element, and the temperature of the top comb pins was regulated between room temperature (21°C) and 90°C. There was a small reduction in percentage noil when the top comb was heated up to 60°C, the reduction of percentage noil being due to more short fibres migrating into the top.

Turpie and Benecke[623] investigated the effects on combing performance of variations in sliver linear density both within and between slivers entering the comb. It was shown that large variations in the "within-sliver" CV of linear density had no effect on percentage noil, mean fibre length or cleanliness of the tops. While it was preferable to have a low "between-sliver" variation in linear density, the comb was able to withstand fairly substantial variations in this parameter without adversely affecting combing performance.

Turpie and Klazar[658] found no detectable change in the combing performance of the rectilinear comb over the range of speeds from 50 to 165 nips/min.

CHAPTER 7

WORSTED PROCESSING PERFORMANCE OF SOUTH AFRICAN WOOLS

7.1 EFFECT OF RAW WOOL BLENDING

Turpie and co-workers[526 533 564 576 619 629 682 698 732 756 772 832 833] carried out a series of wide-ranging studies, in which more than 120 different wool lots were processed, to establish and quantify the effect on processing behaviour, of blending wools (e.g. farmer lots) which differed in their basic fibre characteristics, such as diameter and length, as well as the blending of fleece and non-fleece wools. One of the main aims was to establish whether the processing behaviour of a blend (mixture) of wools could be predicted accurately from the behaviour of its components. It was found that although there were some exceptions, the processing behaviour of a mixture could be predicted fairly accurately from the behaviour of its components (i.e. the mixture behaved largely according to the weighted means of its components). When scouring was carried out under carefully regulated conditions, the subsequent worsted processing performance, including spinning, appeared to be solely a function of fibre properties. The work indicated that, as far as the technical requirements of topmaking and spinning are concerned, quite a significant reduction in the number of different long wool market types may be possible, but this would depend on the needs and practical limitations within the industry. The main findings are given below.

Initial studies on mixtures involving different class descriptions

Initially,[526 533] work was carried out on mixtures which conformed in length, diameter range and composition to normal accepted trade practice, and which were of style and quality commonly sought after in day to day trading. The results indicated that up to the spinning stage, although large differences were recorded between the performance of the various class descriptions of a given length, the mixtures behaved, in most respects, as had been predicted.

Deterioration in style generally resulted in a deterioration in topmaking performance, particularly during combing but not on spinning performance. The conversion ratio, however, was largely independent of style (Fig. 23)[526]. Previously Turpie[453] showed that a deterioration in style, due to weathering, caused a deterioration in combing performance.

Mixtures involving different diameters and lengths

Further studies[564 619] were carried out on mixtures which did *not* conform to normal trade practice at that time, in that the components selected embraced limited variations of around 10 mm in length and 2μm in mean fibre diameter. Mixtures (50/50) of *fleeces* with *fleeces* and of *bellies* with *bellies*, were consid-

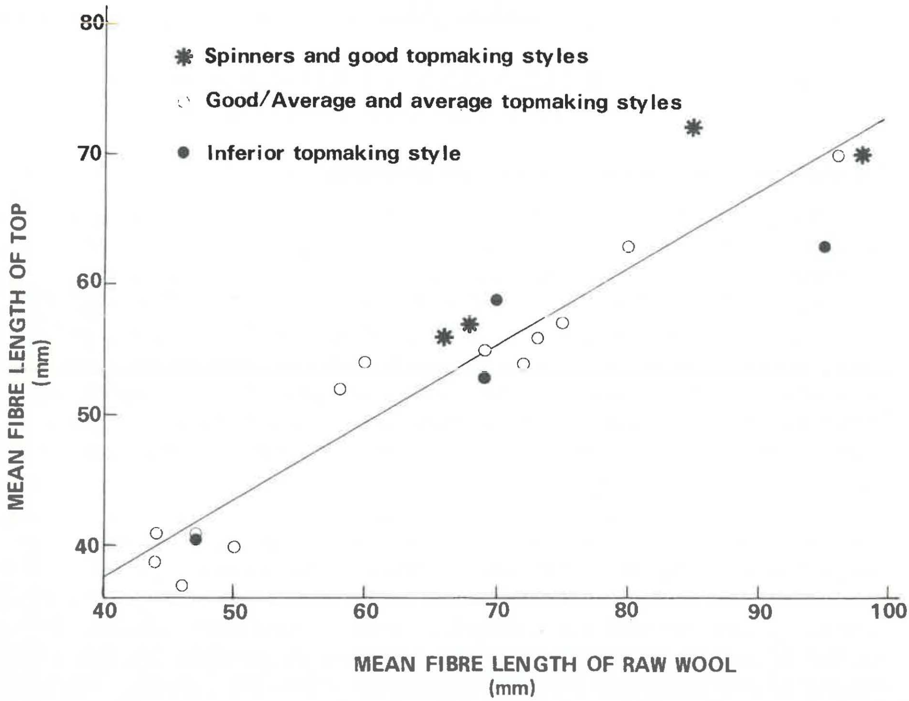


Fig. 23 Relationship between mean fibre length of raw wool and top.(526)

ered. Again, it was not possible to detect any significant differences in the performance of the blends relative to the predicted values up to the spinning stage.

Subsequent studies[576] were carried out on 50/50 mixtures of fleece lots having components which varied by up to 5 μm in mean fibre diameter. With few exceptions results up to and including the top stage showed that the μm blend level (i.e. the difference in the mean fibre diameter of the blend components, expressed in μm) had no apparent effect on processing performance up to the combing stage. With regard to spinning, however, it was shown that the μm blend level did have some effect. To maintain a commercial end breakage rate, it was shown that spindle speeds would have to be reduced by about 230 rev/min for every unit increase in μm blend level (Fig. 24). Results for MSS confirmed this trend.

It was also shown[576] that the finer wools suffered more fibre breakage than the coarser wools during conversion to tops, the staple length to top mean fibre

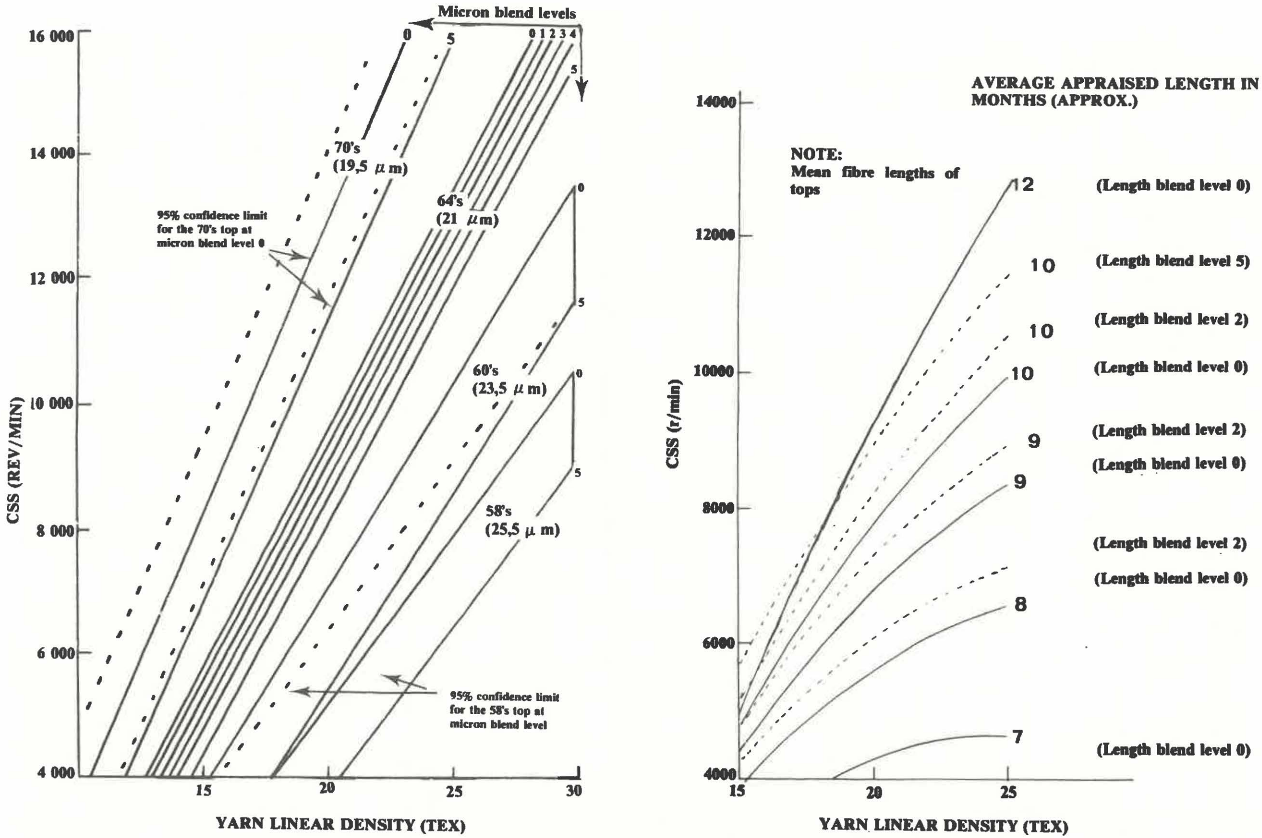


Fig. 24 Effect of blending wools differing in diameter (micron blend level) and length (length blend level), respectively, on the commercial spindle speed (CSS).(576 629 833)

length ratio decreasing from about 1,3:1 for a 20 μm wool to about 1:1 for the wools coarser than about 22μm.

Further studies were carried out on 50/50 mixtures of fleece lots having components which varied by up to five primary length classes, the primary length classes studied being 6/8, 7/9, 8/10, 9/11, 10/12 and 12 months[629] equivalent to unstretched staple lengths of 46, 53, 60, 67, 74 and 81 mm, respectively. The term "length blend level" was used to indicate the number of primary length classes by which the blend components differed (Fig. 24).

The effect of relatively large variations in both diameter and length on the blending of fleece wools (in equal proportions) was also studied[682]. While the blending of raw wool lots differing widely in length was previously[629] found not conducive to optimum carding and combing performance, no significant effects were found in this case[682]. In both cases, however, there was evidence that the spinning potential actually *improved* when the length blend level was increased, in some cases quite significantly[629, 682] (Fig. 24).

7.2 EFFECT OF BLENDING FLEECES WITH OUTSORTS

Turpie and co-workers[756, 772] studied the effects of blending raw wool fleeces with outsorts on subsequent processing performance up to spinning to extend the work carried out by SAWTRI on raw wool blending. Three lots of good topmaking fleeces (long, medium and short), nine lots of bellies (long, medium and short lengths each in three different levels of vegetable fault) and six lots of backs (long and medium lengths, both in three different styles, namely good topmaking, average topmaking and inferior) were processed individually and also in fifteen specific blends. With a few minor exceptions it appeared that blending of these outsorts and fleeces did not detrimentally affect the processing performance up to and including the spinning stage as predicted from the weighted mean performance of the component parts (i.e. relative to the performance or behaviour predicted from that of the components when processed on their own).

Strydom and Turpie[789] also studied the blending of inferior style fleeces with either bellies or backs of similar quality but varying either in vegetable fault or style. Long, medium and short fleeces and bellies and two long and medium backs were selected. The fleeces, bellies and backs were processed individually up to the spinning stage and also in predetermined 50/50 blends. These blends comprised medium length fleeces with long outsorts, long fleeces with medium outsorts and short fleeces blended with the short bellies. Differences between actual and predicted performance and properties in general, were small and from a practical point of view could not be considered as large enough to conclude that blending of these outsorts and fleeces had a serious detrimental effect on processing performance relative to that predicted from the behaviour of the components.

7.3 EFFECT OF FIBRE PROPERTIES

In one of the earliest studies on the processing behaviour of South African wools, Kruger *et al*[105] compared the properties and behaviour of a group of fleeces with a high fluidity grease (oil-tip or tigerstripe) with those of a group of fleeces with low fluidity grease (white tip). The latter tended to be more weathered and appeared to have a poorer processing performance than the former, although it was difficult to draw meaningful conclusions in view of differences in the mean fibre length and diameter of the two groups of wool prior to processing.

In a limited study[135] the processing performance of a Mutton Merino wool (24 μm, 75mm in fibre length in the greasy state, 6,4 crimps/cm) was compared with that of a 56/58's quality (26,7μm) Australian wool. The former processed well and produced bulky yarns for knitting, the knitted fabric felting less than the one Australian wool during washing because of its higher crimp and good resiliency.

In another limited study Turpie and Shiloh[450] compared the processing performance of two wools differing mainly in crimp and found that the two wools performed similarly in carding, whereas the combing performance of the undercrimped wool was better. This wool also produced stronger and more regular yarns.

Turpie and Hunter[530] investigated the effect of changes in CV of fibre length on spinning performance and found no consistent effect on end breakage rates during spinning, whereas the yarn tensile and evenness characteristics, particularly the frequency of neps, tended to improve slightly with a decrease in the CV of fibre length, the effect being largest for the finer yarns.

In a series of wide-ranging studies, in which close on 400 wool lots were eventually processed into top on full-scale worsted machinery Turpie and co-workers[649 676 771 832 833 893 933] quantified the effects of various raw wool characteristics, such as length, diameter and crimp, on worsted processing performance using multiple regression analysis. The question as to the effects of breed *per se* on processing behaviour was also addressed and clarified.

Both multiquadratic and log-log regression analyses were carried out and it was found that, in most cases, the two types of analyses produced a similar fit to the data. Generally more than 80, and often more than 90%, of the observed variation in the characteristics of the tops, including spinning performance, could be explained in terms of fibre characteristics. Wools which were either longer, coarser, of better style or less crimped (Fig. 25), were found to produce less noil. The mean fibre length of the top improved with an increase in staple length and fibre diameter and with an improvement in style.

Mean fibre diameter was generally the most important fibre parameter, followed, by mean fibre length and staple crimp (or resistance to compression).

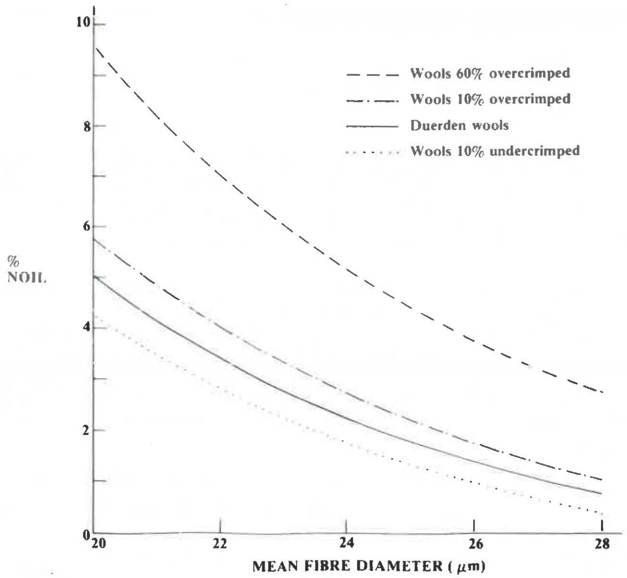


Fig. 25 Effect of fibre diameter and staple crimp on percentage noil(649)

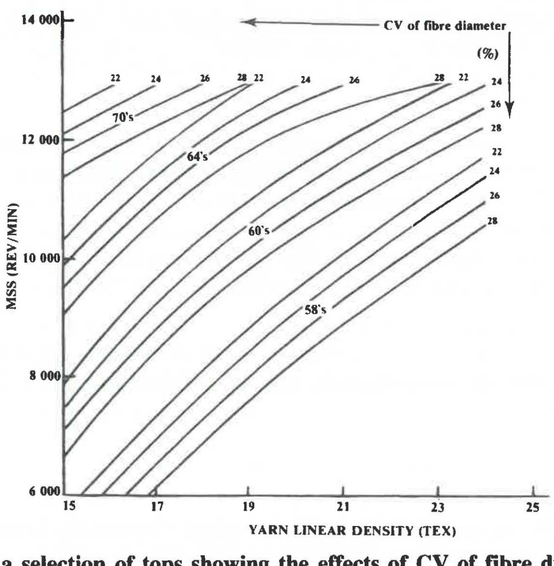


Fig. 26 MSS for a selection of tops showing the effects of CV of fibre diameter and yarn linear density as extrapolated from the regression equation(832 833 893)

Within the normal practical ranges, the coefficients of variation (CV's) of diameter and length generally had a small effect, an increase in CV of diameter tending to affect spinning performance adversely (Fig. 26) whereas, if anything, an increase in the CV of fibre length had the opposite effect. Where an increase in fibre crimp had a significant effect, all other fibre properties being constant, the effect tended to be an adverse one. Such wools were, therefore, at a disadvantage within the context of this study (Figs 27 and 28).

At a given yarn linear density, spinning performance, as measured by the mean spindle speed at break (MSS), improved with a decrease in mean fibre diameter (main effect), staple crimp and CV of diameter and with an increase in mean fibre length and CV of fibre length (Figs 26 and 27).

Mathematical relationships (regression equations) were derived and documented to allow the effects of the various fibre properties on processing performance to be predicted on the basis of the measured fibre properties (examples are given below):

% Noil = 4,27W16 + 0,008 W11.W3 - 0,204 W14.W16 - 0,454 W3.W16 + O,296 W16.W21 - 0,009 W10.W16 + 0,315 $W16^2$ - 0,011 W10.W21 + 7,5

77,7% fit

Top & Noil Yield % = -0,003 $W20^2$ + 0,002 W10.W20 - 0,002 W10.W14 + 1,156 W20 + 1,13

87,8% fit

Single Fibre Length(mm) = 1,94 W10 + 0,079 W3.W14 - 0,014 W23.W16 - 0,005 $W10^2$ - 0,127 W10.W16 + 8,95 W16 - 43,7

88,0% fit

Almeter Fibre Length(mm) = 1,890 W10 - 0,075 W14.W16 + 0,085 W3.W14 - 0,0048 $W10^2$ - 0,127 W10.W16 + 7,441 W16 - 39,7

87,6% fit

CSS = 3,68Z^2 + 7,54Z.P24 + 1,67Z.P25 - 30,55P15.W16 - 1,72P16.P24 - 1,15$P24^2$ + 1423

85,6% fit

CSS = 19.91 Tex^2 + 14;8 Tex.P24 + 8,14 Tex.P25 - 10,86P15,P16 - 8,74P15,P24 - 3,55P15,P25 - 2,58P24.W16 + 11250

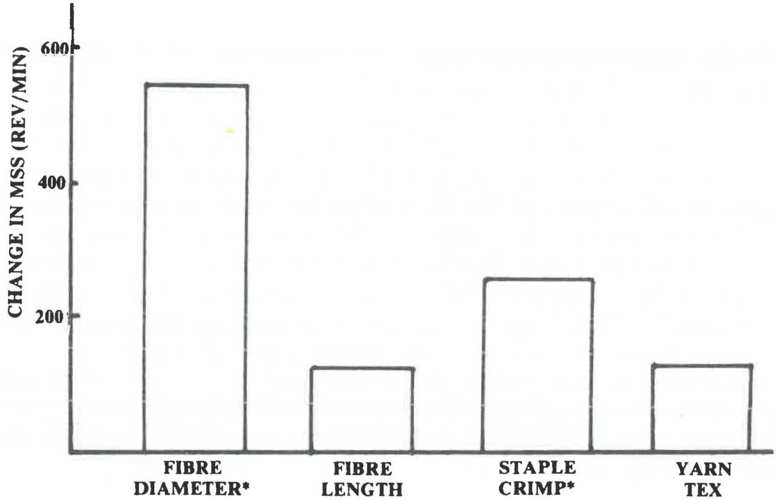
84,7% fit

MSS= 1105Z + 441P15 + 183P24 - 6,27Z^2 - 12,8Z.P15 - 1.72Z.P24 - 1,19$P24^2$ + 2,48P24.P25 - 1,49$P25^2$ - 27307

82,7% fit

MSS= 430 Tex - 1151P15 + 32,8P25 - 21,6 Tex^2 + 36,4 Tex.P15 + 18,56 Tex.W16 - 94,3P15.W16 - 1,08P16.P24 + 24,4P24.W16 + 21302

80,7% fit



*AN INCREASE IN DIAMETER OR CRIMP IS ASSOCIATED WITH A DECREASE (DETERIORATION) IN MSS.

Fig. 27 Change in spinning performance (MSS) for a unit change in the indicated fibre property or yarn tex (calculated for a 25 tex yarn)(832 833 893)

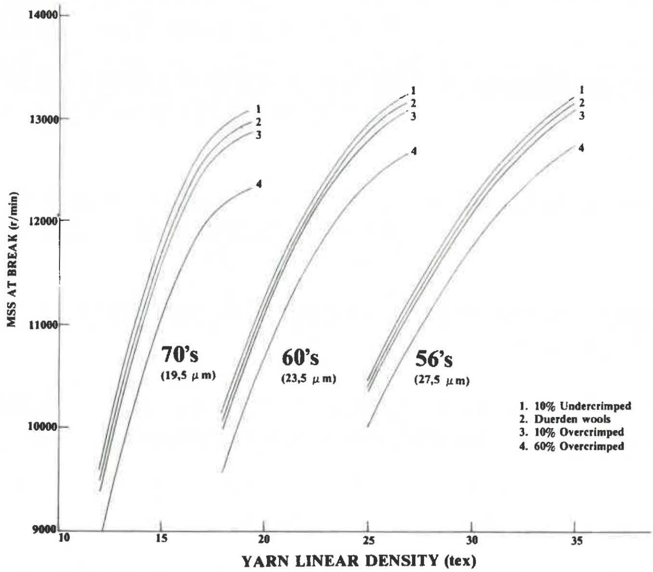


Fig. 28 MSS values for a selection of tops of m.f.l. 75 mm showing the effect of crimp and yarn linear density, as extrapolated from the regression equation. (Each family of curves spans an approximate range of 30 to 46 fibres in the yarn cross-section)(676)

Where W3 Style index
W10 Staple length, unstretched (mm)
W11 CV
W14 Mean fibre diameter (μm)
W16 Crimp frequency (no/cm)
W20 Wool base (%)
W21 VM clean (%)
W23 Methylene blue dye exhaustion (%)
P15 Mean fibre diameter of top (μm)
P16 CV (%)
P24 Mean fibre length of top (Almeter Hauteur) mm
P25 CV (%)
Z No. of fibres in yarn cross-section

This study has generated valuable data on South African wools and their processing, some of which are summarised in Table III.

7.4 EFFECT OF SHEEP BREED[832 833 893 933]

It is well-known that certain breeds of sheep produce wool which, on average, differ in certain important characteristics (e.g. length, diameter and crimp) from those of the Merino and which, therefore, will perform differently during mechanical processing and in the yarn and fabric as illustrated by the trends reported on elsewhere. What needed answering, however, was whether, over and above these measurable differences, there were other differences between the wools originating from the different breeds which were reflected in their behaviour during mechanical processing up to and including spinning (Figs 29 and 30).

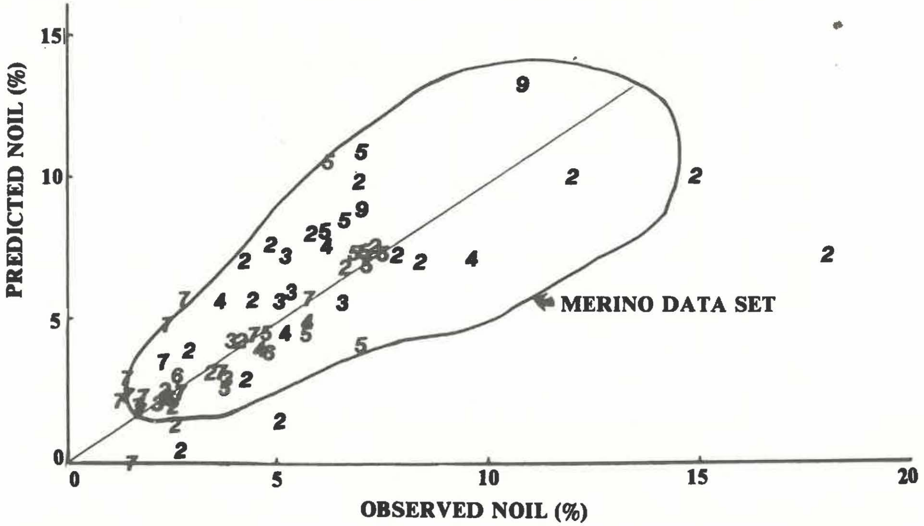
From multiple regression analyses and graphical techniques[832 833 893 933] it appeared that, in the main, *once the measured differences in fibre properties were taken into consideration and corrected* for, breed *per se* had little, if any rôle, in determining the processing performance.

The findings of the study therefore showed that, although different breeds of sheep often produce wool which differ from each other in fibre characteristics, such as length, diameter and crimp (as in fact also happens to a certain extent *within a breed*) and which *therefore* also perform differently during processing, the behaviour of a wool during processing is *largely* governed by its objectively measurable fibre properties (including staple crimp or resistance to compression) irrespective of breed.

TABLE III

MEANS AND RANGES: GREASY WOOL CHARACTERISTICS AND PROCESSING DATA (893 933)

GREASY WOOL PARAMETERS	MERINO			S.A.MUTTON MERINO			DÖHNE MERINO			LETELLE			CORRIEDALE		
	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.
Mean Fibre Diameter (μm)	21,7	18,2	28,3	22,8	20,5	27,1	22,1	19,4	25,7	20,5	19,3	21,6	28,3	23,3	33,6
Mean Staple Length (mm)	69	34	108	76	57	110	82	55	104	78	52	98	89	63	140
CV of Staple Length (%)	16,4	7,0	40,9	16	10,9	30,0	12,4	8,8	16,0	12,1	9,0	14,7	16,8	9,0	28,4
Wool Base (%)	51,5	36,6	61,5	49,5	29,8	59,1	53,8	42,2	62,0	52,3	35,9	59,3	55,7	48,7	63,6
Grease Content (%)	14,6	9	24	10,8	8	15	13,5	9	19	14,0	10	20	10,8	6	19
Vegetable Matter (%)	2,0	0,2	20,3	2,03	0,2	8,9	1,7	0,4	5,6	1,4	0,3	3,2	1,0	0,1	3,0
Staple Crimp Frequency (cm^1)	3,7	1,9	6,3	5,1	4,1	5,9	4,3	3,0	5,3	4,7	4,1	5,8	2,6	1,0	3,3
Duerden Crimp Ratio	0,91	0,64	1,30	1,38	0,87	2,1	1,08	0,74	2,54	1,04	0,82	1,24	1,17	0,69	1,43
PROCESSING PARAMETERS															
Scoured Yield (%)	61,9	44,6	73,7	59,8	39,9	70,5	64,2	49,3	74,9	60,7	43,1	68,1	66,7	59,8	76,1
Card Rejects (%)	6,0	1,9	23,3	6,4	2,7	16,5	5,4	2,4	10,0	5,3	2,6	14,9	5,0	2,7	8,4
Comb Noil (%)	5,7	1,2	45,0	6,2	3,5	11,8	4,4	2,0	7,4	5,9	3,1	9,6	2,3	1,1	5,7
Top and Noil Yield (%)	58,5	40,2	73,4	57,0	33,3	70,2	62,0	45,0	74,6	58,6	36,7	66,5	64,4	57,1	75,1
Fibre Diameter (μm)	21,7	18,1	28,2	22,6	20,5	26,4	22,3	19,5	24,9	20,6	19,6	21,3	28,5	23,3	33,6
CV of Diameter (%)	23,2	19,0	28,2	20,7	19,0	23,1	20,8	18,8	22,7	20,9	17,7	22,5	23,3	20,0	27,6
Resist. to Compr. (mm)	15,7	13	22	20,3	16	24	18,4	15	24	19,4	17	23	15,8	13	20
Almeter Hauteur (mm)	57,2	31,4	98,3	54,7	39,5	73,0	61,3	49,5	77,0	58,2	40,3	74,0	70,7	51,3	115,0
CV of Hauteur (%)	44,9	20,6	59,0	49,3	34,2	63,2	49,3	35,4	60,2	48,7	34,5	63,6	51,1	39,0	66,3
Short Fibre (% < 25 mm)	10,3	0,01	32,8	12,5	3,4	33,1	10,8	3.0	20,5	11,8	3,0	28,8	7,7	1,0	13,7
Long Fibre (L @ 5%, mm)	95,7	48,0	147,5	98,6	76,2	128,0	96,8	91,0	139,0	94,0	89,0	127,0	120,4	85,7	188,0
MSS (Rev/min)	10682	5400	13700	10535	6900	13000	10816	7000	13700	11114	7200	13500	11209	7400	13200
No of Lots Processed	292			18			14			10			15		



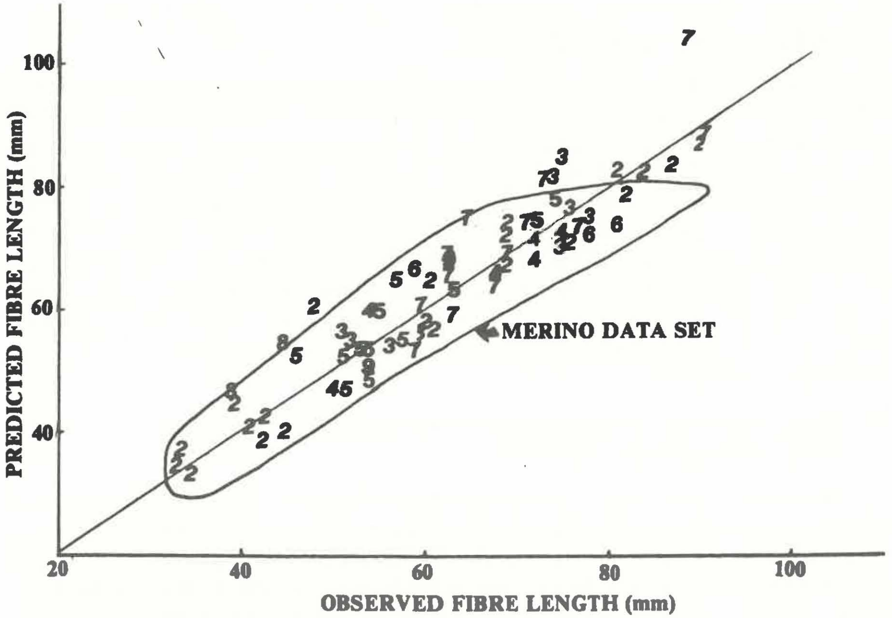


Fig. 29 Predicted vs observed (actual) values for noil and fibre length, respectively, (different numbers represent different breeds)(832 833)

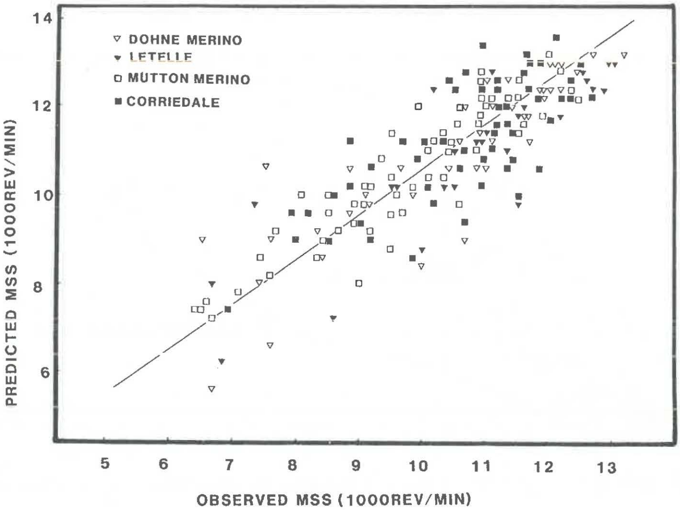


Fig. 30 Relationship between observed and predicted values for spinning performance (MSS)(933)

7.5 INTER-PORT DIFFERENCES

Turpie[668] compared the processing performance during topmaking of a 12 months 60/64's good topmaking wool from the ports of Durban, Port Elizabeth and Cape Town. An interesting finding, was the apparent rôle played by crimp, the Cape Town wools in this specific instance having a poorer processing performance because of their overcrimped nature. In a later study on a 10/12 months 60/64's good topmaking wool, he[713] found only slight differences in the topmaking performance of the wools from the different ports. The differences which were there were thought to be due to slight differences in staple crimp, compressibility or weathering. Turpie and Robinson[753] found no significant inter-port differences during spinning or weaving, yarns and fabrics also being practically identical[753].

7.6 RELATIVE PERFORMANCE OF LOCAL AND IMPORTED WOOLS

Robinson and Turpie[714] compared the performance and physical properties of fibre, yarn and woven fabric produced from a 64's quality imported Merino wool, a Cape Merino 64's wool and a 50/50 blend. The two raw wools were closely matched, the only significant difference being the higher CV of staple crimp of the imported wool. Differences in processing performance were slight, and there were no significant differences in yarn properties and performance during preparation or weaving. The three fabrics had very similar physical properties.

7.7 INTERLABORATORY TOPMAKING TRIALS

Strydom *et al*[830 847 925] obtained a measure of the interlaboratory variation in pilot-scale worsted processing test results by processing twelve replicate batches of S.A. Merino bellies and backs into tops at SAWTRI and the CSIRO Division of Textile Physics in Australia. There was good agreement between the two laboratories in terms of observed trends as well as the relative ranking of the wools in terms of processing criteria. There was no difference in measured top and noil yields although other parameters such as scoured yields, card waste and comb noil differed systematically. These differences could be attributed largely to differences in equipment and differences in processing conditions between the two laboratories. The results confirmed both the usefulness and the validity of mini- and pilot-scale techniques in worsted-processing research aimed at ranking wools and assessing processing differences in general.

7.8 EFFECT OF STAPLE STRENGTH*

Cizek and Turpie[912 918 924 939 948 973a 973 995] showed that the SAWTRI length/strength tester developed for the automatic measurement of the profile, length and strength of raw wool staples, provided useful information for predicting combing performance, top and noil yield and the top length characteristics. It was also shown that collective information on staple profiles could have useful application in the prediction of the length distribution in wool and mohair tops.

In a study (to be published) involving 17 batches of wool varying in diameter, length and staple strength characteristics, it was shown that the staple strength characteristics played an important rôle in determining percentage noil, hauteur, tail length and short fibre content of the resultant tops. It was shown that tenacity should be measured both at standard gauge and at short gauge (20 mm) to more fully explain certain trends.

The following relationships were obtained:

% Noil $= 0{,}00185X_1X_6 + 0{,}00114X_5^2 - 0{,}0077X_5X_6 + 12{,}8$ — 85,7% fit

Hauteur $= 0{,}0087X_1X_4 - 0{,}0105X_3X_4 + 48{,}4$ — 90,3% fit

Tail Length $= 0{,}0163X_1X_2 - 0{,}0018X_2^2 - 0{,}0044X_3X_4 + 20{,}9$ — 94,2% fit

% Short Fibre $= 0{,}0090X_2X_3 - 0{,}0049X_3X_4 - 10{,}7$ — 72,6% fit

Where X_1 = Staple length (mm)
X_2 = The magnitude of the thinnest place
X_3 = The position of the thinnest place
X_4 = Tenacity at standard gauge
X_5 = Tenacity at short gauge
X_6 = Mean fibre diameter

* See also Chapters 3 and 22.

The tops were converted into yarns and the yarns tested. It emerged that the effect of staple strength on yarn properties was largely due to its effect on the fibre length characteristics of the top, i.e. on the fibre breakage pattern during processing. There was some indication, however, that in addition to this, the lower levels of staple strength were associated with higher CV's of yarn extension and work to break. A statistical analysis of the data confirmed earlier findings that the yarn properties can be fairly accurately predicted in terms of the fibre properties such as diameter length and crimp.

7.9 EFFECT OF TOP WITHDRAWAL FORCE

Kruger[146 210 408 433] and Aldrich[433] developed a withdrawal force tester for tops and slivers which allowed the forces required to draw a sliver beard through a stationary bed of pins to be measured (monitored and recorded) by means of a strain gauge assembly. Fibre length was found to be reflected in the shape of the withdrawal curve and this fact was explored as a means of measuring fibre length. It was shown[152] that withdrawal force measurements could be used to indicate the extent of fibre alignment during the processing of card sliver and to assess the optimum conditions for slivers in their preparation for combing. Up to three gillings improved fibre alignment and so did higher drafts in gilling, particularly in the first gilling. Withdrawal forces varied for the different directions of the card sliver and a linear relationship was found between the average withdrawal force and percentage noil. The withdrawal force was related to fibre alignment and percentage noil[329 408 421] during combing and also determined the choice of needle temperature for minimum noil during noble combing. The forces required to withdraw fibres in combs of variable pin density were measured and it was found[170] that increasing pin density produced significant increases in withdrawal forces. Fibre breakage during rectilinear combing was ascribed to poor fibre alignment and the presence of fibre hooks.

7.10 PROCESSING LOSSES

Turpie[680] measured the processing losses during topmaking for a limited selection of (six) medium/short South African wools varying in vegetable matter content. It was found that, although the actual drycombed top noil yields for a specific level of top cleanliness were highly correlated with the yields predicted by the core test, the actual yields sometimes differed appreciably. Furthermore, the actual processing losses did not bear any significant correlation with the values for processing allowance, which appeared to depend on both VM clean and wool base.

Turpie *et al*[824] showed that actual fibre losses, sustained during the pilot-scale processing of 57 lots of short wools and outsorts, expressed as a percentage of the measured bone-dry, clean-scoured wool, ranged from 5 to 25% and could not be explained adequately in terms of fault content or type of fault only. Inclusion of data on the fribbiness of the wools (see 7.12), which were obtained by a test especially devised for this purpose, significantly improved the prediction of fibre losses. Equations for predicting top and noil yields of short wools and outsorts were presented which allowed a more accurate estimate of yields than had been possible using the existing IWTO conversion formulae.

Turpie *et al*[829 928] clearly illustrated the effect of "fribbiness" on processing losses, an increase of 1% in fribbiness increasing fibre losses during processing by about a 0,5%. "Double cuts" were an important source of "fribs" and therefore an important cause of fibre loss during processing (see 7.12).

7.11 PROCESSING FAULTY WOOLS

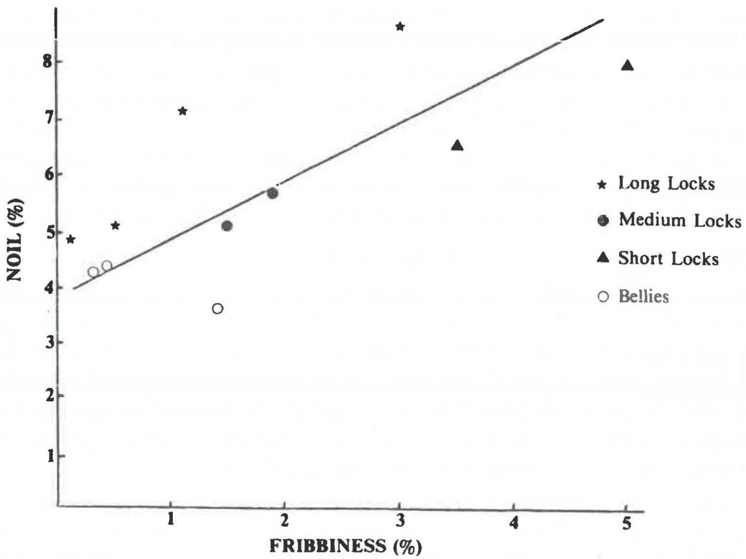
Godawa and Turpie[569] determined the best processing route for a blend comprising three wools differing in vegetable matter content, with the most heavily contaminated wool being described as "carbonising". It was found that similar results were obtained whether the wools were processed on their own, blended during gilling, blended prior to carding or blended in the greasy state. The tops produced from the wools which were blended prior to carding or in the greasy state, however, tended to be marginally shorter.

Schmidt and Turpie[593] investigated the influence of atmospheric conditions, initial regains before carding and water added during gilling on the performance up to combing of two different wools, heavily contaminated with vegetable matter. From the results obtained, practical conditions suitable for the processing of such wools appeared to be an RH of about 70%, a temperature of at least 21°C, a regain on the wool entering the carding machine of about 12% and an amount of water applied during gilling of at least 5% (o.m.f.).

7.12 EFFECT OF MECHANICAL SIFTING ON PROCESSING OF LOCKS

Strydom[799] processed binned Merino locks containing up to 2% seed, in three length categories through a mechanical sifting apparatus, producing three components in each case namely "long" and "short" components (compared with the unsifted control) and a "waste" product. Top and noil yields and mean fibre lengths for the "long" component of each type were generally better than those of the unsifted control batches, while the "short" components generally processed worse than the unsifted control batches. These differences were also reflected in subsequent spinning tests. The appearance of the long component was considerably better than that of the unsifted control.

Subsequently Strydom[834] blended three lots of average to inferior fleeces (in a 1:1 ratio) with long, medium and short locks, either in the unsifted state or after processing through a mechanical sifting apparatus to remove fribs, dags and other impurities. Sifting, in general, had a beneficial effect on processing. In general, the differences between the actual and predicted processing performance, properties of the tops and spinning behaviour were not significant.



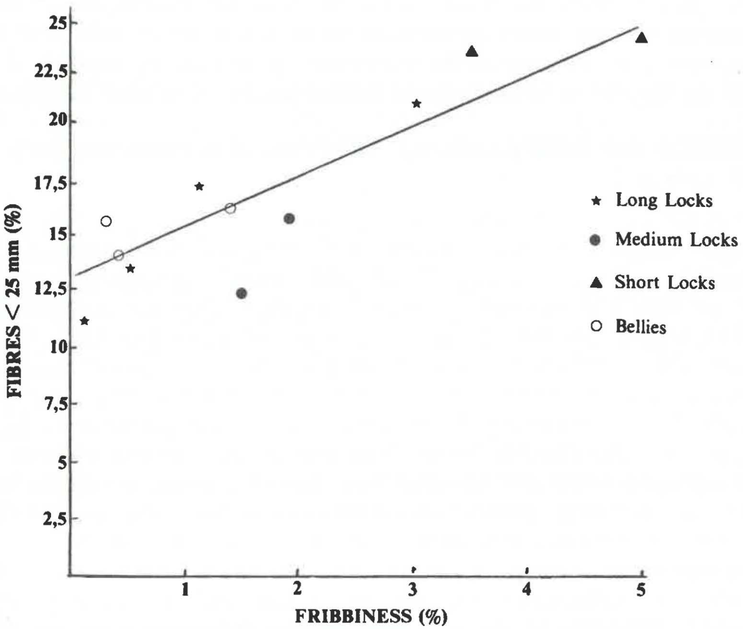


Fig. 31 Effect of fribbiness on noil and short fibre content, respectively(861)

Strydom[861] also processed long, medium and short, good to average style bellies, in blends with an appropriate length class of locks after the latter had been sifted and confirmed the beneficial effect of sifting in terms of improvements in fribbiness of the raw wool, fibre length, card wastes, comb noil and top and noil yields. Card waste, comb noil and the short fibre content of the tops tended to increase with an increase in fribbiness (Fig. 31). The improved length characteristics of tops produced from the sifted batches were reflected in improved spinnability.

7.13 PROCESSING KARAKUL AND OTHER PIGMENTED WOOLS

Turpie and Robinson[705] processed a small quantity of the best grade pigmented wool (referred to as "merino black") on the worsted system into fabric. While the light-fastness results of the naturally pigmented wool were below standard, wet-fastness results were good, no bleeding of the pigment being observed.

Strydom[761] processed five lots of sorted and willeyed karakul, varying in seed content and mean fibre length, into worsted tops and recorded the raw fibre properties and processing performance. The raw fibre had low grease contents and high suint levels compared with Merino wool, while the suint pH was found to be fairly alkaline. It was established that the processing losses were substantially higher than the IWTO processing allowances associated with Merino wools. The tops were about 3-4 μm coarser than the raw fibre.

Strydom and Van der Merwe[862] processed two commercial types of sorted karakul into yarns via the worsted, semi-worsted and the woollen route to compare their relative processing performance. Based upon mass of scoureds, the woollen route produced the highest sliver yield, followed by the semi-worsted route and the worsted route. The worsted route, however, produced the best slivers and yarns in terms of irregularity, neps and other imperfections. There was very little difference in the tenacity of the worsted and semi-worsted yarns, that of the woollen yarns being about 30% lower. Semi-worsted slivers had a lower spinning potential than worsted ones. Considerable fibre breakage occurred during carding.

7.14 EFFECT OF BACKWASHING

Kruger[252] investigated the influence of backwashing and found that, although the backwashing process induced some fibre felting, resulting in high withdrawal forces, the subsequent processes satisfactorily removed this entanglement. Tops backwashed before combing had the lowest number of neps in both the top and the yarn while the wool which was not backwashed gave more spinning end breakages and a slightly more irregular yarn.

Turpie[453] showed that the combing performance of backwashed slivers was dependent on the pH of the liquor during backwashing and on the reagent used to control pH. Combing performance deteriorated with deterioration in wool style brought about by weathering and this deterioration was accentuated when backwashing took place at a pH higher than 10,5. For a good topmaking style of wool, backwashing in an acid media appeared to result in improved combing performance, but for optimum results a liquor pH of 6,5 should be avoided, a slightly lower pH being preferred.

Turpie[574] found that backwashing reduced the crimp frequency of fibres, leading to much reduced noil during combing (Fig. 32) and to a longer mean fibre length of the top. Sodium bisulphite in the backwashing bowl was less advantageous than a wetting agent. The results for percentage noil showed that the lot which was backwashed in the sodium bisulphite solution did not perform as well as the lot backwashed in the normal manner, even when it had been lubricated prior to combing.

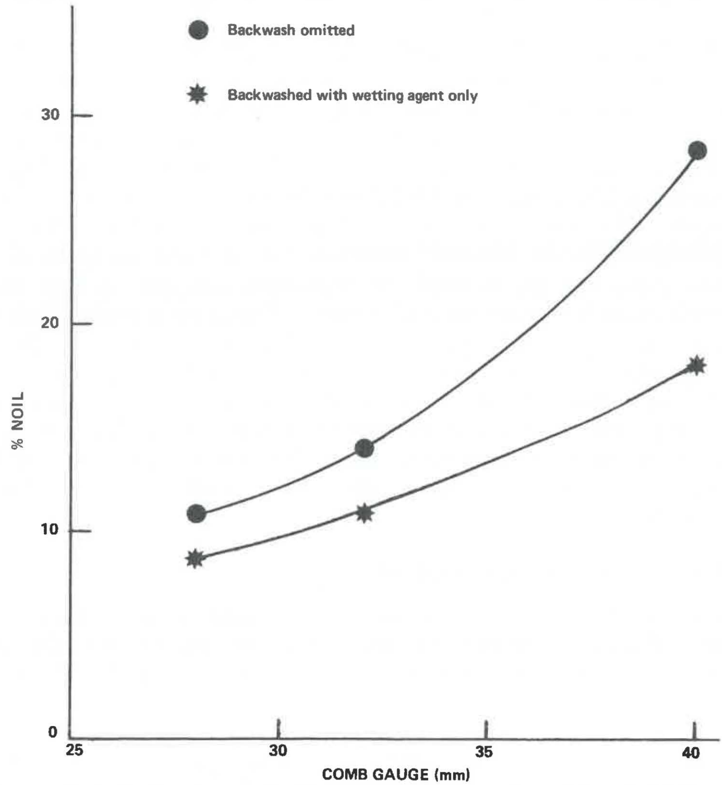


Fig. 32 The Effect of Backwashing on Percentage Noil at Various Comb Gauge Settings(574)

7.15 EFFECT OF STEAMING OVERCRIMPED WOOL

Strydom and Adriaanzen[795] found that the steaming of slivers during preparatory gilling had a small beneficial effect on the combing performance of an overcrimped wool. Improvements in the mean fibre length of the top were also evident, especially when steaming on the first and second preparer gilling, and then combing from balls but omitting a steaming operation on the finisher.

7.16 EFFECT OF RECOMBING

Aldrich[171, 208] developed a technique for measuring fibre breakage during recombing on a rectilinear comb using radio-isotopes and illustrated that the comb broke the finer fibres preferentially, resulting in a relatively fine noil, with fibres longer than a certain "threshold length" also suffering significantly more breakage.

Strydom[908] recombed three undyed tops with mean fibre lengths from 52,7 to 60,3mm having moderate to high short fibre contents (12 to 17% of fibres shorter than 25mm) and low residual vegetable matter at different gauge settings. At the maximum setting the short fibres were reduced to between 5,0 and 7,5%, at percentages noil of between 4 and 5%. Improvements in the mean fibre length and CV's of fibre length, were small. Composite graphs relating short fibre content and noil to comb gauge (Fig. 33) could be useful to assist the comber in balancing the conflicting requirements of minimum short fibre content and maximum top to noil ratio.

7.17 SEMI-WORSTED PROCESSING

Cilliers[242] reported that lambswool could be processed satisfactorily on a modified continental worsted system (combing omitted) although fibre cohesion had to be increased during carding so that the card sliver could withstand the tension between the doffer and the coiler. Slight milling of the knitted fabric successfully obscured the neppiness.

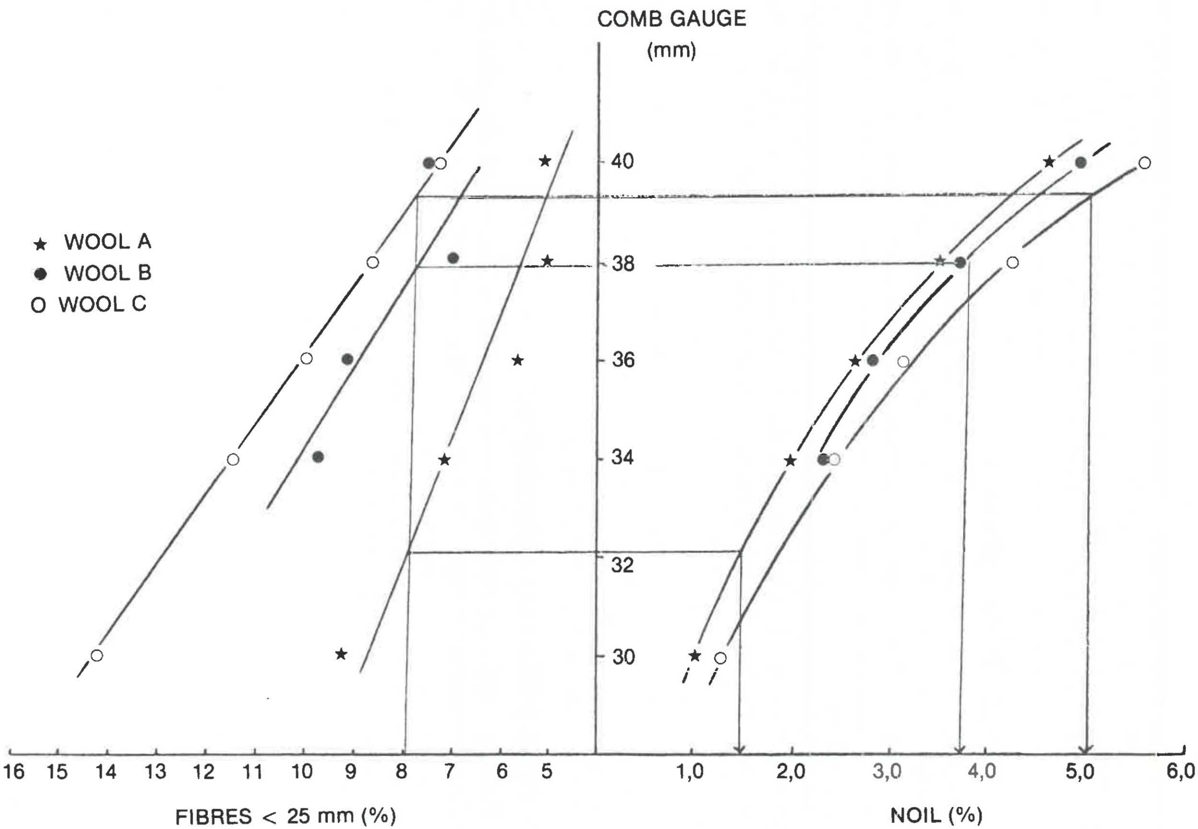


Fig. 33 Relationship between Comb Gauge, Percentage Noil and Percentage Fibres shorter than 25 mm(908)

CHAPTER 8

SPINNABILITY* AND ASSOCIATED YARN PROPERTIES

8.1 RAPID ASSESSMENT OF SPINNING POTENTIAL

Turpie[516] developed a rapid spinnability test in which the spindle speed of a ring frame was increased in steps at a given rate during the spinning of wool until all ends were down. The mean spindle speed at which these end breaks occurred, defined as the MEAN SPINDLE SPEED (MSS) AT BREAK, could be determined in about 1,5 hours and was found to be highly correlated with the spindle speed (CSS) at which a commercially acceptable end breakage rate (taken as 50 per 1000 spindle hours) occurred. The MSS at break was dependent on several factors, such as yarn linear density, fibre fineness, mean fibre length and possibly tenacity x extension, and could thus be used as a first step to compare the spinning potential of different wool lots (Fig. 34).

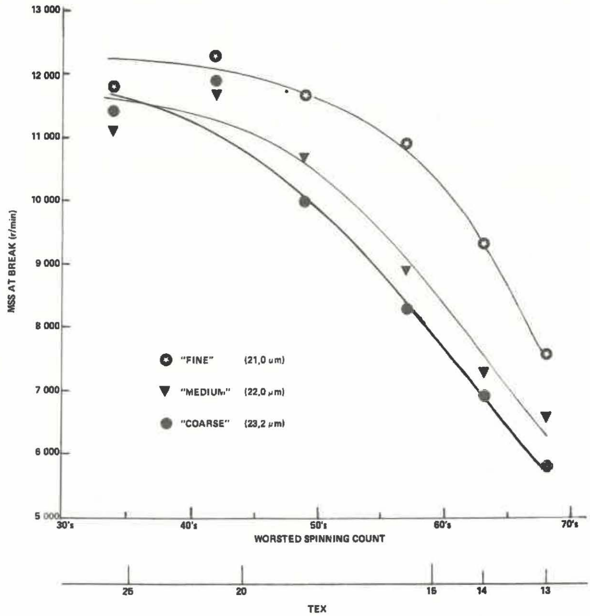


Fig. 34 The influence of Yarn Linear Density on the MSS at break for tops of similar length but different fineness.(516)

*Note: The effects of fibre properties, wool blending and breed of sheep on spinning performance have been covered in Chapter 7.

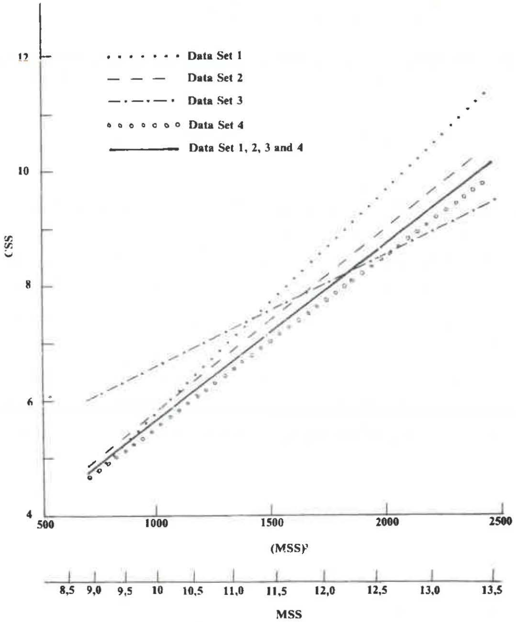


Fig. 35 Regression Lines for CSS versus (MSS)³ for the various data sets (both CSS and MSS expressed in r/min x10⁻³)(589)

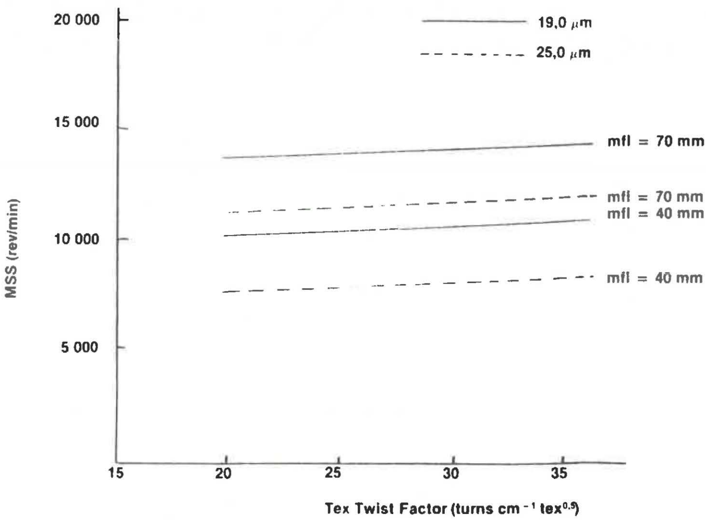


Fig. 36 Effect of Twist Factor on MSS.(785)

Gee and Turpie[589] showed statistically that the MSS technique could provide a measure of spinnability in about 1,5 hours with an accuracy 30 times greater than that of a conventional end-breakage test. They found a cubic relationship between CSS and MSS (Fig. 35) and recommended the following formula for converting MSS to CSS:

$$Y = 0{,}00302X^3 + 2{,}748$$

Where Y = CSS (expressed in r/min x 10^{-3})

X = MSS (expressed in r/min x 10^{-3}).

Strydom and Gee[785] subsequently investigated the effect of twist on the assessment of spinning potential by the MSS technique using tops varying in fibre diameter, length and crimp ratio. Multiple regression analysis of the MSS results showed that the effect of twist on MSS was small compared with the combined contribution of mean fibre length, mean fibre diameter or, equivalently, fibres in the yarn cross-section (Fig. 36). Increasing the tex twist factor by 10 units, increased the MSS by only about 260 rev/min compared with an improvement of 833 rev/min obtained by using a top 1 μm finer or an improvement of 550 rev/min obtained when using a top 5mm longer. It also emerged that the finer the yarn being spun from a given mean fibre diameter, the more sensitive the MSS was to changes in mean fibre length.

8.2 EFFECT OF SPINNING SPEED ON END BREAKS AND YARN PROPERTIES

Turpie and Hunter[725] showed that while an increase in mean fibre length and a decrease in mean fibre diameter generally affected spinning performance and yarn properties favourably, an increase in spindle speed increased end breakages but had little effect on yarn properties (Fig. 37). Statistically signifi-

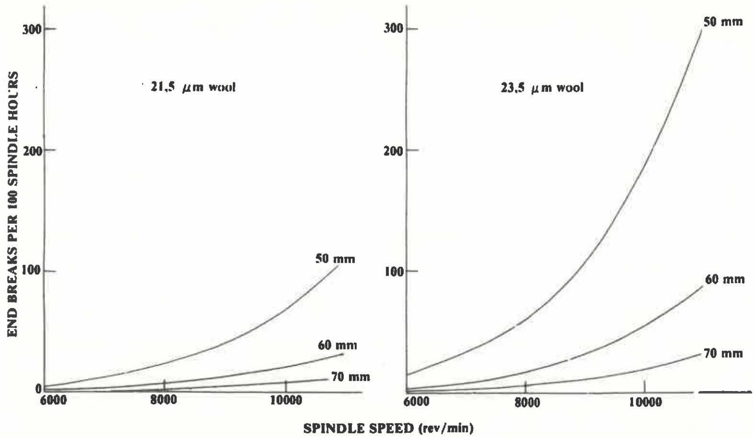


Fig. 37 Regression curves illustrating the effect of spindle speed and fibre length (mm) on end breakage rate of a 21 tex yarn.(725)

cant correlations were found between spinning performance and certain yarn properties but these were generally not high enough for purposes of prediction.

8.3 EFFECT OF DRAFT AND ROVING LINEAR DENSITY ON SPINNING AND YARN PROPERTIES

Turpie and Marsland[480] varied the draft applied at the roving operation and the linear density of the roving and yarn to study their effect on end breakages and yarn properties. The rovings were produced on a double-apron high-draft drawframe and the yarns spun on a double-apron ring spinning frame. There appeared to be good justification for using 375 tex in preference to 250 or 500 tex, and for using a draft of 16 at the roving operation in preference to 12 or 20, when spinning yarns of 16 to 28 tex. Under these conditions there were less end breakages and the yarns were superior.

8.4 SPINNING AND YARN PROPERTIES OF DYED TOPS

The effect of differences in fibre friction, resulting from differences in top dyeing, on the behaviour of the fibres during drawing (roller lapping) and spinning (end breaks), was investigated by Kruger and Veldsman[87] who concluded that it was not advisable to blend wools which differed in friction (resulting from differences in their dyeing conditions).

Hunter[803] studied the effect of wool fibre properties on spinning performance and yarn properties for 27 dyed wool tops and compared the results with those previously obtained for the undyed tops. In the main, the respective rôles of the fibre properties, including crimp, in determining spinning performance and yarn properties, were found to be similar for the dyed and undyed tops. The after-chrome dyeing process applied to the tops did not appear to have a great effect on the relationships between the yarn and fibre properties, although it decreased yarn extension at break and hairiness and increased the frequency of thin and thick places.

8.5 SIROSPUN

Strydom and Hunter[864] carried out a preliminary study, to establish the effect of limited changes in either fibre diameter or fibre length on the spinning performance and properties of Sirospun yarns. For the particular ranges of fibre length and diameter covered, changes in both spinning potential (MSS) and yarn properties were almost solely dependent upon changes in fibre diameter (for average number of fibres in the strand cross-section — Fig. 38) for both the Sirospun and conventional two-ply yarns. About 20 fibres per strand cross-section appeared to be the spinning limit for Sirospun. The Sirospun yarns generally had similar tenacities but higher extension, irregularity and frequencies of isolated weak places, imperfections and faults, than the corresponding conventional two-ply yarns.

In a later study (unpublished) Hunter and co-workers illustrated the importance of fibre diameter and fibre length in determining the spinning and weaving performance of Sirospun yarns as well as the yarn properties.

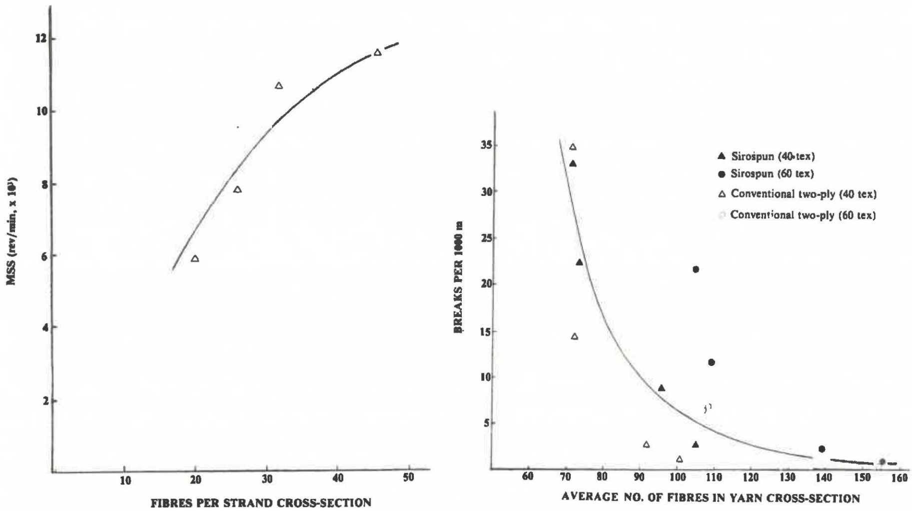


Fig. 38 The effect of Average Number of fibres per Strand Cross-section on MSS and frequency of isolated weak places (Shirley Breaks).(864)

CHAPTER 9
WOOLLEN PROCESSING

9.1 PROCESSING PERFORMANCE OF SOUTH AFRICAN WOOLS*

Van der Merwe[930] investigated the possible application of bleached karakul in Shetland-type hosiery yarns. He found that carding removed a significant proportion of the very coarse karakul fibres, and blending the karakul with about 50% of a cross-bred wool enabled a yarn to be produced which resembled a Shetland-type yarn. He assessed spinning performance by the MSS* test, suitably adapted to the woollen system, and found that MSS decreased as the mean fibre diameter increased (i.e. number of fibres in the yarn cross-section decreased (Fig. 39).

Van der Merwe[957] assessed the spinnability, on the woollen system, of sixteen virgin wools, a carbonised wool, a karakul lot and a bleached lot of the same karakul type, individually, as well as in blends, by means of the modified Mean Spindle Speed at Break (MSS) method. Multiple regression analysis of

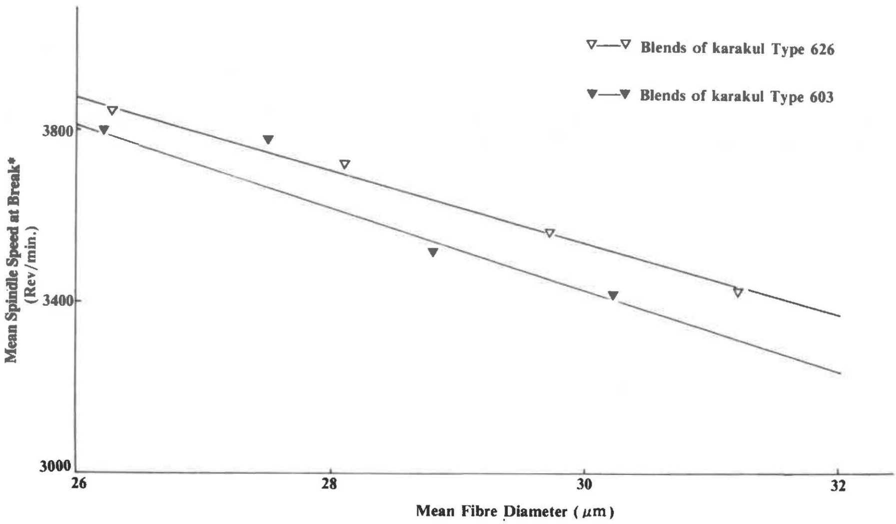


Fig. 39 Effect of Increasing Mean Fibre Diameter on the Spinnability of 100 Tex Karakul/Wool Yarns.(930)

* MSS and spindle speed values given in the various publications are about 25% too low because of a faulty rev. counter on the spinning frame.

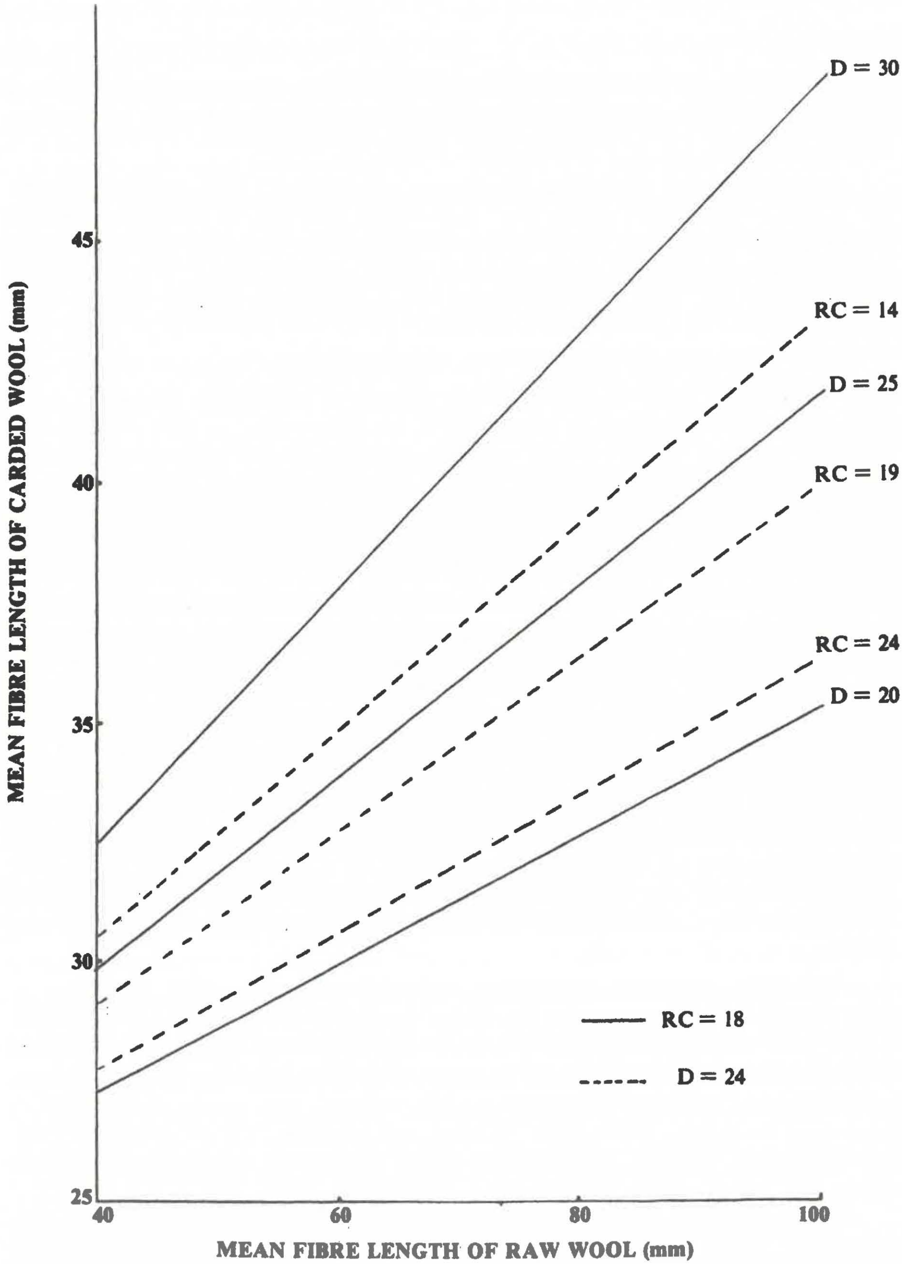


Fig. 40 Regression lines illustrating the effects of fibre length, fibre diameter (D) and resistance to compression (RC) on the mean fibre length of carded wool.[(964)]

the results of the 68 wool lots showed that spinnability deteriorated when CV of diameter and resistance to compression increased but improved as mean fibre length increased up to a mean fibre length of 80mm.

In a subsequent study Van der Merwe and Brydon[958] explored the possibility of using karakul, in blends with other types of wool, to produce simulated tweed yarns. He found that such yarns and fabrics could be produced from different types of karakul in blends with 50% Corriedale wool. When a kempy type karakul was added to the blends very interesting surface effects were obtained.

In a wide-ranging study on S.A. wools, Van der Merwe[938 964 965 966] and Gee[938] processed some 68 lots of wool, varying in mean fibre diameter, mean fibre length and resistance to compression, on the woollen system of manufacture into yarns of 100 tex Z250, which were knitted into single jersey fabrics. (These studies formed the basis of a Ph.D. thesis)[923]. Multiple regression analysis of the results yielded equations by means of which the effects of the various fibre properties on processing performance, spinnability and yarn and fabric properties could be explained (Figs 40 to 42). The results showed that mean fibre diameter and CV of fibre diameter were the most important fibre properties influencing processing performance and yarn and fabric properties. The next most important fibre property was resistance to compression, followed by mean fibre length, with CV of fibre length apparently being of little significance. The results also showed that an increase in mean diameter increased cross card variation, slubbing and yarn unevenness, the frequency of thin and thick places, yarn hairiness, fabric specific volume, bursting strength and air permeability, but decreased carding yield, yarn specific volume, fabric mass, fabric pilling and felting shrinkage (Figs 41 and 42). Changes in CV of diameter affected most of the dependent variables in a similar way to mean fibre diameter although, for the relatively coarse linear density yarn (100 tex) spun, variation in fibre diameter did not have a significant effect on spinnability (MSS).

The most important observation with respect to fibre bulk resistance to compression was that increased resistance to compression resulted in deterioration of yarn tensile strength and fabric strength properties in general. Increased resistance to compression caused an increase in fibre breakage during carding, yarn extension at break and yarn specific volume, but caused a decrease in cross-card variation, MSS, yarn tenacity and hairiness, fabric abrasion resistance, bursting strength, permeability to air, and felting shrinkage (Figs 40 to 42).

Increased mean fibre length was in most cases beneficial to yarn and fabric properties. When mean fibre length increased, the carding yield, MSS, yarn extension, fabric abrasion resistance and bursting strength improved. Yarn irregularity, however, increased when mean fibre length increased (Fig. 41).

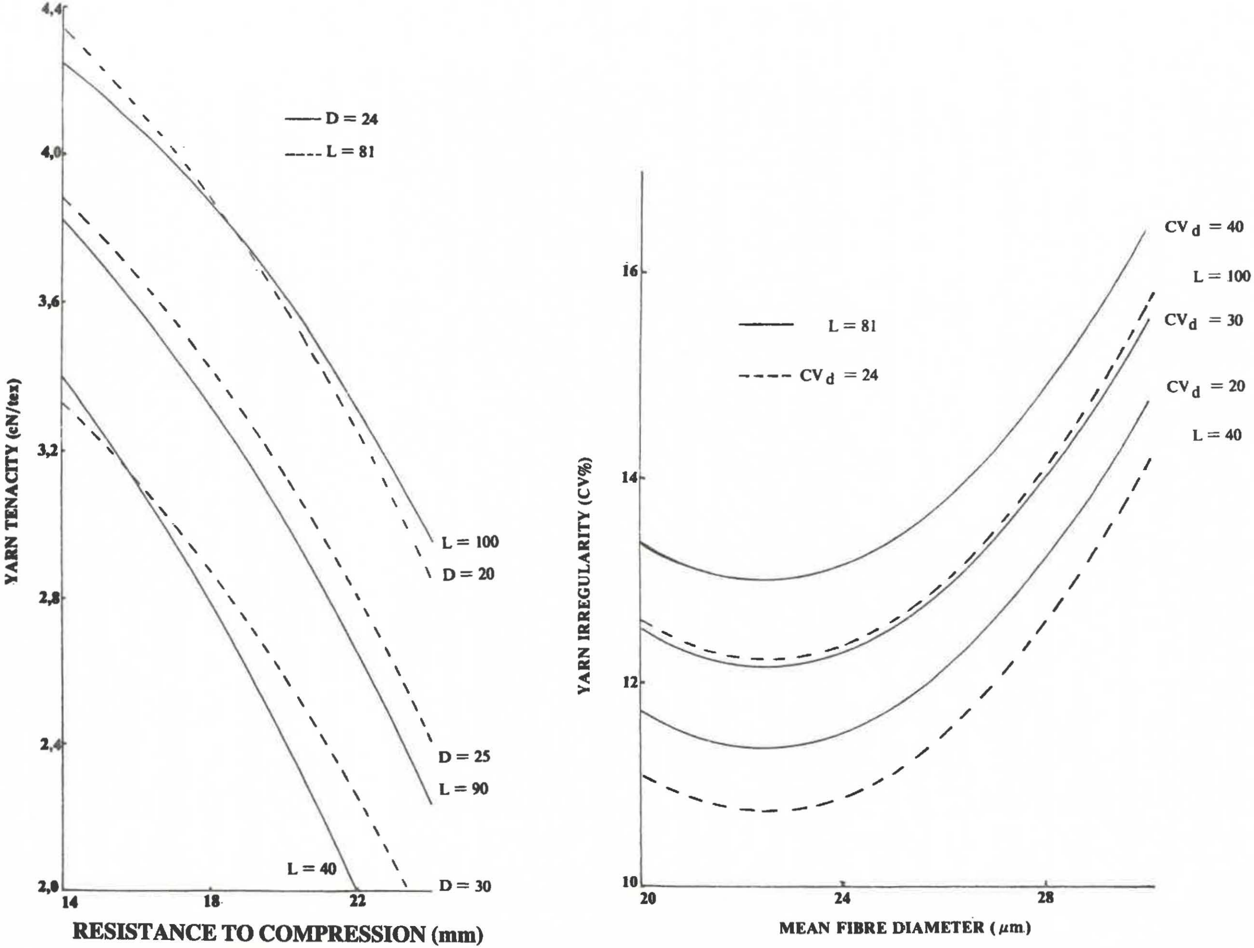


Fig. 41 Regression curves illustrating the effect of certain fibre properties on yarn tenacity and irregularity.(965)

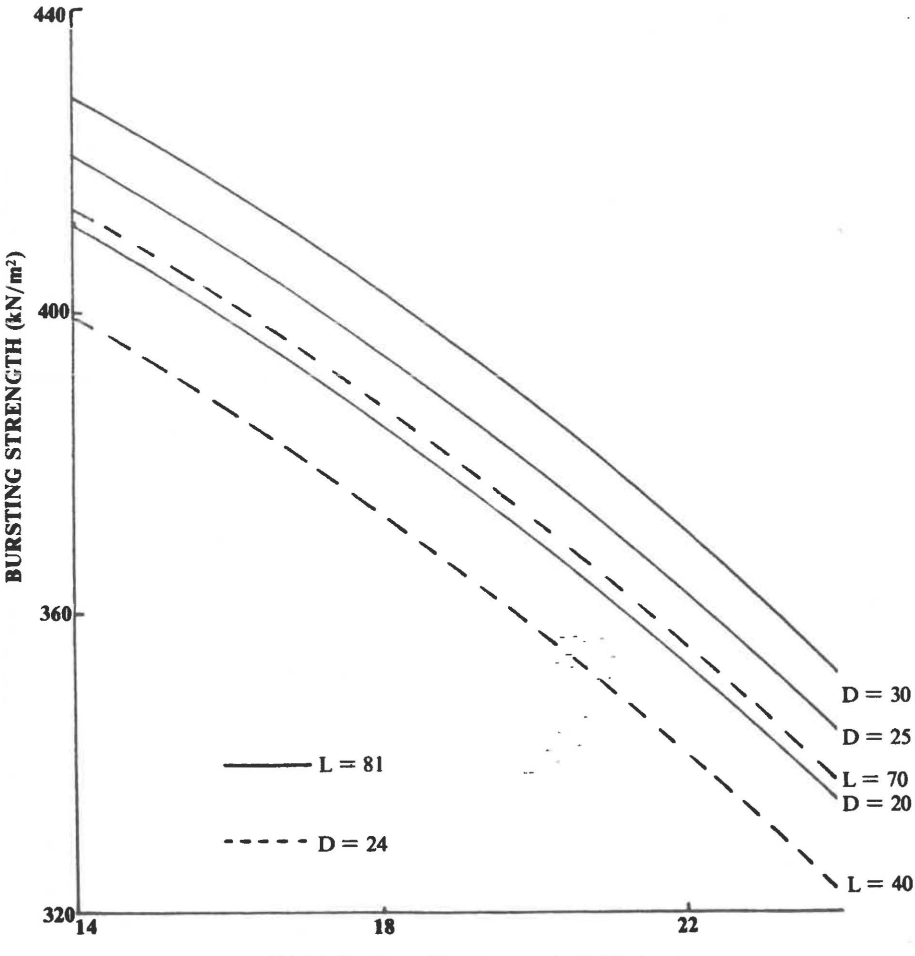


Fig. 42 Regression curves illustrating the effect of fibre properties on knitted fabric bursting strength.(966)

9.2 WOOLLEN SPUN WRAP YARNS

Van der Merwe *et al*[898 905 989] described the production of wrap yarns directly on the woollen card by fitting hollow spindles to the delivery end (Fig. 43) and gave some preliminary results for karakul and wool mixtures. The system was considered to have potential for most, if not all fibre types processed on the woollen system, eliminating the need for a separate spinning machine. In later

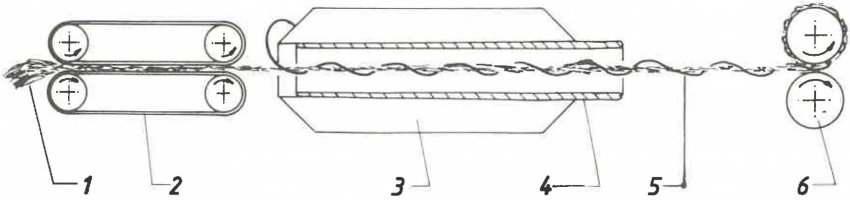


Fig. 43 The production of a woollen wrap yarn directly on a woollen card.(898)

1. Fibre ribbon
2. Rubbing aprons
3. Filament package
4. Hollow spindle
5. Wrap yarn
6. Condenser bobbin winding drums

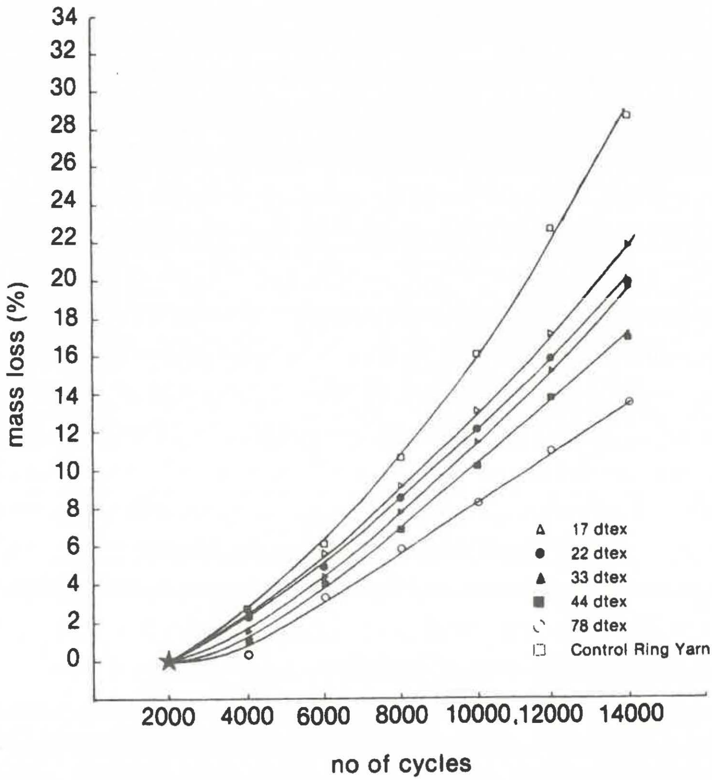


Fig. 44 Effect of Filament Linear Density on Abrasion Resistance of Plain Knitted Fabrics.(980)

work, however, they developed a very simple separate unit which could be fed by the condenser bobbins and which allowed a single adjustment for draft (see next page).

Van der Merwe[974, 980] and Brydon[980, 992, 993, 1001] studied the effects of wraps per meter, wrapper filament linear density on the properties of woollen spun wrap yarns and those of plain fabrics knitted from these yarns. It was found that an increase in filament linear density resulted in higher yarn strength, increased elasticity, improved fabric abrasion resistance (Fig. 44) and greater bursting strength. Fabrics produced from wrap yarns were superior to fabrics produced from the ring yarn with respect to abrasion resistance, bursting strength, air permeability, and stitch clarity.

The above authors also investigated[974, 990, 992, 993, 1001] the effects of applying draft to a woollen slubbing during wrap spinning and the associated changes in yarn linear density. Various levels of draft were used to produce both wrap-spun yarns and ring-spun yarns for comparison. The undrafted wrap yarn was found to be more regular and gave higher values of extension, but lower values of tenacity, than the drafted yarns (which were finer). Increasing the level of draft was found to increase tenacity within the limits of draft investigated, while also increasing irregularity and decreasing yarn extension. Drafting had little or no effect on fabric specific volume, air permeability or area shrinkage.

CHAPTER 10

THE PRODUCTION AND PROPERTIES OF FRICTION-SPUN WOOL AND WOOL BLEND YARNS

Hunter *et al*[764] investigated the effect of wool fibre properties on friction (Dref II) spinning limits and yarn properties and found that the finest yarns which could be spun had similar yarn linear densities (≃ 95 tex), irrespective of the fibre characteristics. In contrast to ring spinning, the number of fibres in the yarn cross-section varied widely (≃ 115 to 255) at the spinning limits. The fibre length of the top had little effect on the yarn properties or spinning limits, probably because of fibre breakage at the card roller reducing differences in mean fibre length. Spinning performance was adversely affected by staple crimp. Yarn irregularity (CV) was found to be proportional to $n^{-0,38}$ where n represented the average number of fibres in the yarn cross-section (Fig. 45), while yarn tenacity varied from about 1,4 to 4,2 cN/tex. Subsequently, Robinson *et al*[815] used the novel feature of the DREF II 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 could be made to predominate on the yarn surface whilst a cheaper fibre, such as carbonised wool noils, made up the body of the yarn. In this manner, the yarn, and subsequent fabric, had the aesthetic qualities of the speciality fibre in spite of the fact that it only makes up a small proportion of the whole.

Bathie and Hunter[885] spun four types of fine wool noils, differing in vegetable matter content and fibre characteristics, on the Dref II into two linear densities and at different perforated spinning drum and card cylinder speeds. A higher card cylinder speed tended to remove slightly more vegetable matter and to produce more regular and but more hairy yarn than the slower speed. On average, about 45% of the vegetable matter was removed by the spinning system. The sliver with the greatest fibre length (≃ 46 mm), and which also had the lowest resistance to compression, produced the fewest end breakages and also the best yarn.

Spencer and Taylor[759] investigated the effect of solvent scouring and milling on the properties of Dref II karakul yarns. Fibre shedding occurred during milling but there was an improvement in yarn strength. Hunter *et al*[845] studied the properties of karakul yarns spun on a Dref II machine and found the spinning limits to range from about 140 to 190 tex with the tenacity of the 250 and 500 tex yarns, ranging from about 2 to 3,7 cN/tex at the highest twist levels employed. Yarn irregularity was related to the average number of fibres in the yarn cross-section.

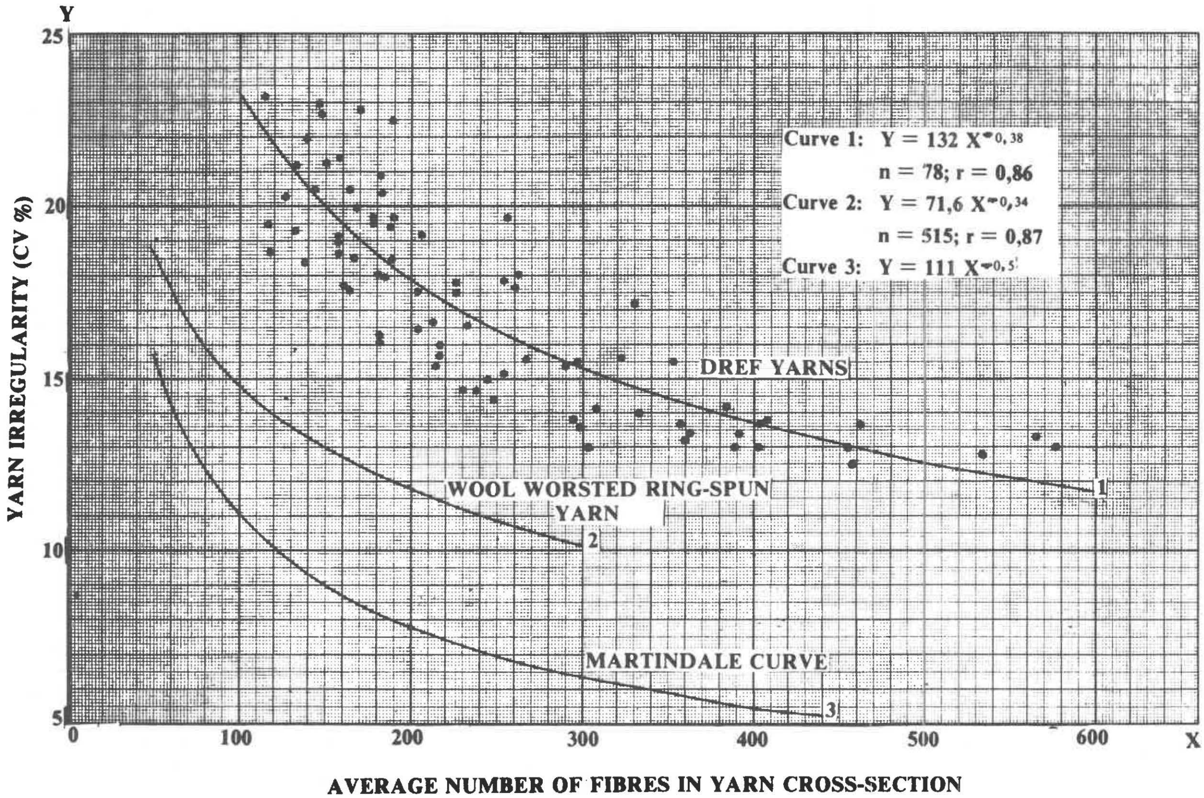


Fig. 45 The relationship between yarn irregularity and the average number of fibres in the yarn cross-section (combined DREF results).[764]

Thierron[922, 945] spun wool/polyester yarns successfully on a Dref III friction spinning machine as well as a short staple ring spinning machine, the Dref III providing considerably higher production rates than the ring spinning machine and also involving fewer processing steps. Yarns were spun to different linear densities, twist levels and at different spinning speeds. The Dref III spinning performance was favourable at relatively low speeds, but higher speeds generally caused a deterioration in yarn properties. The best yarn tenacity was obtained with the type of opening roller (10°) recommended for man-made fibres. The best yarn regularity, but lowest tenacity, was obtained when the wool and polyester were blended on the drawframe. The properties of the ring-spun yarns were generally superior to those of the friction-spun yarns.

CHAPTER 11

WOOL WORSTED RING-SPUN YARN PROPERTIES

11.1 EFFECT OF FIBRE PROPERTIES

In a series of wide-ranging studies[229 479 483 494 547 630 695 712 769 832 833 893] in which several hundred wool lots, differing widely in their fibre characteristics, were processed into yarn, Hunter and co-workers investigated the relationships between the physical properties of the yarns and the fibre properties. Multiple regression analysis was used to identify and quantify the effects of the various fibre properties on the yarn properties and a number of empirical relationships (equations) were derived which allowed the properties of a yarn to be calculated beforehand (i.e. predicted) from the fibre characteristics, within certain constraints. The relative importance of the various fibre properties in determining the yarn properties (and therefore quality) was established and quantified. Some of the earlier work formed the basis of a Ph.D. thesis[479] by Hunter.

From these studies the overriding importance of fibre diameter clearly emerged, it being followed in importance by fibre length and then fibre crimp (or bulk resistance to compression - see Fig. 46). Fibre tenacity was of obvious importance in determining yarn tenacity and fibre extension in determining yarn extension, but these generally vary little in practice when the wool is undyed and untreated and generally only need to be considered when the wool has been chemically treated (e.g. dyed and/or shrinkproofed) or in those isolated cases where the wool has been excessively damaged during growth (e.g. micro-organisms) or during scouring. Wools with a localised tenderness (break) generally break at this position during mechanical processing (notably carding) and the change in fibre length manifests itself in the properties of the yarn but not the "tenderness" as such. Similar considerations probably apply to fibre friction.

The effects of distribution of fibre diameter and length (e.g. CV's, skewness, kurtosis) although often having a significant effect on certain yarn properties, were generally small for the ranges normally encountered in practice. Their effects generally become important when either their ranges became extreme or when relatively fine yarns (i.e. relatively few fibres in the cross-section) were spun or both.

Detailed mathematical relationships and supporting graphs (see for example Fig. 47) were given in various publications, the results indicating that a measure of fibre crimp (e.g. staple crimp or resistance to compression) was important for the accurate prediction of certain yarn properties.

In general it emerged that[483 547 932] yarn irregularity (CV %) was proportional to $n^{-0,4}$ (where n is the average number of fibres in the yarn cross-section) while the frequency of thin and thick places were approximately proportional to n^{-4} (Fig. 48).

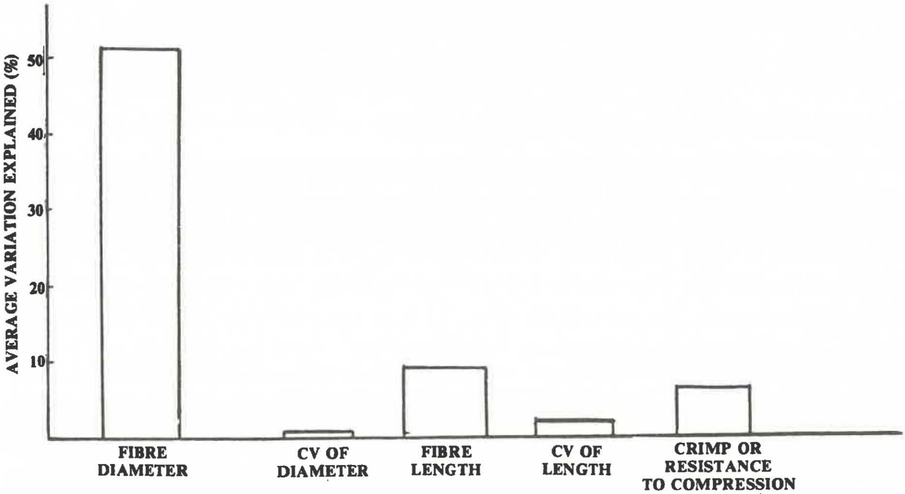


Fig. 46 Percentage contribution of the various fibre properties towards explaining the observed variations in yarn tensile and evenness characteristics (average over 50 and 25 tex yarns, neps excluded)(833)

The following approximate relationships were derived[932]:

Irregularity α (Fibre Diam.)^{0,8} (Fibre Length)$^{-0,2}$ (Compr.)^{0,1} (Tex)$^{-0,4}$
α (Fibre Diam.)^{0,8} (Fibre Length)$^{-0,2}$ (Tex)$^{-0,4}$
α (Fibre Length)$^{-0,2}$ (No. of Fibres)$^{-0,4}$

Thin Places α (Fibre Diam.)^{9} (Fibre Length)$^{-2}$ (Tex)$^{-4}$
α (Fibre Length)$^{-2}$ (No. of Fibres)^{4}

Thick Places α (Fibre Diam.)^{6} (Fibre Length)$^{-2}$ (Tex)$^{-4}$
α (Fibre Length)$^{-2}$ (No. of Fibres)^{3}

Neps α (Fibre Length)$^{-2}$ (CV of Length)^{1,5} (Tex)$^{-1,5}$
α (Fibre Diam.) (Fibre Length)$^{-2}$ (CV of length) (Short Fibres)^{0,1} (Tex)$^{-2}$

Classimat Faults α (Fibre Diam.)^{3} (Fibre Length)$^{-3,5}$ (CV of Length)^{1,5} (Tex)$^{-1}$
α (Fibre Diam.)^{3} (Fibre Length)$^{-3,5}$ (Tex)$^{-1}$

Tenacity α (Fibre Diam.)$^{-0,8}$ (Fibre Length)^{0,4} (Compr.)$^{-0,2}$ (Tex)^{0,2}

Extension α (Fibre Diam.)$^{-1,7}$ (Fibre Length)^{0,7} (Compr.)$^{-0,7}$ (Tex)^{0,7} (Twist Factor)^{0,4}

Hairiness α (Fibre Diam.)^{1,9} (Fibre Length)$^{-0,5}$ (Short Fibres)^{0,1} (Compr.)$^{-1,15}$ (Tex)^{0,35}

Compr. = Resistance to compression

The interrelationship between the various yarn parameters characterising yarn irregularity, was also investigated[483] and, in general, it was found that yarn irregularity (CV) and the frequency of thin and thick places were highly corre-

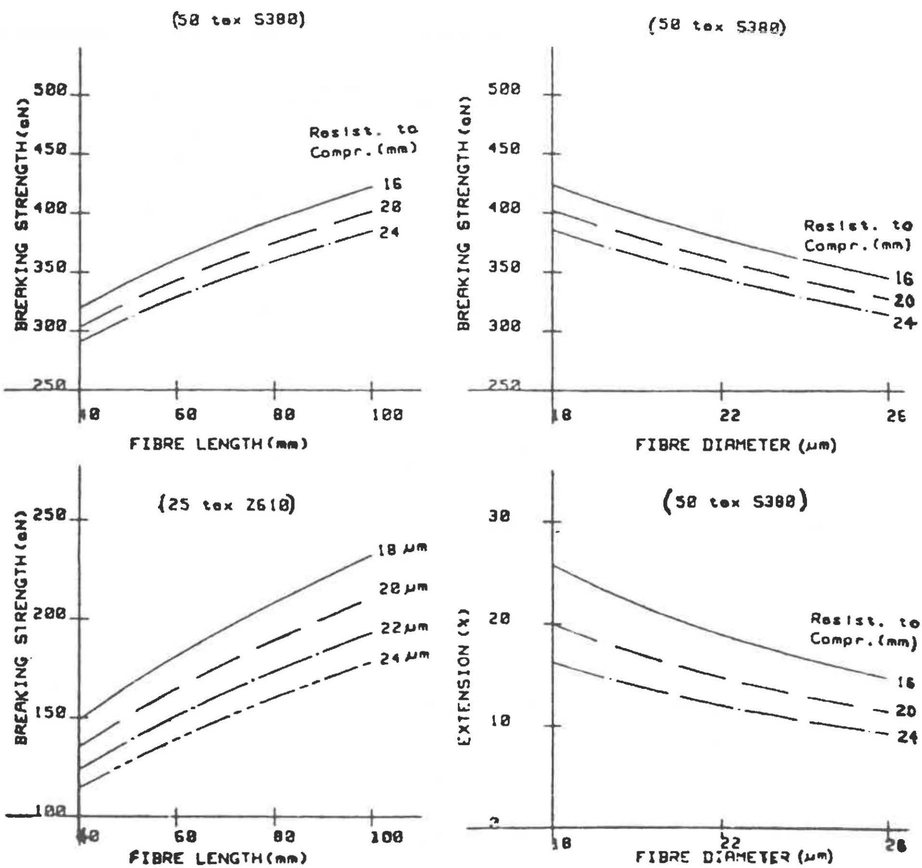


Fig. 47 Regression curves to illustrate the effects of fibre properties on yarn breaking strength and extension[(769)]

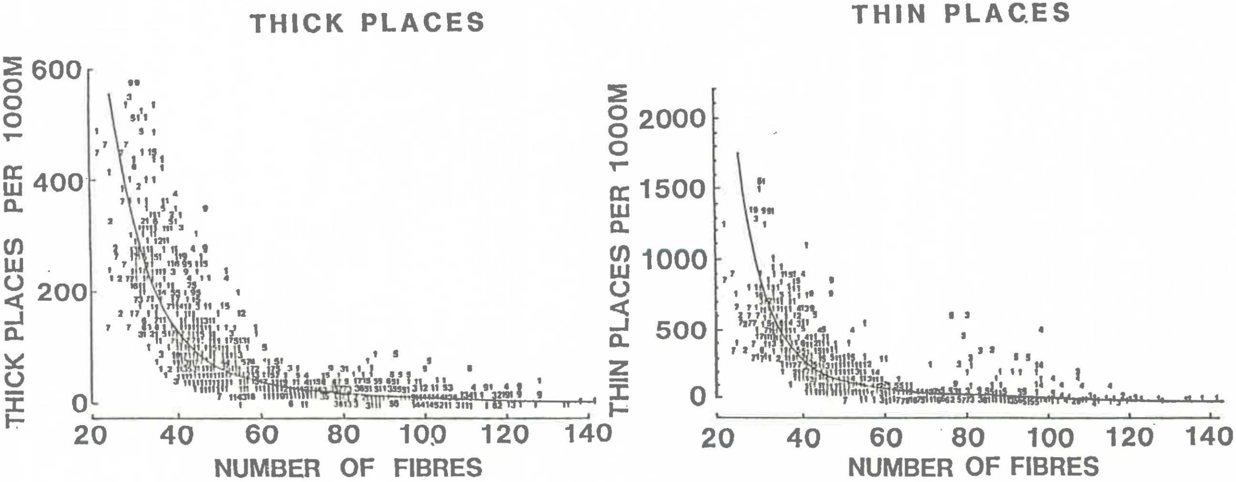


Fig. 48 Thick and thin places vs average number of fibres in yarn cross-section (Numbers represent different sheep breeds)(932)

lated with one another and therefore, strictly speaking, could not be regarded as independent variables describing different aspects of yarn irregularity[483].

Within the context of this study and within the general ranges of fibre properties covered, finer, longer and less highly crimped wools generally performed best. Where fibre crimp (or bulk resistance to compression) had a statistically significant effect, it was an adverse one[712 769 832 833 893 932], except for yarn hairiness which decreased with an increase in staple crimp (or bulk resistance to compression)[832], this being based upon the assumption that other fibre properties, such as diameter, remain constant.

An increase in CV of fibre length had a beneficial effect on certain yarn properties but an adverse effect on yarn extension and the frequency of neps and faults.

Gee[934] found that a positive skewness in diameter distribution was associated with more thin places but fewer neps in the yarns and that higher values for CV, skewness and kurtosis of fibre diameter tended to produce inferior yarns while higher values for the corresponding length properties generally gave better yarns.

Tables of "average" or "typical" values have also been derived for the yarn tensile and evenness characteristics[229 483 494] which can be used in quality control and research laboratories as a basis of reference.

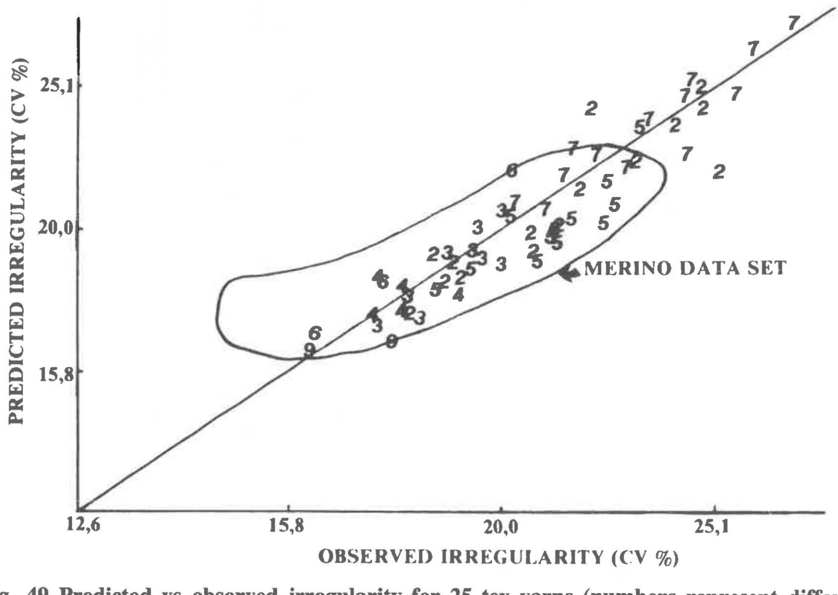


Fig. 49 Predicted vs observed irregularity for 25 tex yarns (numbers represent different breeds)(833)

11.2 EFFECT OF SHEEP BREED

Hunter *et al*[832 833 893 932] investigated the rôle of sheep breed in determining the relationship between wool fibre and yarn properties, using multiple regression and graphical techniques. They concluded[932] that the physical properties of a yarn were determined by the fibre properties (characteristics), such as diameter, length and crimp (or resistance to compression), including their distributions, and only in so far as breed affected these properties did it have an effect on the yarn properties (see, for example, Figs 48 to 50).

In other words, the yarn properties were determined by the fibre properties, with breed *per se* playing little, if any, additional rôle.

11.3 EFFECT OF BLENDING DIFFERENT RAW WOOL LOTS

Hunter and co-workers[533 551 584 594 630 695 772 832 833 893] carried out a series of studies to establish and quantify the effects on yarn properties of blending wools (farmer lots) which differed in their basic fibre characteristics, such as diameter and length as well as the blending of fleece and non-fleece wools. One of the main aims was to establish whether or not the behaviour (performance) of a blend (mixture) of wool in yarn form could be predicted from the behaviour of its components. The results of the various individual studies have been summarised[772].

On the basis of the above studies it was concluded that the blending of wool lots with limited differences in diameter and length resulted in yarns with physical properties which were close to those predicted from the behaviour of the yarns produced from the component lots. Where blending involved wools differing greatly in their mean fibre diameter (e.g. 3 μm or more), resulting in an increase in the CV of diameter, an adverse effect on certain yarn properties could occur particulary when spinning fine yarns. It was found that, within limits, the blending of wools differing in fibre length could have a beneficial effect on certain yarn properties but an adverse effect on other yarn properties, such as extension and neps. Changes in the *mean* fibre diameter and *mean* fibre length of the blend (mixture) were however, always reflected in the yarn properties as already discussed (see Fig. 51 for example).

11.4 RELATIONSHIP BETWEEN FIBRE LENGTH IN THE TOP AND THAT IN THE YARN

Hunter *et al*[796] processed some 50 wool tops, covering a range of fibre diameter, length and crimp, into yarn on the Continental system followed by ring spinning. The mean fibre lengths in the tops and the yarns were compared and it was found that the mean fibre length in the yarn was lower than that in the top, the difference being a function of fibre length and crimp. The longer wools suffered a greater deterioration in fibre length than the shorter wools, with fibre diameter appearing to play no rôle.

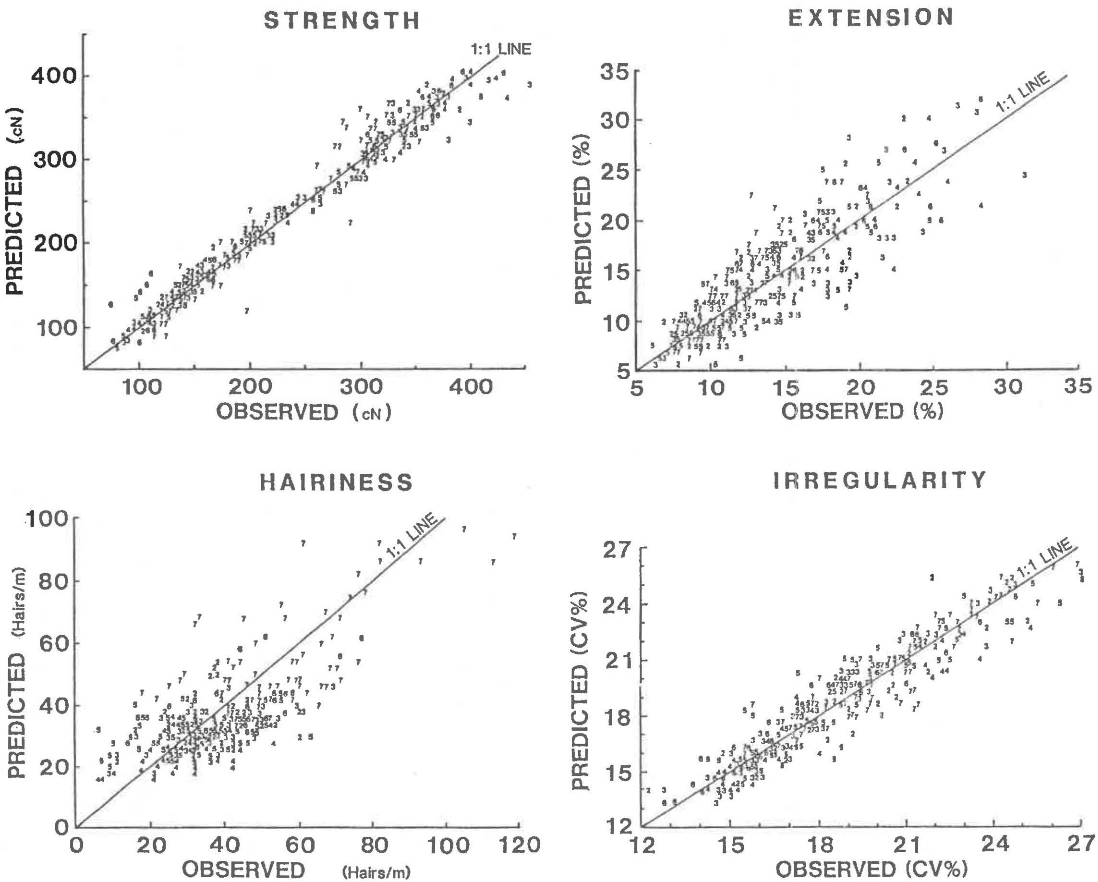


Fig. 50 Predicted vs observed yarn results (different numbers represent different sheep breeds)[932]

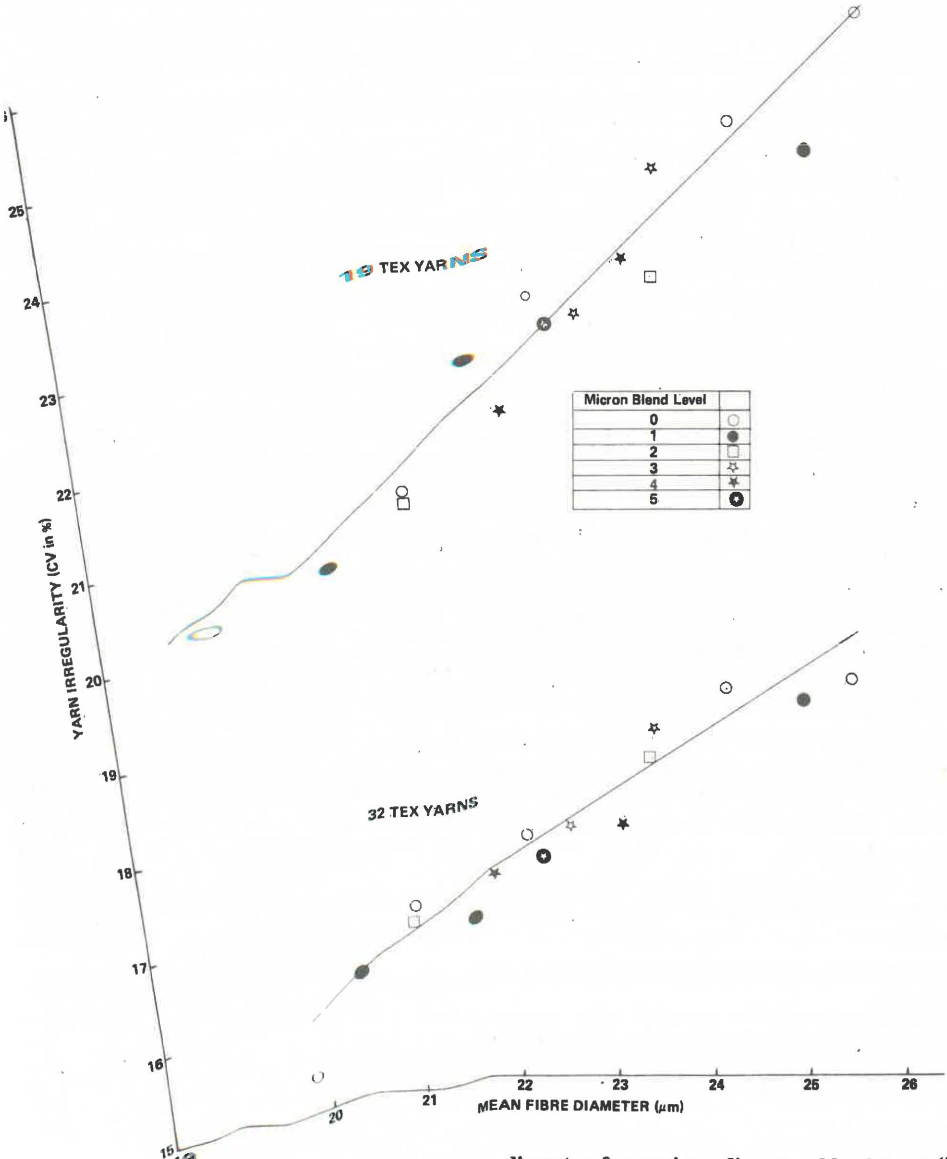


Fig. 51 Yarn irregularity vs fibre diameter for various diameter blend levels(584)

11.5 YARN HAIRINESS* AND DIAMETER

Hunter[627] measured the hairiness of a wide range of dyed a commercial wool worsted yarns and related it to certain fibre and ya ties. The data was used to draw up average or reference values for the of wool worsted yarns for use in quality control laboratories. The va fered according to whether the yarn was measured from a spinning tub (i.e. after rewinding) and whether it was dyed or undyed. Rewind increasing fibre diameter and yarn linear density increased hairiness. showed that, after rewinding, the hairiness of wool and wool/polyeste depended both on the winding speed and type of winding machine us also investigated[746] the effect of blend level on the hairiness of two-ply wo lyester and wool/acrylic yarns and showed that the wool yarn was the hairy, hairiness increasing with increasing synthetic content.

Barella, Hunter and co-workers[831 841 848 855 860 873 874 875 878 879 888 894 895 901 91 953 954 955 959] carried out a number of studies on wool and mohair yarns with a to establishing empirical relationships (using multiple regression analysis) tween yarn diameter and hairiness on the one hand and yarn linear density (twist and the fibre properties (diameter and length) on the other hand. T and used the "Digital ITQT" hairiness meter developed at the Institute for Tex Technology in Spain to measure yarn diameter as well as various hairin parameters as well as to the Shirley Hairiness Meter to measure yarn hairine at the standard distance of 3mm from the yarn axis and reported on the correl tion between the two instruments[873 901 914]. They showed that, in general, yar diameter[831 878 895 955] increased with an increase in yarn linear density and decrease in yarn twist while yarn hairiness increased with an increase in yarn linear density and fibre diameter and a decrease in yarn twist, fibre length an crimp (or resistance to compression)[848 855 860 874 875 879 888 901 953]. The diameter of two-ply worsted yarn was found to be about 1,35 times that of its singl component, this value being close to the theoretical value of 1,5[895]. The hairi ness of singles polyester yarn tended to be higher than that of the correspondin wool yarn. Some of the trends differed from those observed with a Shirle Hairiness Meter.

The variance length curves (unevenness) for yarn hairiness were deter mined by means of the ITQT Digital hairiness meter[913 914 954] and also for yar diameter[926 959].

It should be noted that yarn hairiness is also referred to in other sections o this chapter.

11.6 YARN STIFFNESS AND COMPRESSIBILITY

Hunter and Slinger[166] investigated different ways of measuring yarn flex

* See also 11.1

ural rigidity and resistance to compression and adapted the ring- loop method, proposed by other workers, for measuring yarn stiffness. They showed that yarn resistance to compression was highly correlated with yarn stiffness as measured by the more time-consuming and tedious ring-loop method. Singles and two ply yarns followed the same functional relationship between yarn linear density and flexural rigidity, with dyeing increasing yarn flexural rigidity. Yarn flexural rigidity appeared to have only a slight effect on knittability. This work was presented as an M.Sc. thesis[245] by Hunter.

Hunter *et al*[369] showed yarn flexural rigidity to be approximately linearly related to yarn linear density indicating considerable freedom of fibre movement, flexural ridigity also increasing approximately linearly with mean fibre diameter. An increase in yarn twist also increased flexural rigidity.

Van Rensburg *et al*[854] found that fibre diameter had an overwhelming effect on yarn flexural rigidity, accounting for more than 90% of its observed variation. At the same mean fibre diameter, the flexural rigidities of the wool and mohair yarns were similar. Yarns with a higher twist were marginally

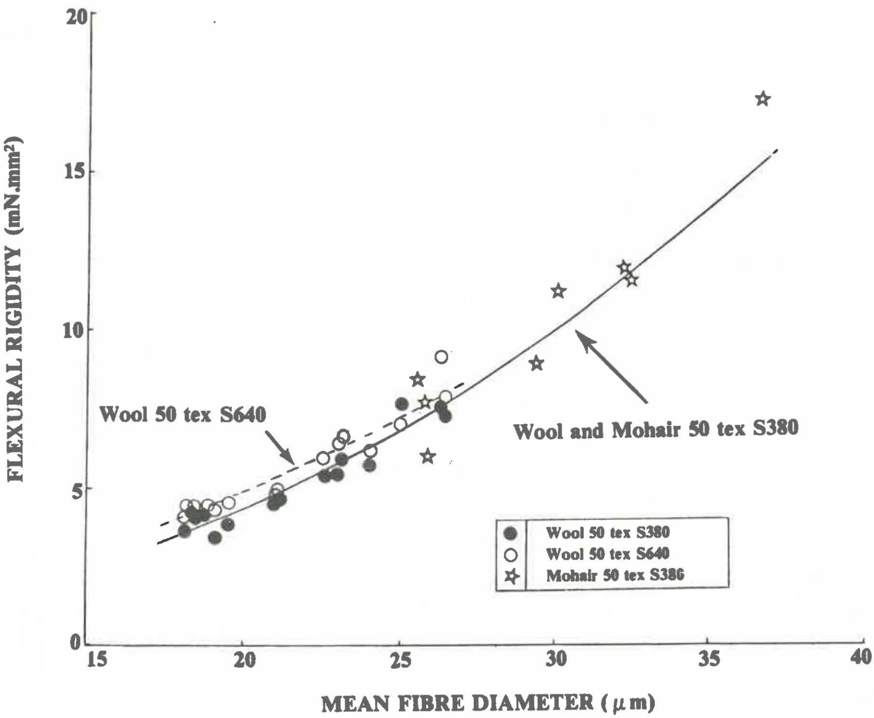


Fig. 52 The relationship between yarn flexural rigidity (G) and fibre diameter for wool and mohair(854)

stiffer than yarns with a lower twist (Fig. 52).

A close relationship was found between yarn stiffness and the stiffness of 1 x 1 rib fabrics.

11.7 YARN FRICTION*

Recognising the critical importance of yarn friction in determining stitch length (i.e. fabric dimensions) and yarn breakages in knitting, Baker and Kruger[129] developed a method for evaluating yarn frictional forces during the actual knitting process. The apparatus, which worked on a strain-gauge principle, was mounted on a V-bed (flat-bed) knitting machine and found to provide a measure of yarn frictional force, this measure being defined as the "inverse of knittability" (I.K.).

Slinger and Veldsman[124] investigated the effect of different dyeing techniques on yarn friction and found that equalising acid and acid milling dyeings did not alter the friction appreciably while the latter increased with increasing premetallised dye concentrations. High friction was recorded for after-chrome dyeings, which increased as the percentage dichromate added, increased. The efficacy of different softening agents and of waxing in reducing the friction was also investigated. The handle of the knitted cloth was found to be dependent to some extent on the yarn friction. The ease with which the yarn could be knitted (knittability) was closely related to yarn friction.

Kruger[299] investigated yarn-to-metal and yarn-to-yarn friction, measured on the SAWTRI Yarn Friction Tester, and showed that yarn-to-metal friction was independent of yarn linear density, only the twist method of measuring yarn-to-yarn friction being influenced by yarn linear density. The shrinkproofing treatments studied did not affect yarn friction, particularly when the yarns were subsequently waxed.

Hunter[243] showed that the friction of yarns differing in linear density was related to the amount of wax per unit length of yarn μg/cm) rather than the percentage of wax based upon mass. He studied[253] the waxing of wool yarns and the friction of yarns waxed with waxes having different melting points and showed that room temperature affected the amount of wax applied but not the friction when the amount of wax applied was constant. Yarn friction was largely independent of the yarn linear density and the original yarn friction when the yarns were waxed under optimum conditions.

Kruger[314] discussed various aspects relating to yarn friction including the measurement thereof, with particular reference to the SAWTRI Yarn Friction Tester.

Galuszynski[899] described a new method, allowing the yarn assembly in a woven fabric to be simulated, for measuring yarn-to-yarn frictional force. The yarn-to-yarn frictional force was examined in terms of yarn tension, contact

* See also Chapter 12.

angle, speed, crimp and linear density. It was found that it increased with tension, contact angle, crimp and linear density, whereas the yarn speed had a fluctuating effect. McMahon[996] showed that yarn frictional forces decreased with increasing guide diameter.

Hunter and Turpie[744] carried out some trials involving the application of a lubricant during backwashing which was claimed to obviate the need for waxing hosiery yarns. The trials involved an assessment of spinning performance, yarn properties, and knitting performance. The work confirmed that the lubricant obviated the need for waxing hosiery yarns produced from dyed tops, and no deterioration in spinning performance was observed.

11.8 YARN WEAK PLACES

Slinger[61] applied two of the statistical distributions used in evaluating the rupture of materials to the breakage of a worsted yarn. The one, the Weibull distribution or third asymptotic distribution, was found to fit the observations better. From this it was concluded that a power function held between the average breaking strength and the length of yarn tested. The assumption of independence, on which the above distributions were based, was tested.

Van Rooyen *et al*[391] investigated the occurrence of isolated weak places (Shirley Constant Tension Winding Test) in commercial wool worsted yarns and found it to be related to the average yarn strength, yarn irregularity and twist, but independent of the skewness and kurtosis of the strength distribution. In a very limited trial, where pairs of yarns of constant average strength, but with different levels of isolated weak places, were knitted, no difference in knittability due to differences in Shirley Test results could be detected.

Hunter[261 444] investigated the question as to whether a yarn always broke at its thinnest place or whether the twist that runs into such places increased their strength so that they no longer represent the weakest place in the yarn. He concluded that the linear density (i.e. thin places) played the major rôle in determining yarn strength, twist redistribution playing a secondary rôle. About 80% of the observed breaks occurred at either the thinnest or second thinnest place.

Other sections deal with the rôle of isolated weak places in subsequent knitting and weaving as well as the rapid measurement of such isolated weak places[798 942 971 972 998].

11.9 YARN FAULTS AND CLEARING

Hunter and Veldsman[138] investigated a simplified method for evaluating the efficiency of electronic and other yarn clearers using an Elkometer for detecting uncleared faults. The Elkometer setting required for different yarn linear densities was determined.

Hunter[463] also reported fault analysis results obtained on the Classimat on some 400 kg of different yarns, paying special attention to the variability in the results within a yarn lot. Confidence limits were calculated and found to be larger than those predicted by a Poisson distribution, except for very low counter (objectionable faults) results. The importance of controlled regain was demonstrated. He gave the following table of confidence limits for different counter results.

TABLE IV

PREDICTED 95% CONFIDENCE LIMITS FOR CLASSIMAT COUNTER RESULTS[463]

Actual Result (x)	Confidence Limits Predicted from experimental data (= ± 2 S.D.)*	Confidence Limits suggested by Uster (= ± 3 $\sqrt{x}$)
1	$1 {}^{+2}_{-1}$	$1 {}^{+3}_{-1}$
2	$2 {}^{+3}_{-2}$	$2 {}^{+4}_{-2}$
5	5 ± 5	$5 {}^{+7}_{-5}$
10	10 ± 7	10 ± 9
20	20 ± 12	20 ± 13
50	50 ± 23	50 ± 21
100	100 ± 41	100 ± 30
150	150 ± 58	150 ± 37
200	200 ± 74	200 ± 42
300	300 ± 108	300 ± 52
500	500 ± 176	500 ± 67
1000	1000 ± 353	1000 ± 95

*S.D. = Standard Deviation

11.10 KNOTS IN SINGLES AND TWO-PLY YARNS*

Hunter and Gee[549] measured the frequency distribution of knots in some commercial singles and two-ply worsted yarns and found them to satisfy a Poisson distribution in the majority of cases. Confidence limits were calculated for the number of knots measured over a certain length of yarn. An average of 70 knots per 100 km was found for the singles yarns tested and 60 per 100 km for the two-ply yarns. McMahon[961, 984] investigated the effect of different yarn joins (Fisherman's knot, weaver's knot, air splice) on the tension of a running

* See also 11.14

yarn in capstan-like conditions in terms of guide diameter and yarn linear density for all-wool worsted yarn. The results showed that the Fisherman's knot caused a greater increase in yarn tension than the weaver's knot. The spliced join produced the lowest increase in yarn tension.

11.11 YARN TWIST

Wolfaardt[198] studied the changes which occurred in the twist of a worsted yarn during different winding processes from cop (spinning tube) to either weft or warp in the fabric. Generally Z-twist yarns gained a small amount of twist.

Hunter[222] compared manual and automatic twist test results and emphasised the operator errors inherent in the former and the greater reproducibility of the latter. He also studied[461] the effect of prior wetting of wool worsted yarns, on the twist values obtained on an automatic twist tester, and found the results obtained on the wet yarns to correspond closely to those obtained on the dry yarns using standard test methods. The agreement between the automatic twist test results and the nominal values was excellent, the correlation between the manual twist test results and the nominal and automatic test values being slightly lower, due mainly to a larger error factor in the manual values.

Hunter[372] studied the twist of a large number of commercial wool worsted hosiery yarns destined for machine knitting and found that twist variability was related to Uster yarn irregularity although the relationship was not a very strong one. He also derived empirical relationships between yarn twist and linear density e.g.

$$\text{Twist (turns/m)} = 3074 \times \text{tex}^{-0,56}$$

The average twist factor of the yarns was about 25 (turns/cm $\sqrt{\text{tex}}$).

11.12 EFFECT OF TWIST ON FRESCO YARN PROPERTIES

Hunter and Andrews[550] investigated the effect of twist on the tensile properties of cabled (Fresco) wool and wool/polyester yarns and arrived at the twist combinations which maximised yarn strength and extension. The effect of singles twist on yarn tenacity was slight while relatively low levels of both plying and cabling twist produced maximum yarn tenacity. Yarn extension on the other hand, benefitted by an increase in both plying and cabling twist, with the effect of singles twist again being small. Equations were derived which enabled the spinner to predict the resultant linear density of the cabled yarn from the single yarn linear density and the plying and cabling twist.

11.13 EFFECT OF TWIST ON THREE-PLY YARN PROPERTIES

Van Aardt and Hunter[978] investigated the influence of singles and plying twist on the tensile properties of three-ply yarns and derived levels and combinations of singles and three-ply twist for optimum tensile properties (Figs 53 and 54). A means of predicting the resultant linear density from the single yarn

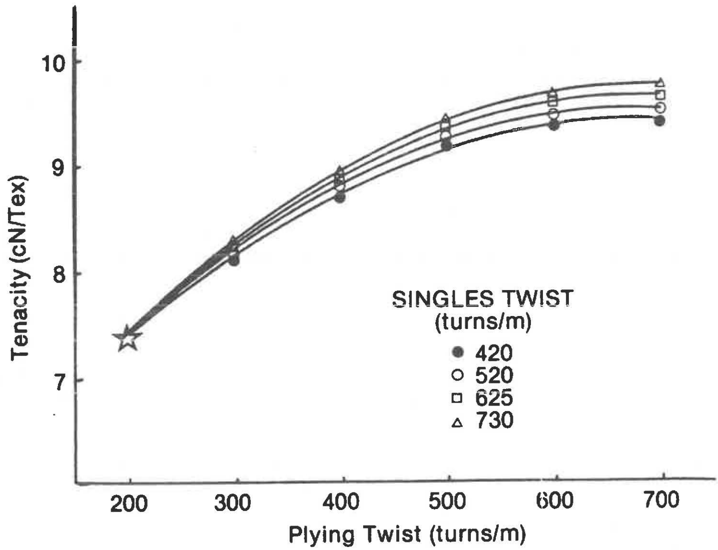


Fig. 53 Regression curves showing the effects of Singles and Plying Twist on Yarn Tenacity(978)

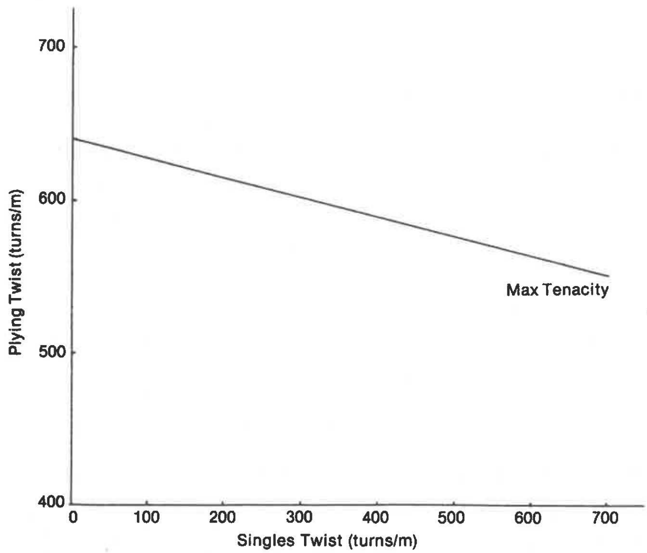


Fig. 54 The Relationship between Singles and Plying Twist required to produce a Three-Ply Yarn with maximum tenacity(978)

linear density and plying twist (i.e. correcting for yarn contraction) was derived. Generally tenacity increased with increasing plying twist and increasing singles twist, until a maximum was reached after which it decreased. Extension increased with increasing plying twist but was only slightly influenced by singles twist. Irregularity and imperfections were not influenced by twist. Hairiness decreased slightly with increasing singles twist. Plying twist had a far more important effect on the yarn tensile properties than singles twist, it being preferable to use a relatively low singles twist together with a relatively high plying twist. This could, however, lead to problems with twist liveliness.

11.14 TWO-PLY YARN PROPERTIES

Hunter[276] gave some limited information on the irregularity and tensile properties of two-ply and singles yarns, also relating the breaking strength of the two-ply yarns to that of the constituent singles yarns. Subsequently Hunter and Gee[991] presented more detailed information on the properties of a large number (over 400) of commercial wool and wool/polyester two-ply yarns (including Repco and Sirospun). Graphs and tables of average or typical values were presented for the various yarn properties which can be used for quality control and reference purposes (Table V).

Cilliers[304] investigated the influence of the level and direction of plying twist on the breaking strength and extension at break of two-ply worsted yarns

TABLE V

AVERAGE VALUES FOR WOOL YARNS[991]

Property	RING			REPCO			SIRO		
	No. of Yarns	Mean	CV (%)	No. of Yarns	Mean	CV (%)	No. of Yarns	Mean	CV (%)
Linear Density (tex)	322	57	25	7	48	2	41	41	27
Friction(cN)	45	38	20	7	34	17	21	34	15
Thin Places per 1000m*	322	4	196	7	26	76	35	19	69
Thick Places per 1000m*	322	7	123	7	32	85	35	24	55
Neps per 1000m*	321	9	94	7	5	34	41	15	82
Knots per 100 000m (singles and two-ply)	46	147***	56	7	67	76	21	95	76
Shirley Breaks per 1000m*	46	5,6	215	7	13,8	95	21	22,7	77
Total Classimat Faults per 100km	12	263	45	0	—	—	4	260	43
Objectionable Classimat Faults per 100km	35	9	129	2	12	71	19	60	49
Fibre Diameter (μm)	306	22	5	7	22	1	21	22	7
Fibre Length (mm)	182	60	15	7	68	8	21	67	6
Calculated Tenacity of Weakest Place (cN/tex)	46	5,3	13	7	4,9	7	33	4,6	23
Actual Tenacity of Weakest Place (cN/tex)	46	4,8	20	7	4,1	13	33	4,1	31
Dynamat Extension (%) undyed	183	21,0	23	—	—	—	35	19,7	27
Dynamat Extension (%) dyed	139	14,6	35	7	20,0	13	6	17,1	9
Dynamat Tenacity (cN/tex) undyed	183	7,4	9	—	—	—	35	7,5	10
Dynamat Tenacity (cN/tex) dyed	139	6,7	13	7	7,3	5	6	7,3	4
Tensorapid Tenacity (cN/tex) undyed	9	8,2	4	—	—	—	27	7,6	11
Tensorapid Tenacity (cN/tex) dyed	37	7,6	8	7	7,5	5	6	7,5	2
Tensorapid Extension(%) undyed	9	18,2	13	—	—	—	27	15,5	33
Tensorapid Extension(%) dyed	37	14,9	28	7	16,3	17	6	13,2	17
Hairiness (Hairs/m) undyed	13	36	25	—	—	—	29	15	21
Hairiness (Hairs/m) dyed	37	36	25	7	37	15	6	25	7
Singles Twist/Plying Twist**	54	0,88	17	—	—	—	—	—	—

*Dependent upon yarn linear density
**Ratio
***Considered to be high

and found a positive relationship between yarn strength and elongation at break. It was found that twist-on-twist yarns were stronger than the conventional reverse-twist yarns. The optimum twist of twist-on-twist yarns was lower than the optimum twist of twist-against-twist yarns. A table was drawn up to show the expected decrease in yarn strength if the plying twist was decreased below the optimum values.

Hunter[364] compiled average values for the CV of plying twist of two-ply commercial hosiery yarns for tests carried out at different gauge lengths and arrived at average values of 9,3, 9,0 and 5,8% for gauge lengths of 25, 50 and 100cm, respectively. For 2,5cm it was of the order of 21%.

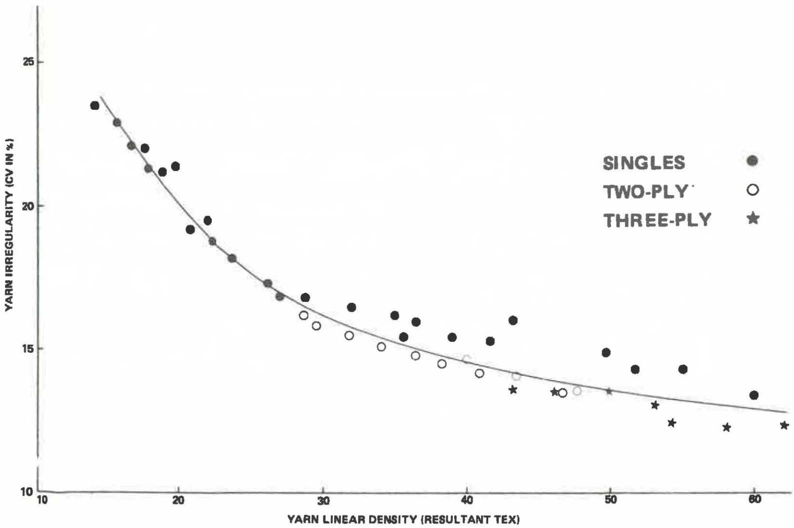
Hunter[517] investigated the relationship between the yarn evenness characteristics of two-ply and single yarns and prepared a table of "average" or "expected" irregularity values for two-ply yarns of different linear densities and spun from fibres varying in mean fibre diameter. The table showed good agreement with values derived by means of a regression equation from a similar table for single wool worsted yarns. In the case of the commercial two-ply yarns, fibre diameter and yarn linear density had the greatest effect on yarn evenness. Equations were obtained by means of which the irregularity (CV in %) and the frequencies of thin places, thick places and neps of two-ply yarns could be predicted with a fair degree of accuracy from those of the single yarns. The effect of yarn linear density on irregularity and the frequency of thin places is illustrated below for singles and ply yarns (Fig. 55).

11.15 CORRELATION BETWEEN DIFFERENT YARN TENSILE TESTER RESULTS

Hunter and Veldsman[136] investigated the correlations and empirical relationships between worsted yarn tensile properties as measured on constant rate of loading (Uster Dynamat), constant rate of extension (Instron) and constant rate of traverse (Goodbrand pendulum) single thread testers. They also determined the correlation between yarn irregularity and CV of yarn strength and the relationship between yarn breaking strength and yarn linear density at a constant twist factor. The breaking strength and extension values obtained on the three different types of instruments were highly correlated and the CV of strength measured on the Uster Dynamat (CRL) was best correlated with yarn irregularity.

11.16 EFFECT OF DIFFERENT CARDING LUBRICANTS

Hunter and Grobler[448] investigated the effect of various lubricants (applied prior to carding) on yarn properties and found that, within the range covered, the different lubricants and levels of application had only a slight effect on yarn properties. In practice therefore, the choice of lubricant and level of application should be governed by factors other than yarn properties. Differences in the



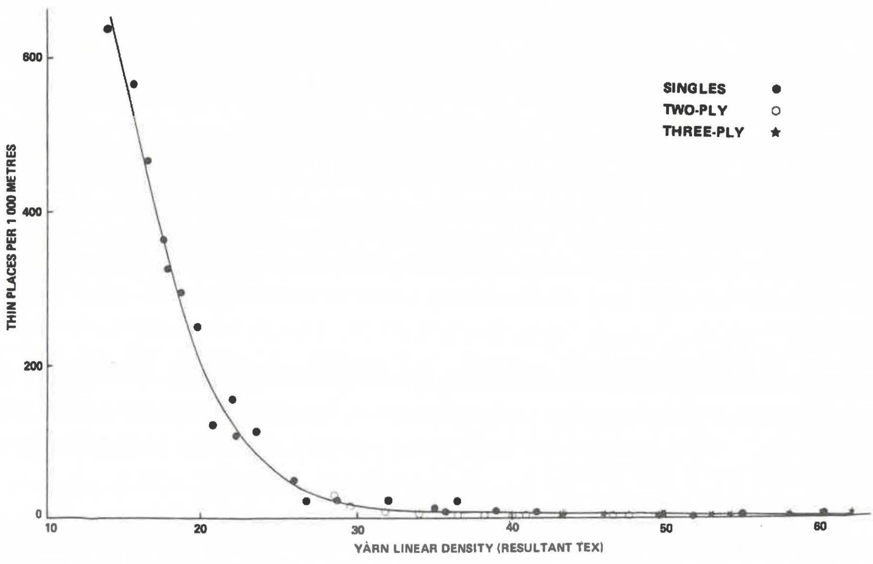


Fig. 55 Effect of yarn linear density on the irregularity and frequency of thin places for singles and ply yarns(517)

dichloromethane extractable matter content, within the narrow range covered (effectively 0,4 - 0,8%), also had no significant effect on the various yarn properties investigated. Nevertheless, extraction of the yarns with benzene methanol effected a slight but significant increase in both yarn strength and extension.

11.17 EFFECT OF CERTAIN YARN DYEING AND FINISHING TREATMENTS

Hunter *et al*[325] studied the effect of afterchrome black dyeing, shrinkproofing, softening and steam- and sodium-bisulphite setting on yarn for flexural rigidity, friction tensile properties, linear density etc. of wool worsted yarns. They found that the DCCA and to a lesser extent the R Dylan treatment increased the strength and extension of dyed yarn but decreased that of the undyed yarn. An increase in both the intrinsic fibre strength as well as the interfibre cohesion accounted for this observation. The resin treatment increased the inter-fibre cohesion and consequently the yarn breaking strength. Addition of a softening agent decreased the yarn breaking strength by decreasing the inter-fibre friction. The softening agent appeared to affect the dyed yarn more than the undyed yarn. None of the treatments affected the yarn flexural rigidity significantly, although an interaction appeared to exist between the softening agent and doubling. Sodium-bisulphite setting decreased the intrinsic fibre strength and consequently the yarn breaking strength. Blank bath treatment at a pH near the iso-electric point of wool caused the least change in the tensile properties of the yarns. To explain the results a quantity called the cohesiveness of the fibres within the yarn was defined.

Hunter[277] did a limited study on the dyeing and shrink-resist treatment of wool yarns and found that after-chrome dyeing or chroming alone, always decreased yarn (and fibre) strength while treating them with DCCA increased the yarn (and fibre) strength, substantially. The chroming rather than the dyeing stage appeared to be responsible for the decrease in strength. Dyeing followed by DCCA treatment was preferable to the reverse in terms of yarn tensile properties.

11.18 CONFIDENCE LIMITS IN IRREGULARITY TESTING

Hunter[262] arrived at some confidence limits for irregularity test results and pointed out[224] some faults which could occur during irregularity testing if proper precautions were not taken.

11.19 VARIANCE-LENGTH CURVES FOR YARN IRREGULARITY

Grosberg and Palmer[3,4,5,10,11] carried out analytical studies of the underlying principles of the variance-length curve of a yarn, the theory of the Uster Irregularity tester and integrator for finding the variance-length curve, as well as experimental methods for determining the variance-length curve as quickly and accurately as possible. They gave some examples of variance-length curves and their use in practice. Their relatively quick method of determining the variance-length curve agreed well with the Uster instrument method. Grosberg [14] also derived an equation whereby it was possible to calculate the variance-length curve of a yarn, knowing the variance of the slivers and he discussed the detection of faulty processes in worsted drawing by means of the variance-length curve of yarn irregularity (in terms of Huberty's K).

Grosberg and Palmer[7] discussed the requirements of a theory of drafting and attempted a more limited theory based upon a previous model. Three successively more complicated methods were set up and compared with experimental results.

De Beer[68] studied the practical validity of Grosberg's[6] theoretical relationship as modified and simplified by Giesekus. He also described a method[104] whereby the linear density of wool worsted strands, could be determined by using an Uster evenness tester. The method seemed to provide results with an accuracy within the limits normally demanded by industry.

Hunter[515] used the irregularity (CV) corresponding to different "test lengths" (by means of the "Inert" test on the Uster) of a wide range of commercial single wool worsted hosiery yarns to obtain different points on the variance-length curve. Most of the values were found to be correlated with normal yarn irregularity but not with mean fibre diameter and length. Long-term variation in yarn linear density (over 100 metre lengths) was found to be independent of the short-term yarn irregularity but was dependent upon the average yarn linear density. Tables were prepared of "average" values for the yarn irregularity corresponding to different "test lengths".

CHAPTER 12

KNITTING

12.1 USE OF POSITIVE FEED AND STORAGE FEED

Knapton[303] discussed the various types of positive feed units and their principles and advantages in knitting by controlling yarn tension, loop length and fabric dimensions. He recommended[340] that the yarn input tension to the knitting zone should be about 0,1 cN/tex and listed some recommended "median" run-in-ratios for various structures, as well as the yarn linear densities best suited for double-jersey machines of various gauges.

Robinson and Green[579] investigated the use of two types of storage feed units (revolving drum and stationary drum) on a fully-fashioned machine. Occasionally the revolving drum type created a difference in the mean twist value of the yarn between cone and fabric. This difference became critical when the knitting machine stopped and the storage feed unit commenced, or continued to wind on. Faults appeared in the fabric in the form of horizontal lines of distorted loops created by the torque present in the yarn.

12.2 YARN INPUT TENSION

Cawood *et al*[734] determined the effects of the yarn tension before and after five different positive feed mechanisms during knitting (interlock) on stitch length and the strength, extension and hairiness of the yarns. They found that the input tension to the positive feed had a slight effect on stitch length. The unravelled yarns which had been waxed were found to have slightly higher breaking strength and extensions at break but were more hairy than the unwaxed yarns. Certain positive feed mechanisms or yarn storage units decreased yarn hairiness. The knitting and unravelling actions generally decreased yarn strength and extension and increased hairiness. Cawood *et al*[583] found that, within limits, the input tension between the positive feed and the knitting zone did not affect yarn breakages while an input tension to the positive feed of about 1 cN gave the best knitting performance.

12.3 EFFECT OF TAKE-DOWN TENSION

Robinson *et al*[784] studied the influence of take-down tension and stretcher board width on knitting performance and fabric dimensional properties. Fabric take-down tension had a significant effect on the knitting performance, the effect being dependent on either fabric tightness or yarn linear density or both (Fig. 56). An increase in stretcher board width did not influence the knitting performance. The effect of take-down tension on fabric properties was less evident after wet relaxation but still present in the wales/cm and fabric thickness.

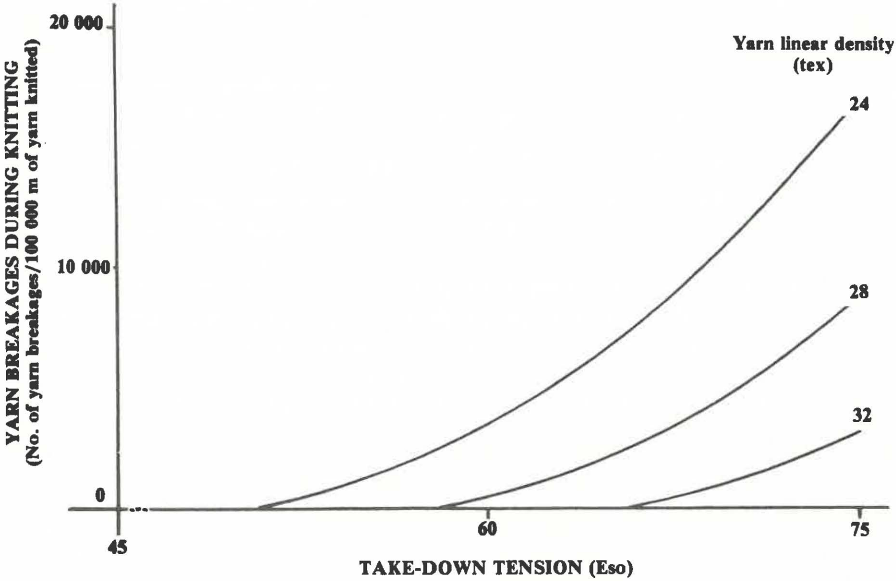


Fig. 56 The effect of take-down tension and yarn linear density on yarn breakages during knitting at constant MTF = 16.(784)

Hunter *et al*[747], Dobson *et al*[748] and Robinson *et al*[809] fitted devices (mechanical and compressed air) at individual feeders of an 18 gauge double-jersey machine, which enabled knitting to be carried out without take-down tension. These devices reduced the number of yarn breakages during the knitting of relatively tight fabrics and also reduced lengthwise fabric shrinkage but tended to increase widthwise shrinkage. The adverse effect of high fabric take-down tensions on the knitting performance of relatively tight fabrics and on fabric length distortion during knitting, and therefore potential length shrinkage, was confirmed.

12.4 FLY GENERATION DURING KNITTING

Kerley and Stocker[163] found that yarn input tension was important in the generation of fly during knitting, overdyeing with afterchrome dyes giving a significant increase in fly waste. Premetallised and afterchrome dyes appeared to lead to much greater fly production during knitting, with dyeing below the boil reducing fly generation in the case of afterchrome dyes but not in the case of acid milling and premetallised dyestuffs. No effect of machine speed, lubricants or softeners on fly was observed.

Stocker and Müller[223] found fly formation during knitting to be relatively high at high temperatures (33°C) and humidity (75% RH) conditions, and recommended 20°C and 65% RH for the knitting of waxed wool yarns.

12.5 EFFECT OF MACHINE SETTINGS

Buys and co-workers[435 465 505 507] investigated the influence of certain machine variables (e.g. dial height, run-in-ratio, timing and knitting sequence) as well as run-in-ratio on the knitting performance (yarn breaks) of interlock and Punto-di-Roma on three different double-jersey machines and found certain differences in the trends and behaviour of the different machines which they ascribed to differences in the cam systems and distribution of take-down tension amongst other things. The optimum dial height depended upon run-in-ratio and other factors, a run-in-ratio of 1:1 generally pproducing fewer holes than one of 1,5:1. Machine settings were suggested for improved knitting performance. They concluded that the effect of some machine settings had previously been underestimated and that large improvements in knitting performance could be obtained when the correct (optimum) machine settings were used. Some of the above work formed the basis of an M.Sc. thesis[486] by Buys.

12.6 EFFECT OF ATMOSPHERIC CONDITIONS

Hunter *et al*[578] investigated the effect of atmospheric conditions on the knitting performance of wool worsted yarns on an 18 gauge double jersey and a 28 gauge single jersey machine. The trend was for yarn breakages during knitting to decrease as the temperature increased, provided the relative humidity was constant (Fig. 57). Where relative humidity had an effect, the trend was for yarn breakages to decrease as relative humidity increased. High temperature and relative humidity therefore appeared preferable from the point of view of reducing yarn breakages. Atmospheric conditions generally had a greater effect on unwaxed than on waxed yarns (Fig. 57).

12.7 EFFECT OF DIFFERENT TYPES OF KNOTS

Hunter *et al*[801] compared the knitting performances of three different knots (dog, Fisherman's and weaver's) and found that the number of yarn breakages during knitting, attributable to knots, depended upon the fabric structure and, in the case of the Punto-di-Roma structure, also on the particular feeder at which the knot occurred. The different types of knots did not differ much in their performance during knitting, although, on average, the weaver's knot caused the least yarn breakages and the dog knot the most. None of the 750 knots knitted into the interlock structure caused holes whereas for the Punto-di-Roma structure more than 5% of the knots resulted in holes, knots being responsible for about 50% of the total number of holes. The corresponding figure for the plain single jersey structure was approximately 6% while for the interlock and satin stitch structures it was zero. Other yarn breakages were largely due to thin places, the total number of breakages being reduced by waxing and decreasing fabric tightness.

12.8 EFFECT OF YARN PROPERTIES AND LUBRICATION ON KNITTABILITY

Yarn flexural rigidity was found[166] to have a small effect on knittability. Hunter and Slinger[229] showed that knittability on a Lawson FAK was mainly affected by yarn-to-metal friction, knittability deteriorating with an increase in friction in spite of the fact that positive feed was employed.

Hunter[258], using a force-measuring instrument (strain-gauge) developed by Baker and Kruger[129] fitted to a V-bed machine, showed that the forces required to knit soft twist yarns were similar to those required to knit high twist yarns indicating that changes in yarn flexural rigidity due to changes in yarn twist had little effect on knitting forces. Knitting forces were related to yarn friction (Fig. 58) first decreasing with increasing wax level on the yarns after which they remained more or less constant. Stitch (course) length was dependent upon the yarn friction, input tension and cam setting, but was independent of yarn linear density. Optimum yarn friction was obtained at about 0,8 μg/cm, and was independent of the number of wax applications. When knitting force was plotted against cover factor a minimum was generally observed at a cover factor of about 1,2 (Fig. 58).

Knapton and Schwartzkopff[327] studied the structural knitting performance (SKP) of all-wool double-knit fabrics and found that when knitting at the optimum SKP, increasing the knitting machine speed did not adversely affect knitting performance and knitting efficiencies were at their best.

Hunter[335] investigated the factors affecting stitch length on a fully fashioned plain machine. He found that the average distance between the needle stems and the throats of approximately the first three fully forward sinkers, at the instant of loop measuring, critically affected the stitch length. An instrument was designed which could be used to measure the distance. The predicted stitch length agreed very well with the actual stitch provided the yarn input tension and fabric take-up tension were kept low. In a follow-up study[377] it was shown that stitch length and its variation were highly dependent upon input tension and yarn friction, with a wax level of about 0,55 μg/cm giving the best knitting conditions. Greater variation in stitch length occurred at the needles closest to the selvedges than at the more central needles.

Robinson *et al*[509, 972] developed ways of measuring knittability whereby stitch length was systematically decreased (i.e. fabric tightness or machine tightness factor increased) and the number of yarn breakages per 100km of yarn knitted, recorded. The MTF at which 100 yarn breaks per 100km of yarn knitted occurred was calculated and defined as the "knittability" of the yarn (Fig. 59).

Hunter *et al*[511, 596, 683] investigated the effect of yarn properties on the number of yarn breakages, when knitting different single and double jersey structures on circular machines of different gauges and equipped with positive feed. The relative importance of the various yarn properties in determining yarn break-

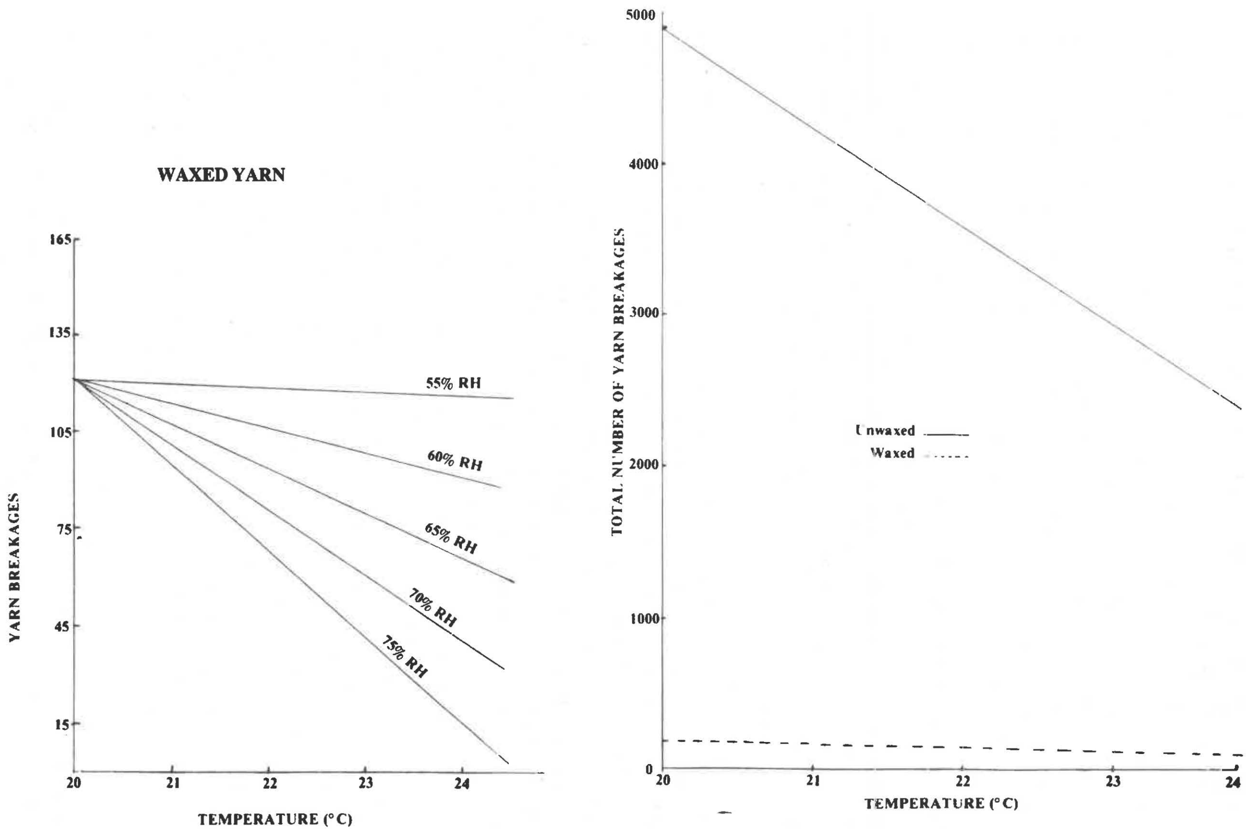


Fig. 57 Regression lines illustrating the effect of atmospheric conditions on the number of yarn breakages (Punto-di-Roma; 28 tex yarn).(578)

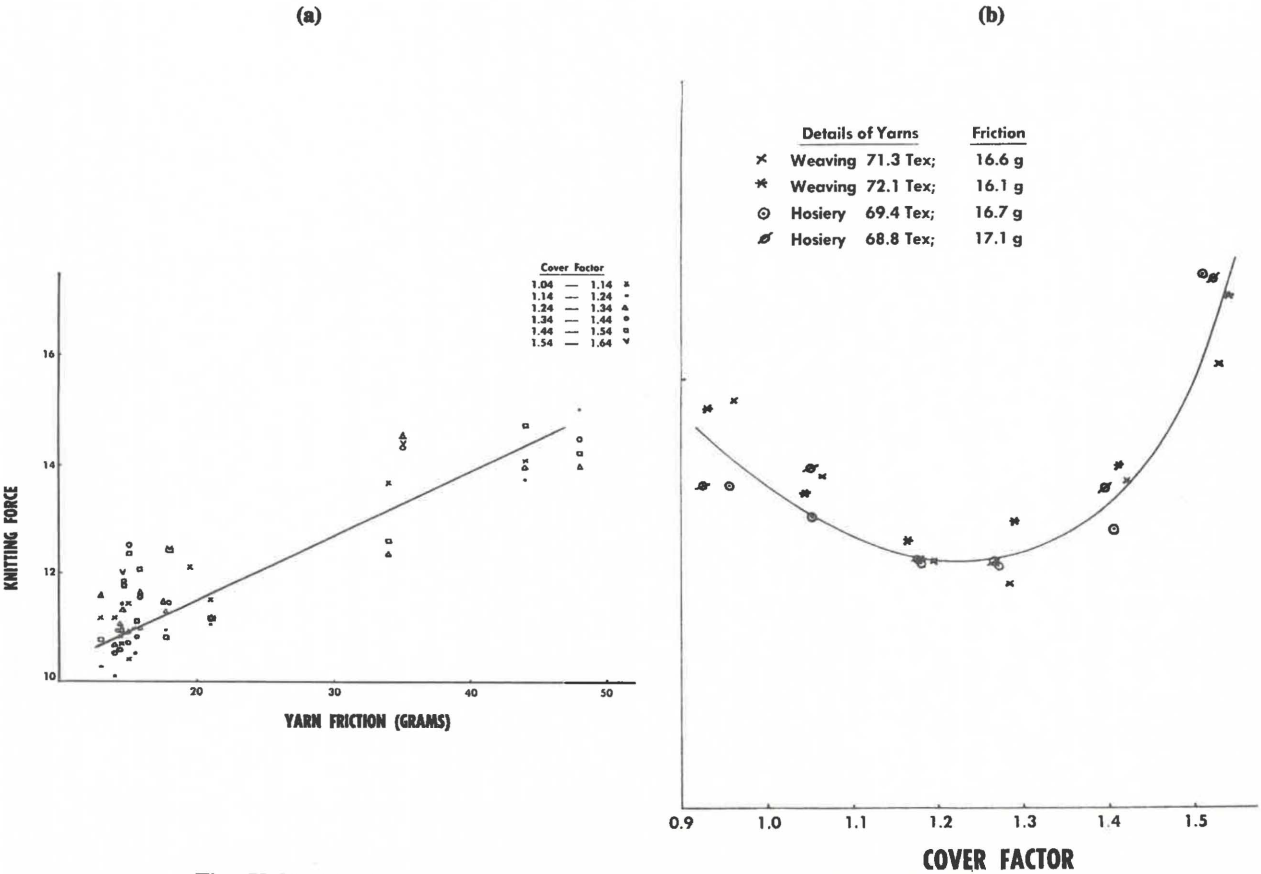


Fig. 58 Knitting Forces vs (a) yarn friction and (b) cover factor, respectively.(258)

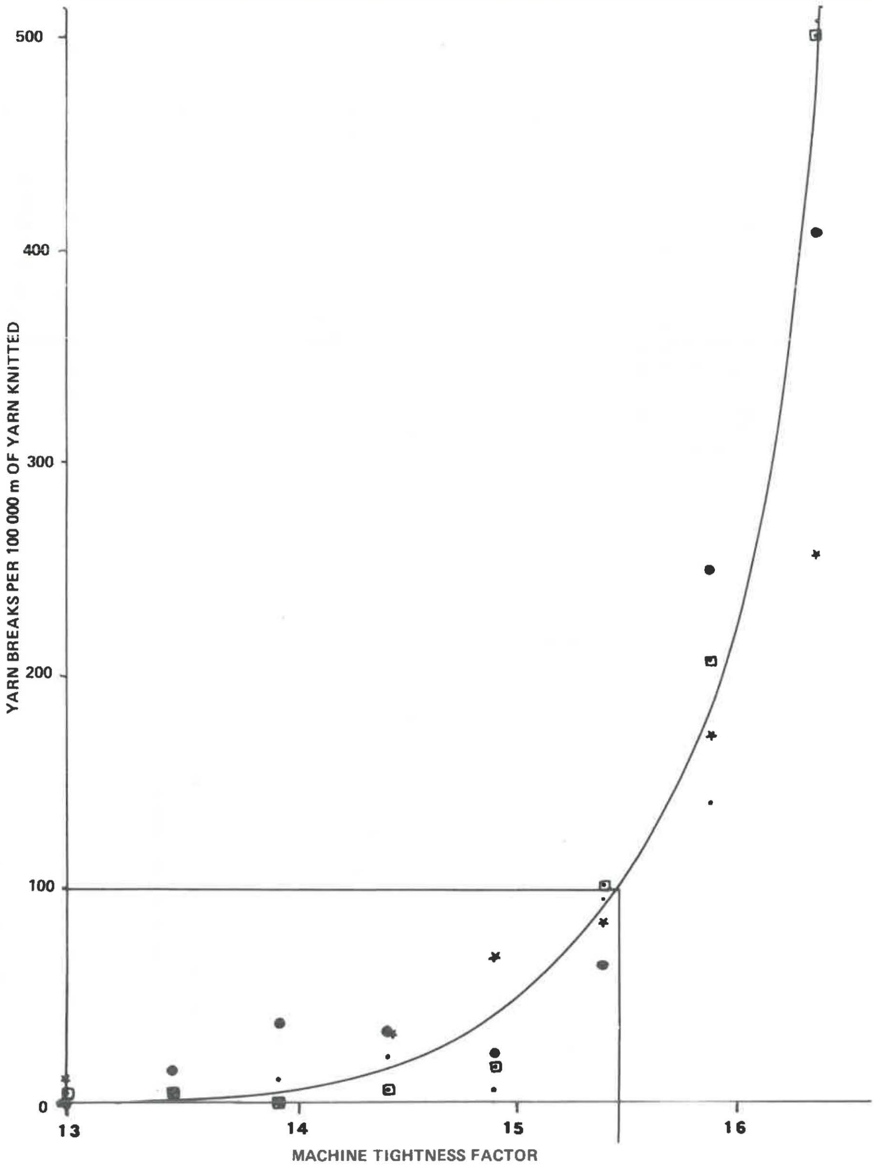


Fig. 59 Knittability Curve showing Relationship between Yarn Breaks per 100 000m of Yarn Knitted and Machine Tightness Factor.[509]

ages (holes) during knitting was found to depend upon the fabric structure and tightness. Hunter *et al*[596] found that yarn-to-metal friction, yarn linear density, yarn tensile properties and yarn irregularity all at some stage had an effect on yarn breakages during knitting, although their significance and relative importance depended upon the fabric structure. For example, yarn friction appeared to be less important for Lacoste and satin-stitch structures than for the plain structure[596]. A reduction in yarn friction, by an effective lubrication or waxing treatment, was generally the most effective way of improving knittability. It was concluded that waxing could be very beneficial provided it was carried out under minimum tension and with least damage particularly in the case of fine yarns. (Cawood *et al*[583] also found waxing more beneficial for coarse than for fine yarns). The trends obtained when MTF was kept constant were often different to those obtained when stitch length (SCSL) was kept constant[596, 683]. The most striking difference was that when MTF was kept constant, an increase in yarn linear density caused a *decrease* in the number of yarn breakages during knitting due to the fact that the stitch length was increased so as to keep MTF constant, Robinson *et al*[568] having also observed this. On the other hand, when the *stitch length* was kept constant an increase in yarn linear density caused an *increase* in the number of yarn breakages due to the fact that the coarser yarns, being knitted at the same *stitch length* as the finer yarns, were actually being knitted at a higher tightness (MTF). This would simulate conditions, in practice, where a thick place or slub occurs in the yarn and illustrated the harmful effect these could have on knitting performance. It was concluded[683] that, under the relatively severe knitting conditions (i.e. high tightness factors) employed, an increase in yarn breaking strength and yarn extension at break and a decrease in yarn friction and yarn irregularity had a beneficial effect on the number of yarn breakages. Thick places in a yarn, or knitting coarser yarns at a *constant stitch length*, had an adverse effect on the number of yarn breakages during knitting, but if knitting was carried out at a *constant tightness factor*, coarser yarns generally performed better than finer yarns, provided the yarn linear density remained within the range suitable for the particular gauge of machine. Nevertheless, at *commercial* tightness factors, other yarn properties such as knots, slubs and thick places could be expected to play an important rôle in determining the number of yarn breakages (holes) during knitting.

Silver[510] found that the class of dye influenced the knittability of the yarn when dyed in cheese form. It was found that the knittability was worst for 1:2 metal-complex, and improved progressively for chrome, reactive, acid milling, equalising acid and undyed (best). At acceptable low levels of friction, yarn extension was the most important property determining the knittability of the dyed yarns. A second series of dyeings was undertaken in order to investigate the influence of dyestuff concentration on the knittability. A reactive dye and a 1:2 metal-complex dye were chosen and the yarn lots dyed at 1, 2, 3, 4 and 5% (o.m.f.) dyestuff for each dye type. Correlations between dyestuff concentration (for the 1:2 metal-complex dye) and knittability and between concentration and yarn extension were found to exist but no correlation was found with the reactive dye.

In the case of double jersey tuck structures, Hunter[521] found that most yarn breakages occurred at the interlock feeders and it was shown that a high run-in at these feeders and an intermediate run-in at the tuck feeders gave the best knitting performance.

Hunter *et al*[536] also investigated and compared the knitting performance (yarn breakages) at different feeders within a pattern repeat for a range of single jersey structures (seven in all including Satin Stitch, 1/1 Weft-knitted Locknit, Lacoste fabric, Cross-tuck 1 x 1), on a 28 gauge single jersey Jacquard machine, equipped with positive feed. A run-in-ratio of 1,5:1 was employed when all-knit and alternate knit-miss courses were incorporated in the same structure while a run-in-ratio of 1:1 was used when knit-tuck and all-knit courses were incorporated in the same structure. Consistent results were obtained for the different course lengths. Feeders at which most breakages occurred were identified for each structure thus enabling the knitter to improve knitting performance by supplying yarns with superior tensile properties at these feeders, when feeder blending was feasible. Robinson *et al*[568] found that tucking (in accordion structures) affected knitting performance, it being possible to knit the straight and alternate accordion structures at the tightest stitch lengths and producing the lightest fabrics. Nevertheless, for fabrics of similar mass per unit area, the no-tuck structures knitted best, followed by the selective accordion and then the straight and alternate accordion structures.

In another study, Hunter and Andrews[538] investigated the effect of different types and levels of lubricant on the knitting performance of wool worsted yarns on single and double jersey circular knitting machines fitted with positive feed. They found that on the double jersey machine, knittability generally followed a similar trend as yarn friction, although optimum knitting performance appeared to occur at a higher level of lubricant (Fig. 60) The paraffin waxes (A to D) performed best while the emulsion lubricant H (emulsified mineral oil) performed relatively poorly. Waxes with different melting points performed similarly provided they were applied at the same level.

Hunter *et al*[805] found that the presence of a few isolated cones of unwaxed (i.e. high-friction) yarns on multi-feeder single and double jersey circular knitting machines, equipped with positive feed, did not appear to affect knitting performance adversely provided the rest of the yarns were well waxed. In such cases, the waxed yarns probably maintained sufficient wax on the knitting needles to facilitate the knitting of the unwaxed yarns. Waxing the yarn, by means of solid paraffin wax discs, generally had a beneficial effect on the knitting performance of the two double jersey structures (interlock and Punto-di-Roma), but not on that of the two single jersey structures (plain and satin stitch).

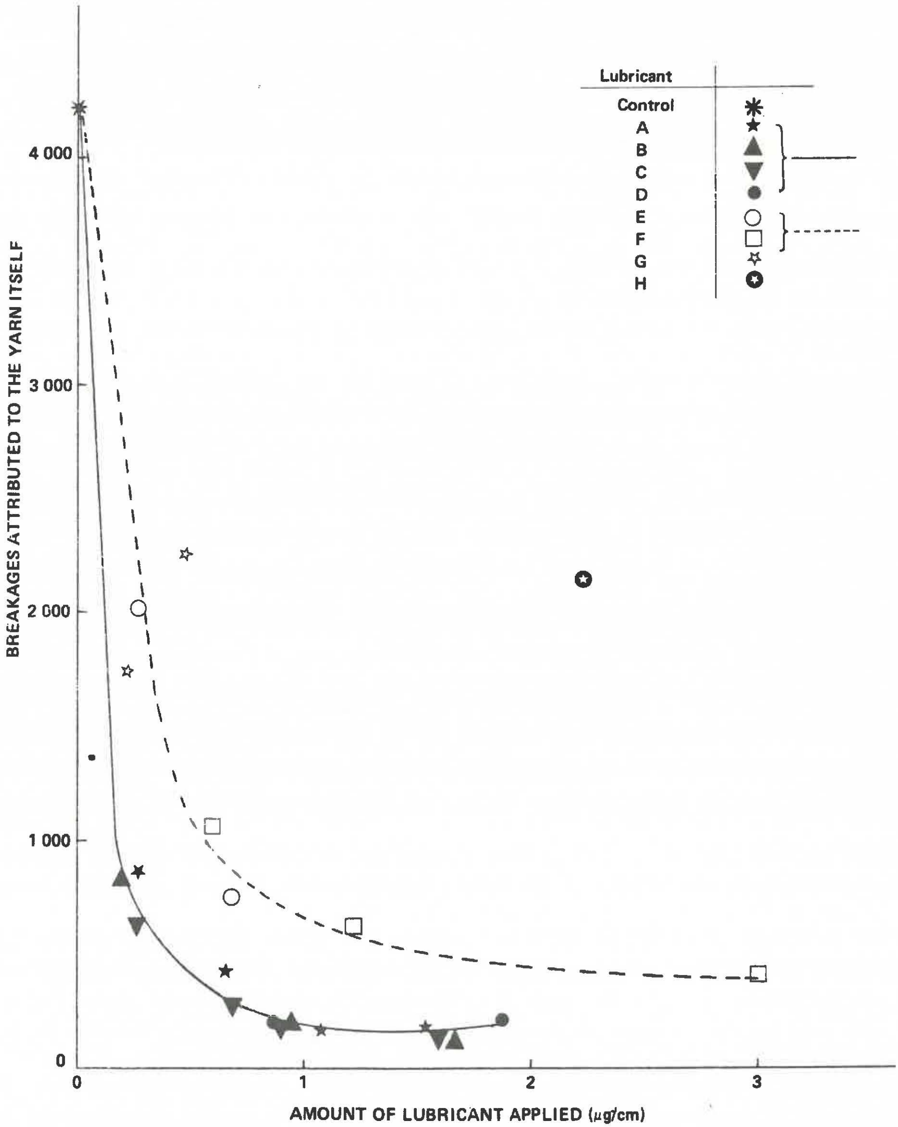


Fig. 60 Breakages attributed to the yarn itself vs amount of lubricant applied for the Punto-di-Roma structure (28 tex yarn).(538)

12.9 DOUBLE JERSEY PLATING AND PLUSH

Stocker and Kerley[225] described a way in which plush fabrics could be produced on a double jersey circular machine using a dial needle latch opener, wire needle support (presser foot) and a wire for preventing the latches from closing, while Wolfaardt[419] discussed the relatively easy machine modifications required for the production of double jersey plated fabrics.

CHAPTER 13

KNITTED FABRIC PROPERTIES

13.1 EFFECT OF YARN AND FABRIC STRUCTURE

Kerley[141, 156] and Kerley and Swanepoel[240] investigated the influence of cover factor and structure on the abrasion resistance of knitted fabrics as measured on a Stoll Flex Abrasion Tester. He reported that the results were affected by the elasticity of the fabrics, a more stretchable fabric ''riding'' with the abradant over the diaphragm surface of the instrument and therefore suffering less abrasion.

Schulze and Stocker[194] investigated various aspects associated with the production and properties of Double Piqué fabrics (French, Swiss and an eight-course piqué) knitted with different rates of yarn intake. They recommended the median rate of yarn intake as the best starting point for double piqué fabrics of any structure. In a follow-up study[250] various physical properties of the fabrics were measured and related to a fabric tightness factor. Steaming the fabrics reduced fabric stiffness, thickness and pilling propensity.

For the Punto-di-Roma structure (constant MTF), Hunter[535] found that Martindale abrasion resistance improved with an increase in the fabric mass, yarn twist and fabric density, and deteriorated with an increase in the yarn linear density (for a constant fabric mass and density). Pilling propensity decreased as yarn twist and fabric density increased. Bursting strength increased with an increase in yarn strength, yarn linear density and fabric density. Air-permeability increased as yarn twist increased and it decreased as the fabric mass per unit area or fabric density increased.

13.2 EFFECT OF FIBRE PROPERTIES AND SHEEP BREED

Hunter and co-workers[535, 594, 689, 772, 776, 792, 793, 832, 833, 872, 893, 932] made an in-depth study of the effects of wool fibre properties, such as mean fibre diameter and length, CV of fibre diameter and length and staple crimp (or bulk resistance to compression), on the physical properties of single (plain) and double jersey fabrics (1x1 rib and Punto-di-Roma). They used multiple regression analysis to determine and quantify the various effects and also to establish whether or not the breed of sheep from which the wool originated had any additional effect on fabric properties over and above its effect on the fibre properties as such. Empirical relationships (regression equations) between fibre and fabric properties were established, documented and some of these relationships were illustrated graphically. Some 200 different wool lots were converted into fabric giving a total of some 700 fabrics.

In general, mean fibre diameter was found to have the greatest effect on fabric properties (Fig. 61) followed by mean fibre length and staple crimp (or

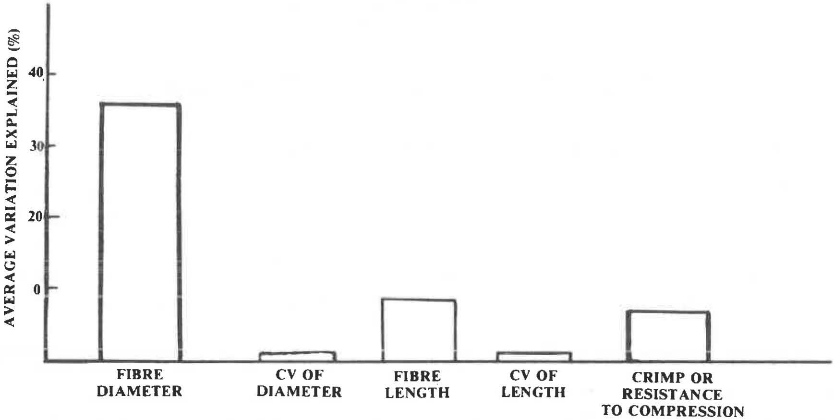


Fig. 61 Percentage contribution of the various fibre properties towards explaining the observed variations in fabric physical properties (averaged over the properties of both knitted and woven fabrics).(833)

bulk resistance to compression). The effect of fibre length was often not that large considering the ranges covered. The actual relationship between fibre length characteristics and fabric properties often also depended upon whether the physical tests were carried out on the fabrics prior to or after dynamic wet relaxation.

Occasionally the CV's of fibre diameter and length of fibre properties affected certain fabric properties, for example fabric stiffness and drape increased slightly with an increase in CV of fibre diameter, but the effects were generally small and negligible in practice for the ranges of CV's normally encountered in practice. The handle of the knitted fabrics [594] was directly related to mean fibre diameter, CV of diameter and the blending of wools differing in mean diameter appearing to have little effect on the handle/diameter relationship.

The main findings can be summarised[932] as follows:

Abrasion: Fabric resistance to abrasion increased (i.e. mass loss decreased) with an increase in fibre diameter and length and also in some cases with a decrease in resistance to compression (Fig. 62). The following approximate relationships applied:

$$\%\ \text{Mass Loss}\ \alpha\ (\text{Fibre Diam.})^{-1,3}\ (\text{Fibre Length})^{-0,7}\ (\text{Compr.})^{-0,5}$$

$$\alpha\ (\text{Fibre Diam.})^{-1,3}\ (\text{Fibre Length})^{-0,7}$$

The various breeds generally followed the same relationship as illustrated for the single jersey structure in Fig. 63.

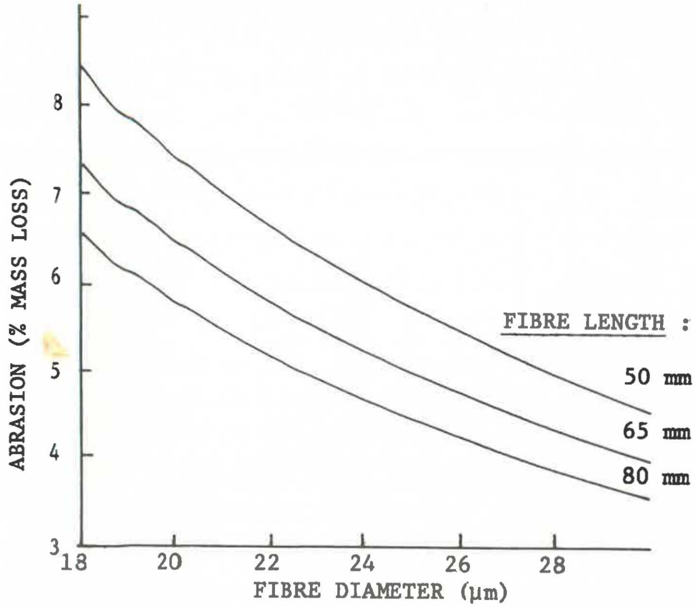


Fig. 62 Regression curves illustrating the effects of fibre diameter and fibre length on fabric abrasion resistance (1x1 rib).(872)

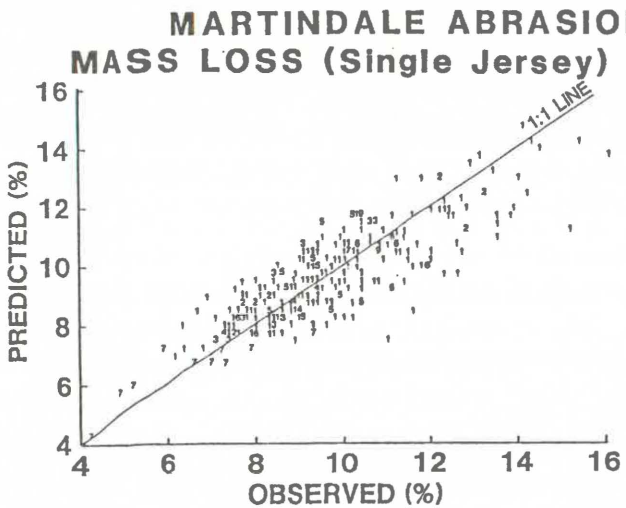


Fig. 63 Actual vs predicted abrasion mass loss for single jersey (different numbers represent different breeds).(932)

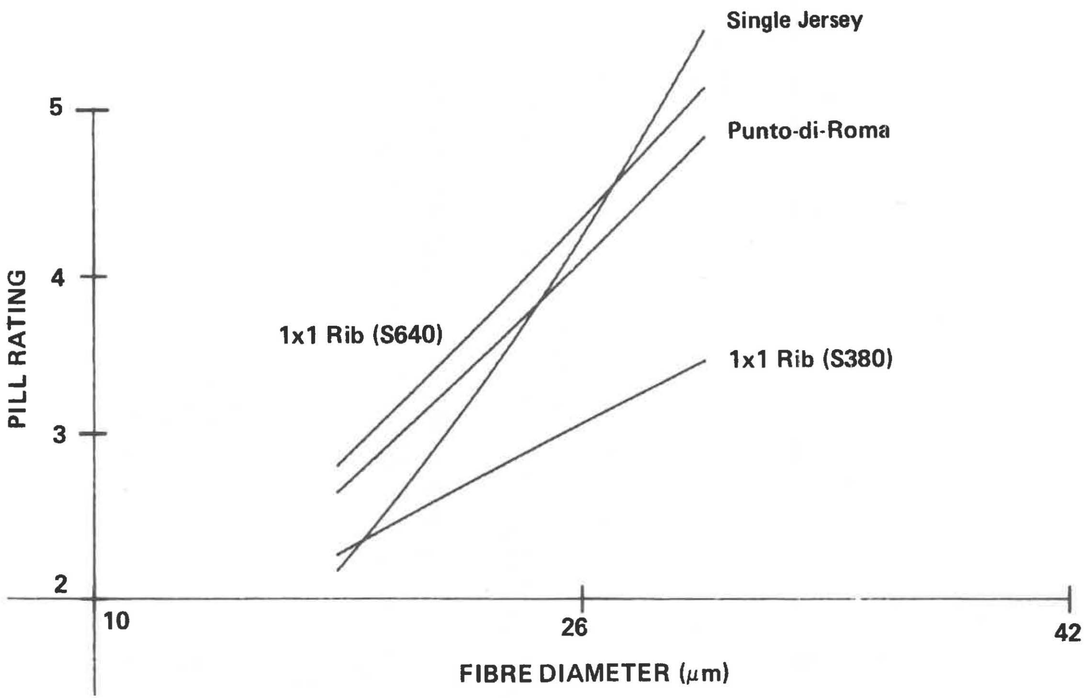


Fig. 64 Regression Curves Illustrating the Effect of Mean Fibre Diameter on Pill Ratings after 2 000 Cycles on the Martindale Tester.(972)

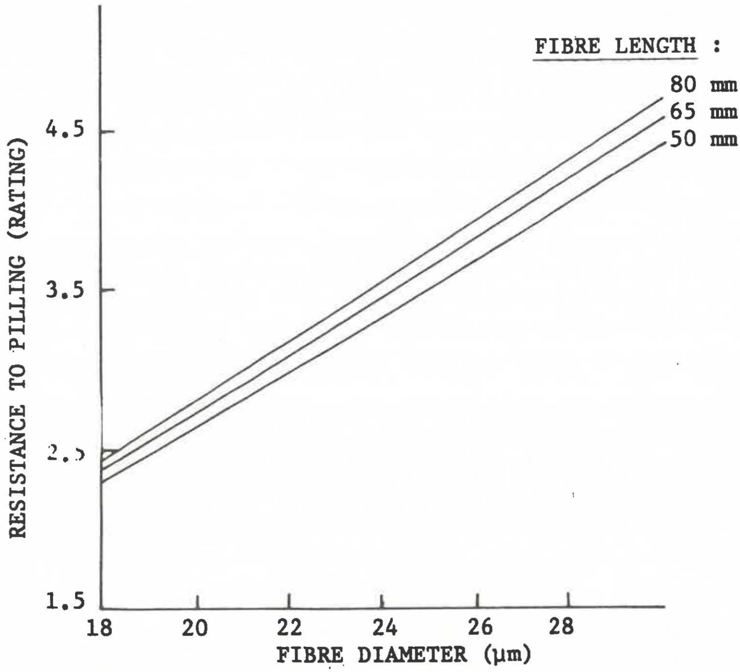


Fig. 65 Regression curves illustrating the effects of fibre diameter and fibre length on fabric resistance to pilling (Punto-di-Roma).[872]

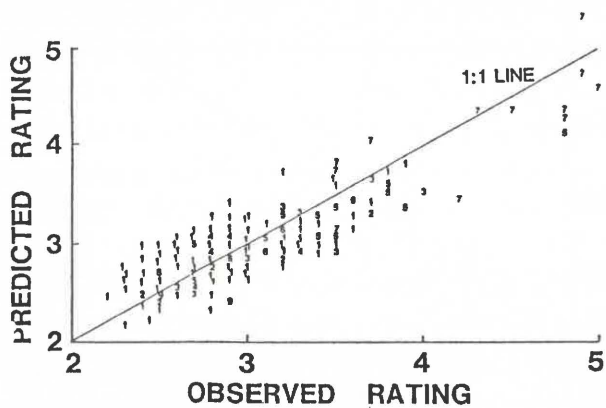


Fig. 66 Predicted vs actual Martindale Pill rating for single jersey (different numbers represent different breeds).[932]

Pilling: Although the results for the different structures and states of relaxation were not always consistent, the overall trend was for resistance to pilling to improve (i.e. pill rating to increase) with an increase in fibre diameter (main effect), length and resistance to compression (Figs 64 and 65), with the different breeds behaving similarly (Fig. 66). The following approximate average relationship applied:

Pill rating α (Fibre Diam.)^{0,8} (Fibre Length)^{0,15} (Compr.)^{0,1}

Bursting Strength: In virtually all cases, bursting strength increased with a decrease in fibre diameter (main effect) and resistance to compression and in most cases also with an increase in fibre length, the various breeds behaving similarly. The following approximate relationship applied:

Bursting Strength α (Fibre Diam.)$^{-0,3}$ (Fibre Length)^{0,05} (Compr.)$^{-0,15}$

Drape and Bending Length: The drape and bending length (stiffness) of each structure were largely determined by fibre diameter, increasing as fibre diameter increased, with the different breeds following the same general trend (Fig. 67). Bending length also tended to increase with an increase in resistance to compression. The following approximate relationships applied:

Drape Coeff. α (Fibre Diam.)^{0,8}
Bending Length α (Fibre Diam.)^{0,5} (Compr.)^{0,05}

Air-Permeability: Air-permeability increased with increasing fibre diameter (main effect) and fibre length and with decreasing fabric mass, the effect of fibre length probably being due to its effect on yarn hairiness and bulkiness. For the Punto-di-Roma and single jersey structures, air-permeability also tend-

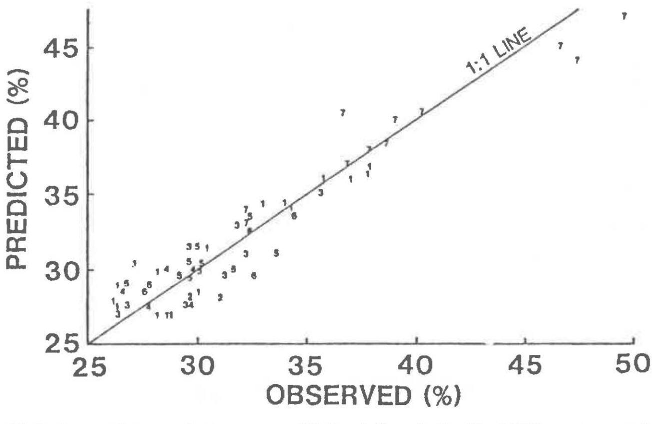


Fig. 67 Predicted vs observed drape coefficient for 1x1 rib (different numbers represent different breeds).(932)

ed to decrease with an increase in resistance to compression. The various breeds followed the same relationship. The following approximate relationship applied:

Air-Permeability α (Fibre Diam.)^{0,9} (Fibre Length)^{0,2} (Fabric Mass)$^{-2}$

Felting Shrinkage: Felting shrinkage depended upon fabric structure but generally increased with a decrease in fibre diameter (main effect), resistance to compression and fabric mass and sometimes also with a decrease in the CV of fibre length, the different breeds following the same general relationship. The following approximate relationship applied:

Felting Shrinkage α (Fibre Diam.)$^{-1}$ (Compr.)$^{-0,7}$ (Fabric Mass)$^{-1,5}$

Crease and Wrinkle Recovery: Although the trends were not always consistent for the different fabric structures and crease recovery tests (IWS and Monsanto), there was a tendency for crease (or wrinkle) recovery to increase with increasing fibre diameter and sometimes also with increasing fibre length.

Delaney[810] investigated the effects of fibre diameter and crimp on various bending parameters (e.g. visco-elastic, hysteresis, residual curvature) of Punto-di-Roma fabrics and found a significant difference in the behaviour of the fabric in the course and wale directions respectively. In the case of the latter, fibre diameter and fabric thickness played equally significant rôles in determining the bending characteristics whilst for the former, fabric thickness was the most important. Bulk resistance to compression was found to play only a minor rôle. Significant differences were found in the responses of the knitted and woven fabrics to bending stresses, and these were explained in terms of fabric geometry.

13.3 EFFECT OF WOOL STYLE AND CLASS DESCRIPTION

Hunter and Robinson[551] studied the physical properties of knitted fabrics produced from South African Merino wool of various styles and class descriptions as well as from mixtures of the different types of wool. Only in a few isolated cases were differences of any importance observed between the physical properties of the fabrics produced. Taking an overall view of all the results, it appeared that, although large differences were often observed between the lots in the earlier processes up to the yarn stage, the differences between the physical properties of the *fabrics* produced within each series were generally small. The fabric properties were almost solely determined by the fibre dimensions and physical properties and only insofar as differences in style and class description were reflected in the fibre properties, did they affect the fabric physical properties.

13.4 EFFECT OF BLENDING DIFFERENT RAW WOOL LOTS

Hunter and co-workers[594 689 772 832] studied the effect of blending raw wool lots (farmer lots), differing in their fibre characteristics such as length and diameter, on knitted fabric properties and investigated whether the behaviour of the blends (mixtures) in fabric form could be predicted from the behaviour of their individual components in the fabric. The general conclusion was that the physical properties of the fabrics containing wool blends or mixtures could be predicted from the weighted mean properties of the individual components and that the fabric properties were largely determined by the mean fibre properties, the main ones being mean fibre diameter and to a lesser extent mean fibre length and staple crimp or bulk resistance to compression.

13.5 DIMENSIONAL PROPERTIES AND STABILITY

Schulze[233] discussed the various factors involved in the dimensional stability of knitted outerwear fabrics, while Veldsman[319] showed that the fully relaxed state of all-wool, double jersey fabrics could be achieved commercially to within the 8% tolerance limits of area shrinkage by first decatising the fabrics, followed by tumbling in a charged system of perchloro-ethylene. Spin-drying for two minutes, followed by a 10-minute tumble-drying at 70°C, completed the operation. A final one-minute decatising, Hoffman pressing or calendering, gave a smooth, attractive appearance, handle being neither flabby nor harsh.

Schulze[320] reported on the fabric physical properties of a wide range of double jersey structures after wet-relaxation, Hunter[339] showing that the properties of these fabrics were largely a function of fabric structural tightness factor rather than of the particular structure.

Wolfaardt[322, 354] found that approximately 10 minutes uninterrupted tumbling in steam at atmospheric pressure, followed by 15 minutes tumble-drying at 70°C, was an effective means of relaxing all-wool, shrink-resist treated plain-knit and 1x1 rib structures. Tumble-drying, however, did tend to distort 1x1 rib fabrics, the degree of distortion depending upon fabric tightness and extensibility and sample size and shape. He showed[351] that the 3-minute Australian Wool Board standardised wash-relaxation test was effective for relaxing shrink-resist treated wool knitted fabrics, although subsequent tumble-drying relaxed the plain fabrics further as opposed to flat drying. This did not apply to the 1x1 rib fabrics. His results indicated that loop length was an unreliable measure of felting.

Knapton[278] showed that by the use of a tumble-drying technique, the fully-relaxed states of simple and complex knitted structures in wool, were geometrically predictable and uniquely determined by the length of yarn in the Structural Knit-Cell (SKC). The mechanism of relaxation differed from the felting mechanism. In any other state, fabric dimensions were not easily predictable as they were dependent on processing variables. In subsequent washing of untreated wool plain-knitted fabrics, the general shape of the area shrinkage/time curves (A_S/t) was defined by two parameters, (a) the "saturated felted value" and (b) the rate of change factor of the (A_S/t) curves. For treated fabrics, the general shape of the (A_S/t) curve was linear and could be defined by one parameter. For untreated or under-treated fabrics, linear and area dimensions in washing were dependent upon most yarn and fabric variables. Two "Tightness Factor" (TF) expressions were suggested. The "Structural Tightness Factor" (STF) which took into account the energy state of the fabric, and the "Machine Tightness Factor" (MTF), which represented an industrial means of setting any machine to any desired fabric quality. A means of setting double-knit machines to the most desirable run-in ratio was also suggested.

Wolfaardt and Knapton[289] showed that the K-values of a plain-knitted structure were only really constant with changes in loop length when the structure was in its fully-relaxed state, the latter best being achieved by tumble-drying. K_1 appeared to still depend upon yarn linear density even in the fully relaxed state. Dimensional changes due to felting were largely (but not entirely) associated with loop contraction (i.e. felting shrinkage of the yarn).

Knapton[294] proposed various definitions and relationships in an attempt to establish a unifying system of nomenclature for the geometry of complex knitted structures. He also discussed the concept of a standard yarn intake ratio. Knapton and Schwartzkopff[283] extended the concepts of full-relaxation and dimensional constants and geometry developed for single jersey fabrics by other workers, to double jersey fabrics and introduced the concept of a structural knit-cell as the smallest repeating unit of fabric structure together with appropriate cell-stitch length (SCSL) and dimensional constants (K- or U-values). The concept of machine tightness factor (MTF) was also developed. Use was also made of the concept of Structural Tightness Factor previously introduced. They[290] showed that using the concepts of the fully-relaxed fabric state and the Structural Knit Cell (SKC), the shape of the SKC of the Punto-di-Roma structure was geometrically determined, and predictable in the fully-relaxed state, being defined by a series of constants (K-values). These K-values could be used to predict finished fabric dimensions and mass in the fully-relaxed state.

Wolfaardt[347] made a theoretical study of the geometry of 1x1 rib structure and calculated the standard tightness factor to be 6 and the corresponding machine tightness factor (MTF) to be 11,9. He and Knapton[389] proposed a geometrical model of the smallest repeating unit or structural knit cell (SKC) of the fully-relaxed 1x1 rib structure, based upon an elastica configuration. They found dimensional constants determined experimentally to agree well with those calculated theoretically.

Buys[449] investigated the dimensional properties and K-values of eightlock and double eightlock pure wool structures and found that, in certain cases, the K-values were slightly dependent upon the SCSL. At a constant stretcher board width, length and width shrinkage depended upon the SCSL whereas the area shrinkage was largely independent of SCSL.

Silver and Creed[567] showed that dimensionally stable all-wool single jersey fabric could be attained by scouring, setting and shrink-resist treating the fabrics. The finishing routine had no adverse effect on the physical properties of the fabrics. Relaxation shrinkage could not be contained by any setting treatment and scouring was selected to remove the relaxation shrinkage.

Hunter *et al*[747], Dobson *et al*[748] and Robinson *et al*[809] showed the advantages to be gained in increased fabric dimensional stability by knitting with virtually zero take-down tension on circular double-jersey machines to which special devices had been fitted for this purpose.

13.6 MEASUREMENT OF FABRIC UNEVENNESS

Kruger and co-workers[525] developed a relatively simple apparatus for the detection of defects, such as barré and streakiness, in fabrics. The image of a slit illuminated by a small lamp was focussed onto the fabric and either the reflected or transmitted radiation analysed. Reflected radiation was collected by an integrating sphere and detected by two photomultipliers, one sensitive to the green and the other to the near infra-red. A phototransistor was used for the detection of transmitted light. Differences in depth of colour for a blue shade show up in the response of the green-sensitive photomultiplier but not in the response of the infra-red detector (which was insensitive to the dye) or the phototransistor. Other 'faults' could be detected by all three detectors. It was possible to obtain a quantitative measure of barré and streakiness with the aid of an electronic counter.

Hunter and Smuts[488] measured the variation in surface irregularity of single jersey fabric by means of a stylus lightly resting on, and traversing along, the fabric surface as well as the variation in transmitted light measured by means of a photodensitometer, and found them to be related to yarn irregularity. The latter method appeared to be the more promising for obtaining a measure of the unevenness of knitted fabrics. Subjective rankings of fabric streakiness were correlated with all these variables. The effect of an increase in stitch length on the results obtained for surface irregularity was different to that on the fabric irregularity results measured by transmitted light. In the case of the surface irregularity test the sample had to be mounted carefully since slight variations in mounting tension caused large variations in the results.

13.7 COCKLING AND PUCKERING

Kerley[249] reported on a simple technique, for the planning of rib cuffs and welts for fully fashioned garments, that was based on the classical knitting geometry of plain and 1x1 rib fabrics. The effects of cover factor and some common loop ratios at the join of 1x1 rib and plain fabrics on puckering at the knitted join and the effects of cover factor and some yarn characteristics on cockling in plain-knitted fabrics were also reported. He linked cockling to twist distortion and yarn irregularity, twist liveliness and coarse fibres being aggravating factors. Hunter *et al*[423] found cockling to be particulary severe in wool-/mohair blends, deteriorating with an increase in mohair content. They related cockling to short-term variation in yarn torque resulting from variations in fibre diameter and yarn linear density and twist, certain factors during knitting aggravating the problem. Setting the yarns had little effect on cockling while autoclave setting of R Synthappret treated fabric effected a significant improvement.

Robinson *et al*[556, 774] defined different forms of loop distortion, including cockling, with the aid of photographs. Cockling was found principally in fabrics containing wool or mohair. The average cockle was found to extend over 7 to 8 loops and it was found that cockling was generally associated with thick places in the yarn which had a low twist. A simple method of quantifying the severity of cockling in single jersey knitwear knitted from wool or wool blend yarns involving a set of SAWTRI standard photographs of cockling was developed[673, 729].

Robinson and Green[604] concluded that the unevenness of the yarn mainly determined the degree of cockling, cockles forming when a relatively thick place in the yarn coincided with a relatively thin place in either the preceding or succeeding course or both. Lower-twist yarns tended to be more prone to cockling and also loosely knitted fabrics. Wool yarn developed untwisting torque when wetted out, which, together with high yarn irregularity, were the prime factors in cockling. Wool yarns for plain single jersey knitwear should be spun from wool of sufficient fineness and with sufficient fibres in the cross-section to ensure minimum cockling.

Robinson and Green[615] compared the cockling of two yarns spun from a local and an imported wool respectively and found that the local wool fabric cockled more than the one knitted from the imported wool. Although the local wool produced a yarn generally more even than the imported wool, the latter contained a lower frequency of thick places with a relatively small cross-section and it was felt that this, and possibly torque differences, were mainly responsible for the observed differences in cockling.

Robinson *et al*[604, 703, 729, 774] attempted to correlate certain fibre and yarn properties with the degree of cockling. Mean fibre diameter and crimp frequency were found to have a significant effect on cockling for a specific yarn linear density. The evenness of the yarn was very important in the degree of cockling. Coarser and undercrimped wools tended to increase cockling (Fig. 68).

In a later study, Robinson and co-workers[751, 774] investigated the effects of shrinkresist and anti-cockle treatments and found that a chlorination 'pretreatment' of the fabric gave the greatest single anti-cockle effect, even more effective than a standard bisulphite anti-cockle treatment. Chlorine- R Hercosett shrinkresist treatment of the fabric gave a slightly better effect than chlorination alone.

Robinson *et al*[722, 729] also investigated the cockling of fabrics knitted on three different types of machines with completely different knitting actions, namely, fully-fashioned, flat-bed and RTR machines. Flat-bed knitting produced a fabric with a higher cockling rating (better) than fully-fashioned knit-

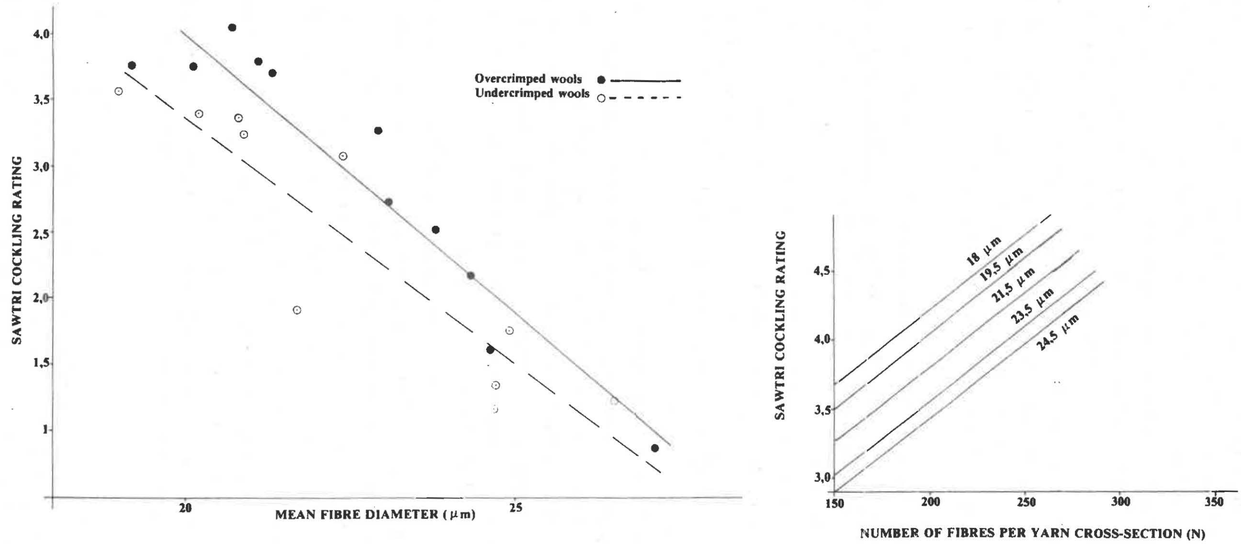


Fig. 68 Effect of fibre properties on cockling.(703)

ting with the circular knitting action giving relatively lower cockling ratings (worse) in the case of fine wools.

13.8 TYPICAL PHYSICAL PROPERTIES OF COMMERCIAL DOUBLE JERSEY FABRICS

Hunter and Smuts[501] measured the physical properties, generally associated with fabric quality, of a range of commercial double jersey fabrics. Those of the pure wool Punto-di-Roma fabrics were related, by means of multiple linear regression analyses, to the various fabric structural parameters, such as mass per unit area, density, run-in-ratio and machine tightness factor. Graphs were prepared of the various fabric properties plotted against the fabric mass per unit area (g/m^2) for use in quality control laboratories to assess the performance of similar wool double jersey fabrics relative to these commercial fabrics. The abrasion mass loss at 10 000 cycles was found to be highly correlated with that at 20 000 cycles. The former was also correlated with the number of cycles to end-point and was considered the preferred method of determining abrasion resistance. According to the results obtained on the all-wool fabrics, a mass loss at 10 000 cycles, of more than about 5,5% could be regarded as excessive, and would, on the average, correspond to an abrasion resistance (cycles to end-point) of roughly 20 000 cycles. The fabric drape was shown to be highly correlated with bending length.

In a later more comprehensive study, Smuts and Hunter[711] measured the physical properties of more than 500 knitted wool fabrics (mostly double jersey structure). The results were related by means of multiple linear regression analyses to fibre diameter and certain fabric structural parameters. The various fabric properties were plotted against fabric mass (g/m^2) for the various structures and reference tables were prepared for these structures showing the effect of fabric mass and machine tightness factor on the air-permeability, bursting strength, abrasion resistance and bending length. These graphs and tables can be used in practice as a basis of reference, i.e. to assess the performance of similar wool fabrics relative to other commercial fabrics.

13.9 DOUBLE JERSEY TUCK STRUCTURES

Hunter[521] investigated the dimensional properties and knitting performance of four double jersey tuck structures (Single Piqué, Royal Interlock, Pin-tuck and Texi-piqué) knitted on an 18 gauge machine from a shrinkresist-treated wool worsted yarn and employing different SCSL's and run-in-ratios. The dimensional constants (K-values) were in general dependent upon the run-in-ratio even after dynamic relaxation and washing. The characteristic appearance of the Single Piqué structure depended upon the run-in-ratio (interlock-to-tuck feeder). In a follow-up study[570], the physical properties of three structures were compared for a wide range of course lengths and run-in-ratios. It was concluded that the bagging propensity of these fabrics was generally high, making them unsuitable for end-uses, such as trousers and slacks, where bagginess could present problems. The fabric properties were in many cases affected significantly by either the course length (run-in or SCSL) or run-in-ratio or both. Of the four structures, the Single Piqué appeared to be the most promising from a commercial point of view. Nevertheless, the relatively high relaxation shrinkage and low dimensional stability of these tuck structures could limit their suitability to certain end-uses only (e.g. dresses, skirts, etc.).

13.10 SEWABILITY

Kelly *et al*[677] and Hunter and Cawood[818] measured the sewability of commercial double jersey fabrics on an L & M Sewability Tester and investigated the effect of several yarn lubricants as well as certain experimental variables on sewability. Variation in needle diameter within needles, of nominally the same size, significantly affected sewability (Fig. 69) and the sewability of commercial fabrics depended upon the percentage of dichloromethane extractable matter and fabric tightness (Fig. 70). The addition of lubricant to yarns already containing processing lubricants and natural waxes did not materially improve

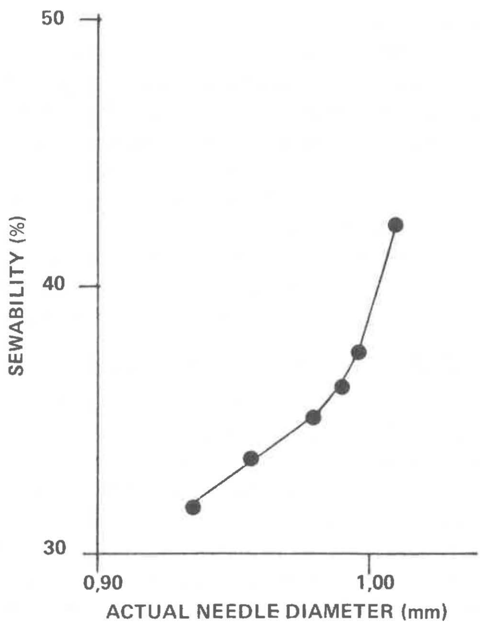


Fig. 69 Relationship between Needle Diameter and Sewability for Sewing Needles of the same Nominal Size.(677)

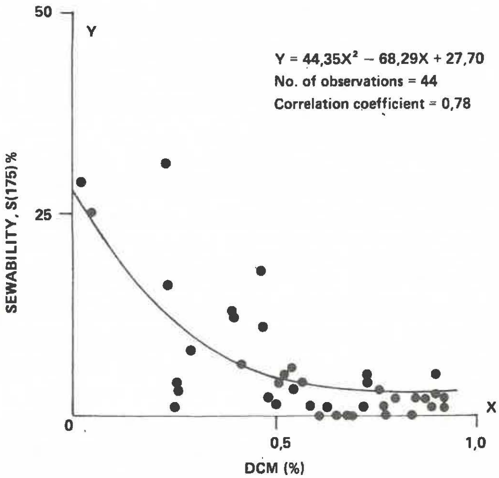


Fig. 70 Sewability, S(175)%, vs Dichloromethane Extractable Matter of Staple Punto-di-Roma Fabrics.(677, 818)

sewability. Some average values for sewability were given for various commercial knitted fabrics.

13.11 REJUVINATING FUZZED AND PILLED GARMENTS

Kerley[139] proposed a method whereby pills and fuzz could be removed from knitted garments by shearing.

13.12 KNITTED END-USES FOR KARAKUL*

Kerley[219] discussed some end-uses for karakul wool and described some work carried out at SAWTRI in which the fibre was converted into Milano rib-knitted fabric which was tailored into a fashionable jacket for leisurewear which showed good wear characteristics.

13.13 CO-WE-NIT FABRICS

Robinson, Layton and co-workers[306 309 313 316 324 331 378 381 415] showed that a great number of different structures and designs could be produced on a Raschel type Co-we-nit machine and, in combination with colours, many different effects could be produced suitable for men's outerwear fabrics. The subtle differences of the various colour and Co-we-nit effects introduced a completely new concept in cloth design. Applications of karakul, wool, mohair and synthetic fibres in sunfilter curtaining and upholstery were described.

***See also next section (13.13).**

CHAPTER 14

WEAVING

14.1 YARN SIZING AND WAXING

Robinson and Layton[652] investigated the sizing and weaving performance of singles wool worsted yarns, using a modified Hergeth sample sizing machine. They concluded that sizing of all-wool worsted yarns could effectively be carried out, although yarn linear density was a dominant factor in respect of weaving performance. Desizing of the fabrics in preparation for piece dyeing necessitated the use of an enzymatic desizing agent. Robinson *et al*[671, 699] described the production and finishing of light-weight all-wool shirting fabrics which involved the sizing of the singles yarns and which had good machine washable properties.

Robinson and Layton[687] showed that a relatively short wool could be blended with cotton and short staple polyester fibres and satisfactorily processed into fabric, sizing increasing the yarn strength. A standard size mix gave satisfactory results for relatively coarse yarns but not on the finer yarns, the latter requiring higher add-ons. The size performed better on the wool/cotton and wool/polyester yarns than on the all-wool yarn indicating that a better size for the wool fibre was required. Later Robinson and Layton[694] extended the work on sizing to cover ring and rotor yarns in wool/cotton blends (60/40 and 40/60) in three different yarn linear densities, all-wool worsted ring yarns and all-cotton rotor yarns being used for purposes of comparison. The yarns were sized (10% size mix) and weaving trials carried out on both conventional and projectile weaving machines. The yarns lost some strength during preparation, but sizing increased the yarn strength to above the original values. The rotor yarns generally had higher size pick-ups and abrasion resistance than the ring yarns. The cotton and cotton-rich blends benefited most from sizing, the relatively poor performance of the wool component again indicating the need for further work to find a more suitable size. Subsequently Robinson and Layton[828] applied 22 different size formulations to fine worsted singles yarns to assess their effect on weavability during the weaving of a light-weight all-wool gaberdine fabric only. Certain of the formulations were found to perform satisfactorily.

McMahon[949] carried out a limited study to determine the effect of warp waxing of two all-wool worsted yarns on weavability. Four wax products were selected. The results showed that significant reductions in breakage rate for both singles and two-ply yarns could be achieved by waxing.

14.2 WEFT TENSION AND WEFT SKEWING

Robinson[241] showed that the more the twill was broken up the lower the percentage skewness, with the skew line following the twill lines only in the case of the step 1 twills. The skew increased with increasing boldness of the twill line. He developed a method of calculating the expected percentage skew (RSF) from the weave structure and direction of yarn twist. In a subsequent study he[284] showed that fabric width and sett played a rôle in fabric skewing. An increase in weaving tension also increased fabric skewing and fabric contraction in the loom state was found to be related to skewing. In a later study[326], it was shown that yarn twist was very important in terms of weft skewing, the higher the twist factor the greater the skewing (Fig. 71). Conventional S-warp, S-weft fabrics (i.e. where the folding twist was in the S-direction) gave higher skew than all other twist combinations in fabrics where the skew was in the same direction as the twill. When the direction of skew opposed the twill direction the use of S-warp, S-weft yarns gave minimum skew. It was also found[363] that weft tension had an effect on weft skewing and that suitable temples, which hold the fabric out to full reed width, were essential, the full width temple and strong ring temples giving the best results with minimum skewing. Late shed timing with a low backrest and minimum warp tension gave much less skew than the other settings used.

The above work on weft skewing formed the basis of an M.Sc. thesis[317] by Robinson.

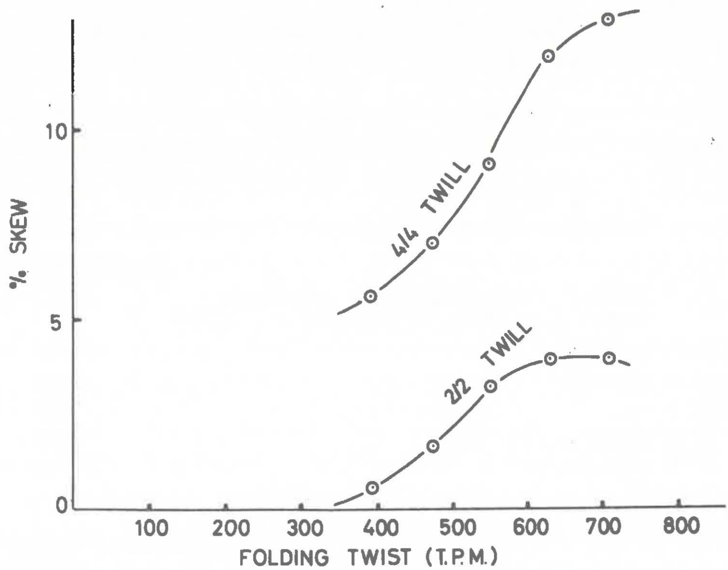


Fig. 71 Change of % skew with folding twist. (326)

McMahon[950] measured the fluctuations in weft tension on a double rapier loom, at different tension settings, a weft accumulator reducing the maximum transient tensions significantly.

14.3 WEAVABILITY

In an attempt to explain observed differences in weavability in a mill, Hunter *et al*[798] compared the physical properties of commercial lots of two-ply ring-spun and Repco self-twist (STT) weaving yarns, spun from similar wools. The frequencies of isolated weak places, as measured on a Shirley Constant Tension winding tester for the STT and ring-spun yarns differed significantly. The ring-spun yarns averaged 0,7 breaks per 10 000m, the STT yarns spun on a Repco Mk I machine 21 breaks per 10 000m, and the STT yarns spun on the Repco Mk II machine 38,7 breaks per 10 000m. These differences ranked the yarns in the same order as their commercial weaving performance. All the breaks in the constant tension winding test occurred at a thin place of relatively high twist. For the STT yarns, the breaks during the constant tension winding test generally followed a Poisson distribution.

Robinson and co-workers[942, 972] carried out weavability trials on a large number of worsted yarns (wool and wool blend) and showed, by means of multiple regression analysis, that weavability (warp breaks per 1 000 ends per 100 000 picks) warp breaks could be predicted with an 83% fit to their data (Fig. 72) from yarn properties, such as isolated weak places (Shirley test), extension at break, tenacity, linear density (tex), objectionable faults (Classimat), thin places and knots. The most important property by far was the occurrence of isolated weak places. The following best fit equation was obtained[942, 972].

$$\begin{aligned}\text{Weavability (W)} = {} & A\,(0{,}033\,BE + 0{,}106\,BD - 0{,}097\,BC - 0{,}244\,BF \\ & + 0{,}013\,EF + 0{,}781\,CF - 0{,}023\,DE - 0{,}00048\,DG \\ & - 6{,}6\,C - 1{,}7\,F) - 16{,}7\,C - 15{,}4\,B + 0{,}71\,BC \\ & + 362{,}2\end{aligned}$$

$$n = 71;\ R = 0{,}91$$

		Contribution to % fit
where	A = isolated weak places (No. of Shirley breaks per 1 000m at a tension of 211cN)	27
	B = extension	17
	C = tenacity	16
	D = tex	11
	E = objectionable faults	6
	F = thin places	5
	G = knots	1
		83%

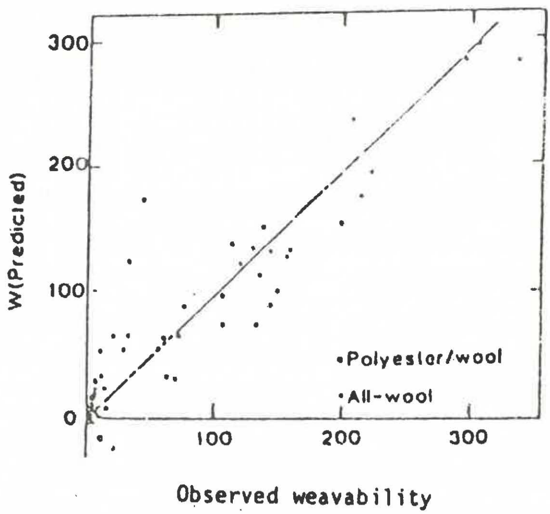


Fig. 72 Relationship between actual and predicted weavability for all types of worsted yarns.(942, 972)

Hunter *et al*[971 998] confirmed the importance of isolated weak places, as measured by three different techniques (Shirley, Tensorapid and SAWTRI Tester), in determining weavability.

McMahon[961 984] reported on the effect different types of knots and splices have on the tension developed in worsted yarns under conditions similar to those encountered by a yarn during weaving as well as on the effect of guide diameter on yarn frictional forces[996].

CHAPTER 15
WOVEN FABRIC PROPERTIES

15.1 EFFECT OF FIBRE PROPERTIES AND SHEEP BREED

Hunter, Smuts and co-workers[726 733 763 776 780 783 791 832 833 872 893 932 946] made an in-depth study of the effects of wool fibre diameter, length and crimp (or bulk resistance to compression) characteristics on the physical properties of plain and cavalry twill weave fabrics. They used multiple regression analysis to determine and quantify the various effects and also to establish whether or not the breed of sheep from which the wool originated had any additional effect on fabric properties over and above its effects on the fibre properties as such. Empirical relationships (regression equations) between fibre and fabric properties were established and some of the relationships were illustrated graphically.

The results obtained are summarised below[932]. In all cases the various breeds behaved in a similar manner and in accordance with their measured fibre properties. Fig. 73 illustrates this and the accuracy of prediction.

Bending Length and Drape: Both bending length and drape were almost solely determined by fibre diameter, there also being a trend for bending length (i.e. stiffness) to increase slightly with an increase in CV of fibre diameter. An increase in fibre resistance to compression or a decrease in fibre length (twill) was associated with an increase in drape although it could be that these fibre properties affected other fabric properties, such as weave crimp, and that they, in turn, affected fabric drape.

Delaney[800] also investigated the effects of fibre diameter and crimp on the bending properties of cavalry twill weave fabrics. Samples were taken through an isothermal bending stress/strain cycle, and from the hysteresis observed, various bending parameters were determined. An increase in fibre diameter resulted in an increase in stiffness, and a decrease in residual curvature and hysteresis loss. Mean fibre diameter explained by far the greatest variation in the results, followed by fibre length and staple crimp.

Abrasion: The abrasion resistance of the twill weave fabrics tended to improve (i.e. mass loss decreased) with an increase in fibre length, an apparent effect of fibre diameter being due to its effect on fabric mass.

Strength: Tensile and bursting strength decreased with an increase in fibre diameter and resistance to compression or staple crimp (Fig. 74). In some cases an increase in fibre length or a decrease in CV of length also resulted in an increase in strength.

Extension: Extension at break decreased with an increase in fibre diameter (main effect) and also with an increase in resistance to compression (twill) and a decrease in fibre length (plain).

Air-Permeability: Air-permeability decreased with decreasing fibre diam-

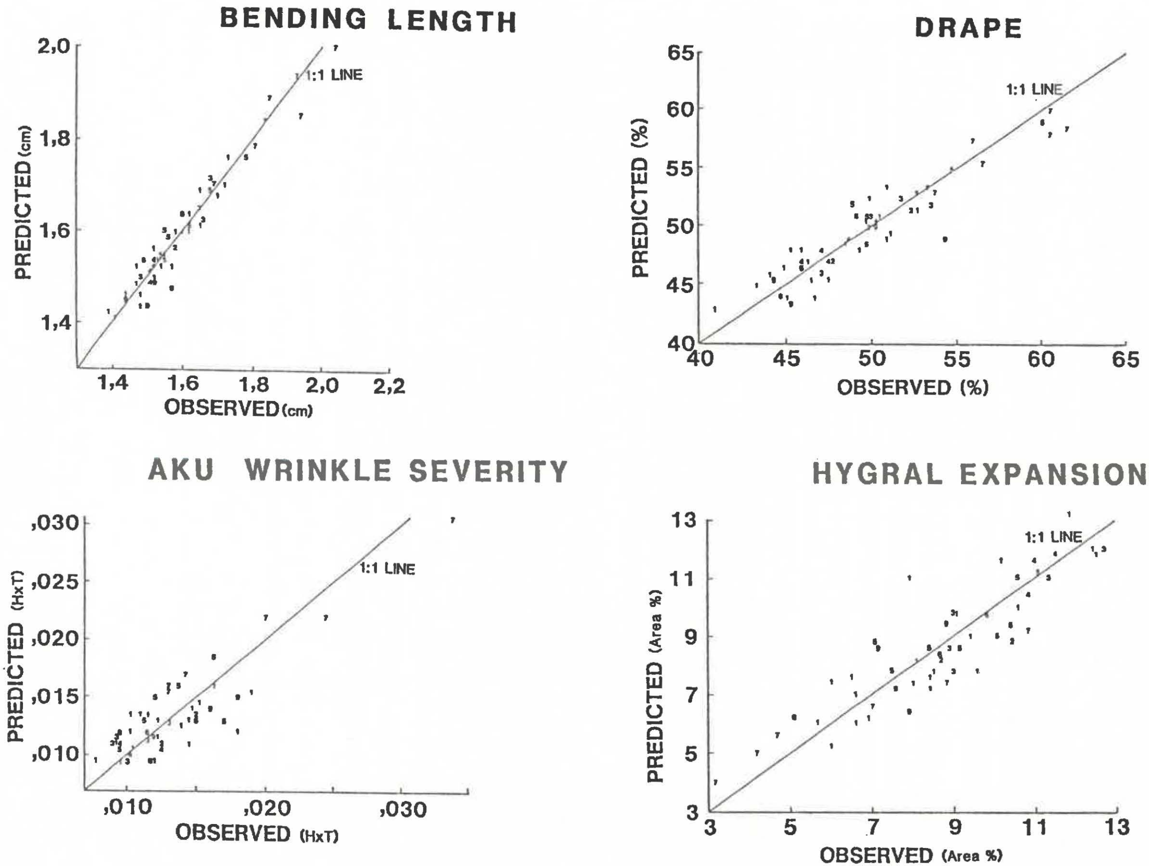


Fig. 73 Predicted vs observed Twill Fabric results (Numbers represent different breeds).(932)

eter (main effect) and increasing fabric mass, and in the case of the twill weave, also with an increase in fibre resistance to compression.

Shiloh[457] had previously investigated various aspects related to the laboratory testing of air-permeability and derived an equation for the prediction of the air-permeability of composites.

Wrinkle Recovery: The overall tendency was for AKU and IWS wrinkle recovery to increase with a decrease in fibre diameter, with the effects of the other fibre properties being small and mostly inconsistent. (See also section on Wrinkling).

Felting Shrinkage: Both relaxation and felting shrinkage decreased with an increase in fibre diameter, while felting shrinkage also decreased with an increase in fibre resistance to compression. No correlation was found between felt ball density results and woven fabric felting shrinkage, the latter being mainly dependent upon fibre diameter whereas the former was mainly dependent upon fibre resistance to compression (or staple crimp).

Weave Crimp: Weave crimp (weft crimp in the case of the plain weave) decreased with an increase in fibre diameter. In the case of the plain weave fabrics, changes in the fibre properties of the weft yarn caused changes in the weft crimp and opposite changes in the warp crimp (i.e. crimp interchange), weft crimp decreasing with increasing fibre diameter (main effect), CV of fibre diameter and fibre length.

Hygral Expansion: Hygral expansion increased with increasing staple crimp (or resistance to compression) and weave crimp, the effects of other fibre properties being due to their associated changes in weave crimp. The various breeds once again behaved according to their fibre properties (Fig. 73).

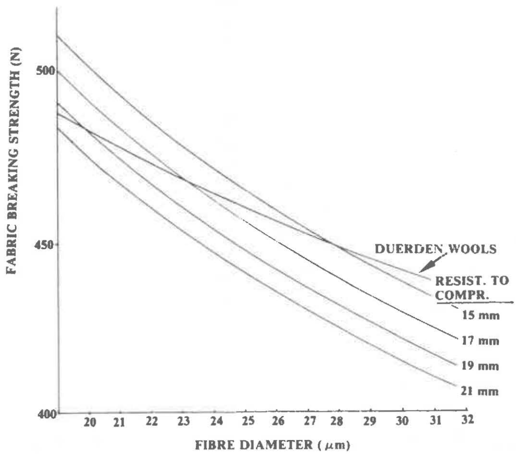


Fig. 74 Regression curves illustrating the effects of fibre diameter and resistance to compression on fabric breaking strength (cavalry twill).(726)

15.2 EFFECT OF WOOL STYLE AND CLASS DESCRIPTION

Slinger and Godawa[175] compared the processing performance and woven fabric properties of a good quality (uniform fibre character, well defined and regular crimp, kind handle and absence of deviating fibres) with that of a poor quality wool. It was found that the fabric woven from the good quality wool had a kinder handle, higher breaking strength, higher felting rate and was less stiff than the fabric woven from the "poor quality" wool. Nevertheless, the latter was coarser than the former and the former was also relatively more undercrimped which could explain the observed differences in fabric properties.

Hunter and co-workers[551 772] studied the physical properties of woven fabrics produced from South African Merino wool of various styles and class descriptions as well as from mixtures of the different types of wool. It was concluded that, although large differences were often observed between the lots in the earlier processes up to the yarn stage, the differences between the physical properties of the fabrics produced within each series were generally small. The fabric properties were almost solely determined by the fibre properties and only insofar as differences in style and class description were reflected in the fibre properties, did they appear to affect the fabric properties.

15.3 BUNTING FABRICS

Robinson[286] found that long coarse wools performed best in all-wool bunting fabrics, but did not recommend them for commercial use in windy locations. They did not compare favourably with wool/nylon bunting materials. Subsequently Robinson and Alcock[321] tested storm size flags of various intimate blends of coarse wools and nylon for performance based on time and wind velocities. Whilst the addition of 10% nylon gave the highest rate of improvement, 70/30 - wool/nylon blend bunting was considered to give the best results in respect of flying life, aesthetic properties and economics.

15.4 LENO WEAVES

Robinson *et al*[485] investigated the incorporation of leno weave units into a plain all-wool ladies' dress material of approximately 160-180 g/m^2 in various percentages, for purposes other than design and showed that there were possible advantages accruing from this practice in respect of fabric wrinkling propensity and stiffness, without detracting too much from the original fabric appearance. Disadvantages were slight increases in fabric thickness and slightly higher air-permeabilities. In a further study, Robinson and Ellis[532] investigated the effect of incorporating leno and up to 5% of either multi-filament or monofilament nylon into light-weight worsted suitings, some fabrics being shrink-resist treated. It was shown that a combination of leno and filament yarns gave improved performance. The monofilament yarns caused no problems in weaving, fine monofilament yarns being preferable.

Robinson and Ellis[558] described, with the aid of diagrams, various lightweight leno-weave (5% leno) all-wool shirting and Safari suiting fabric structures. The leno fabrics were slightly thicker and tended to have a slightly reduced abrasion resistance than plain weave fabrics. The fabrics had a high relaxation shrinkage, but the addition of 0,75% resin reduced felting shrinkage without impairing handle. The leno fabrics had similar mechanical properties to those of a plain weave fabric but appeared to have slightly improved wrinkle resistance and greater air permeability.

15.5 CROTCH WEAR IN TROUSERS

Bird and Hunter[863] evaluated trousers returned to retailers because of unacceptable wear in the crotch region. Tests on fabric cut from the trouser legs were conducted using three different abrasion machines. None of the three abrasion tests appeared capable of predicting the problem of crotch wear and there was no correlation between the results of the different abrasion machines. Alkali solubility was slightly higher in the crotch area than the leg area of the trousers but the difference was small in relation to the degree of wear which took place.

15.6 CORRELATION BETWEEN DIFFERENT ABRASION TESTS

Bird[906] compared the results obtained on three different abrasion testers on plain and twill weave fabrics differing in fibre content and mass. He found that no two tests ranked the fabrics in the same order. The correlation between abrasion tests, even where significant, did not allow for the results of one tester to be predicted from those of another. The degree to which each fabric and yarn property affected the result, varied between abrasion tests. The weft yarn tensile strength was a significant factor in the three standard abrasion tests applied.

15.7 PHYSICAL PROPERTIES OF COMMERCIAL WOVEN FABRICS

Hunter and Smuts[693] measured the physical properties of some 174 commercial wool and wool blend fabrics with a view to establish preliminary "average" or "reference" values for those fabric properties often used to characterise fabric quality. The results were plotted against fabric mass and a table of "average" values prepared to facilitate the practical use of the data. Insufficient fabrics were available to allow a distinction to be made on the basis of fabric structure.

15.8 FABRIC HANDLE

Hunter *et al*[827] investigated the effect of wool fibre diameter and crimp on fabric handle, objectively measured according to the Kawabata system, for plain- and twill-weave fabrics. Fibre diameter generally had the main effect on fabric stiffness (Fig. 75) and handle, the latter being evaluated according to the

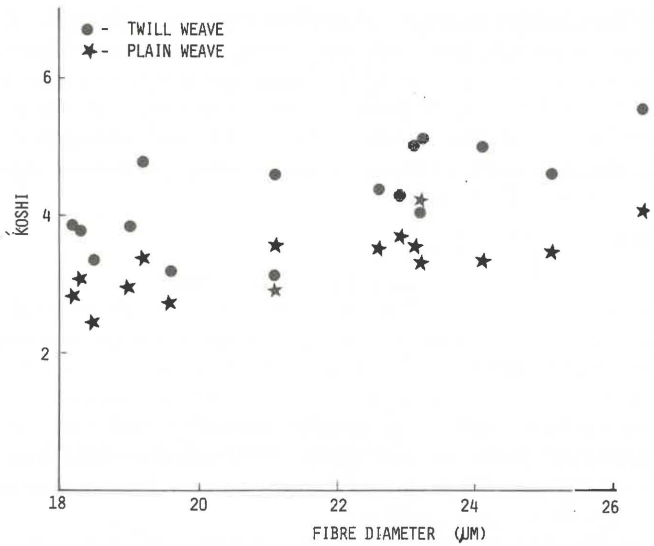


Fig. 75 Effect of Fibre Diameter on "Koshi" (stiffness).(827)

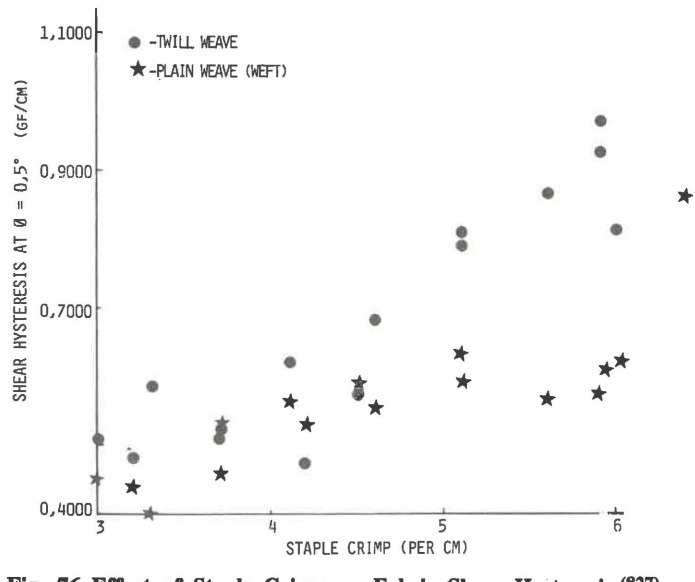


Fig. 76 Effect of Staple Crimp on Fabric Shear Hysteresis.(827)

requirements for summer suitings, while fibre crimp had the main effect on the fabric shearing properties (Fig. 76) and bending hysteresis. Fibre crimp and fabric thickness appeared to increase in importance when the fabric handle was evaluated in terms of the requirements for winter suitings. In certain cases, the effects of the fibre properties on the fabric handle and mechanical properties could be explained in terms of their effects on fabric properties, such as thickness, weave crimp and mass.

15.9 HYGRAL EXPANSION*

Mandel[95] showed that woven fabrics which had been set (chemically or otherwise) were less stable to changes in relative humidity than fabrics which had not been set, with tighter fabrics more stable than more loosely woven ones. Making up the fabric at intermediate relative humidity (≃ 65% RH) was preferred, i.e. extremes in relative humidity should be avoided during making up. Garments made up under high relative humidity conditions would shrink when exposed to relatively dry conditions. Hoffman pressing for two minutes caused fabric shrinkage due to a decrease in regain, while ironing with a very damp cloth caused hygral-expansion.

Shiloh *et al*[763 837] investigated the effects of fibre properties, notably diameter and crimp, and weave crimp on hygral expansion of plain and twill weave fabrics. It was found that fabric geometry, as reflected in weave crimp, was the most important factor contributing to hygral expansion, higher weave crimp leading to higher hygral expansion. Weave crimp also increased with an increase in staple crimp as did hygral expansion. This confirmed the results obtained in various other studies[932]. The results obtained on the 108 all-wool fabrics, and on six identical mohair fabrics produced, confirmed that fibre cross-sectional swelling and fabric geometry (mainly weave crimp) played the main rôle in determining hygral expansion, fibre properties such as diameter, staple crimp and bilateral structure, mainly being of importance when they cause a change in weave crimp (Fig. 77).

15.10 FABRIC SEWABILITY, SEAM SLIPPAGE, AND SEAM PUCKER

Hunter and Cawood[842] found very high correlations between percentage sewability and average penetration force, for twill and plain weave fabrics woven from wools differing widely in their fibre characteristics. Lower, but still highly significant, correlations were also found between the sewability of some of the same fabrics when measured on the L & M and HatraSew testers respectively. Fabric sewability deteriorated with an increase in fibre bulk (crimpiness) and fabric mass.

*See also 15.1

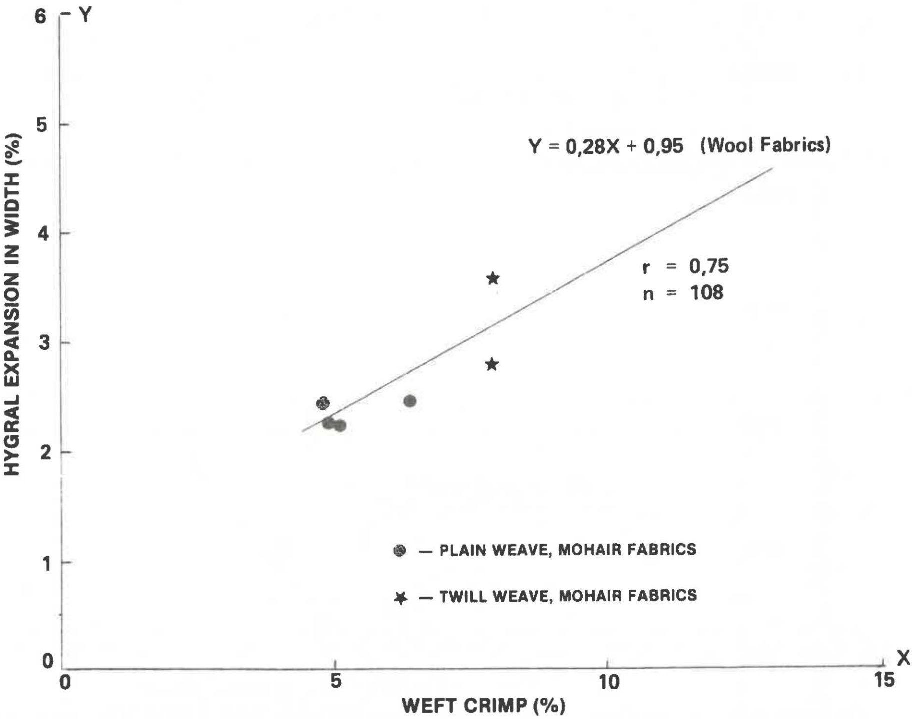


Fig. 77 Regression curve illustrating the relationship between hygral expansion in the width direction and weft crimp for all-wool plain and twill fabrics.(763)

Galuszynski[947] presented a theoretical analysis of the principles of seam slippage in woven fabrics and showed that the amount of seam slippage, or fabric resistance to seam slippage, depended on such factors as yarn-to-yarn friction, yarn-to-sewing-thread friction, yarn flexural rigidity, and stitch and fabric geometry. He showed[919, 970] that the fabric resistance to needle piercing was closely related to the product of fabric tightness and mass (Fig. 78), with an increase in needle diameter always increasing the needle penetration forces. The trends were largely independent of whether or not a sewing thread was used, although the latter significantly changed the magnitude of the forces. He also investigated ways of reducing seam slippage in woollen fabrics for leisure wear[1002].

Galuszynski[944, 956] compared medium ball and slim-set needle points in terms of the forces opposing needle penetration of woven fabrics and found that needles with the medium ball points generally produced smaller forces than those with slim-set points. This trend was generally independent of stitch

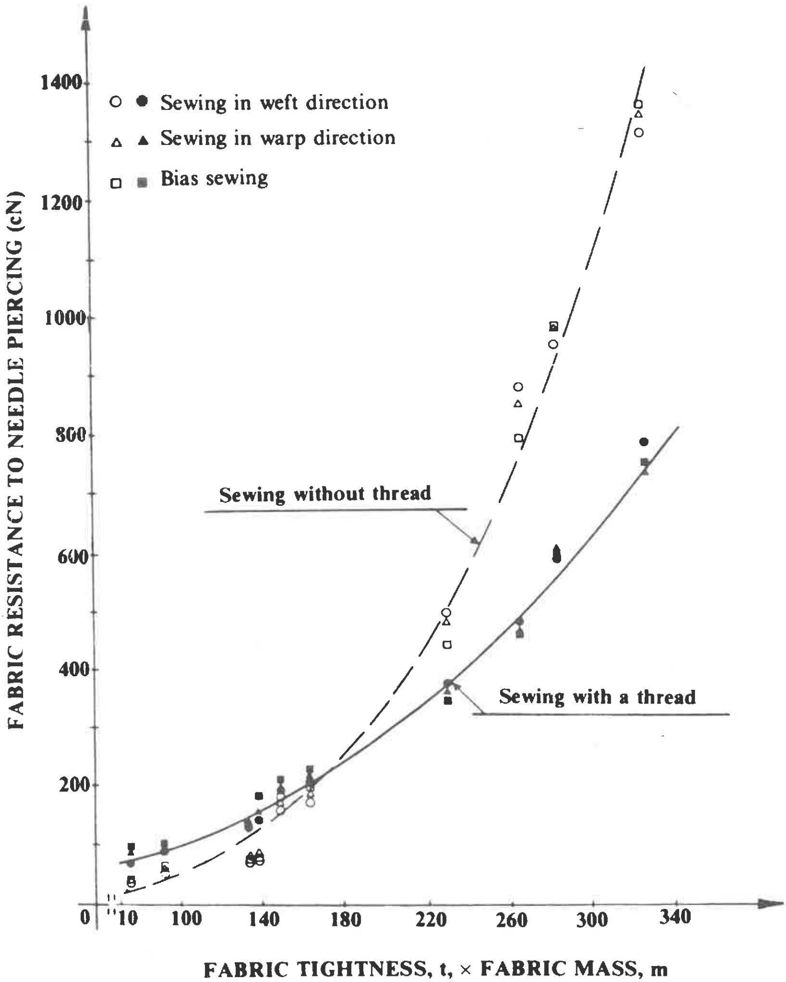


Fig. 78 Effect of the product of fabric tightness and mass (g/m²) on fabric resistance to needle piercing.(970)

length, pressure of presser foot or sewing speed. A thick ball point needle (diameter of 1,00 mm), in some cases, produced greater forces than the set point needle.

Galuszynski[977, 979] investigated the factors which affect seam pucker as well as the measurement of seam pucker and the correlation between different methods of measuring seam pucker (Fig. 79). He developed an apparatus (Puckermeter) which allowed seam pucker to be measured easily and relatively quickly. His theoretical analysis[987] of the mechanisms involved in producing seam pucker, illustrated the importance of presser foot pressure, the coefficient of friction between presser foot and fabric and that between the two fabrics, the fabric elastic properties and the radius of curvature of the front part of the presser foot.

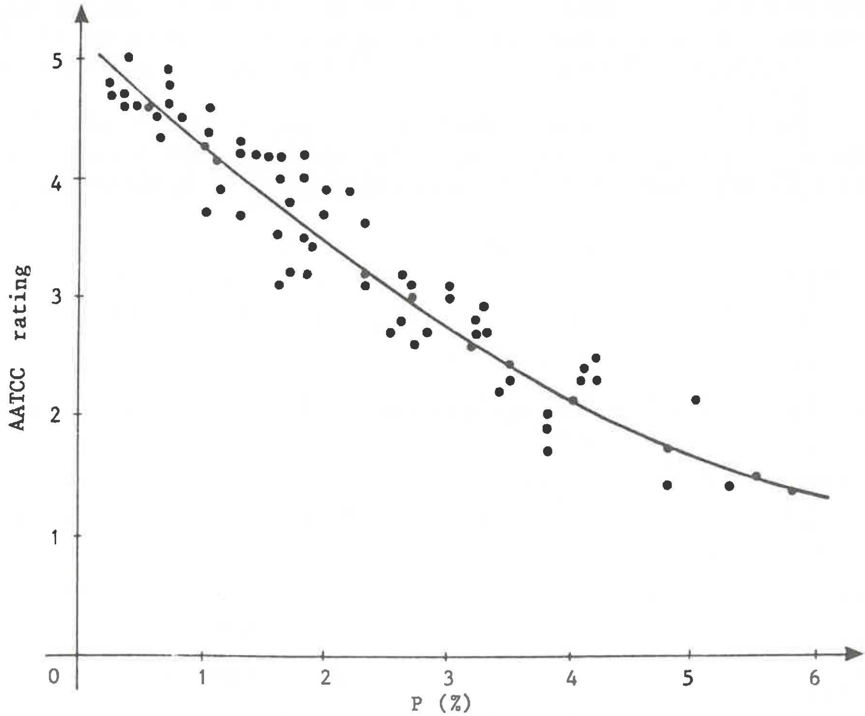


Fig. 79 Relation between Puckermeter results and AATCC rating.(977)

15.11 DIMENSIONAL STABILITY TO FUSING, PRESSING AND DRY-CLEANING

Silver and Roberts[612] investigated the effectiveness of the 'heat-shock' treatment as a means of inducing fabric dimensional stability and found that the time and temperature of treatment were of little significance compared to the prior addition of moisture to the fabric. A moisture add-on of 30% (omf) followed by a 'heat-shock' treatment of 15 seconds at 120°C gave rise to a warp shrinkage of about 6% (Fig. 80). Subsequent commercial steam and fusion pressing routines resulted in a further warp shrinkage of only 1 to 2% compared to 4 to 5% without such a heat-shock treatment.

Investigating the effect of fusing temperature and time on dimensional changes of outer fabrics, Cawood and Robinson[766] found that, in many cases, both fusing temperature and time significantly affected the shrinkage of the fabrics although the effects were small, within the ranges of temperature and time used for commercial fusing. The fusing shrinkage of the all-wool fabrics was relatively low compared to that of the polyester fabrics. The shrinkage measured immediately after fusing was higher than that measured after the fabric had been conditioned (at 20°C and 65%), because of a loss in moisture during fusing.

Robinson *et al*[826] measured the fusing shrinkage of both the outer fabric and the interlining when twelve commercial interlinings were fused to an all-wool 2/2 twill outer fabric. The results indicated that the interlining played a

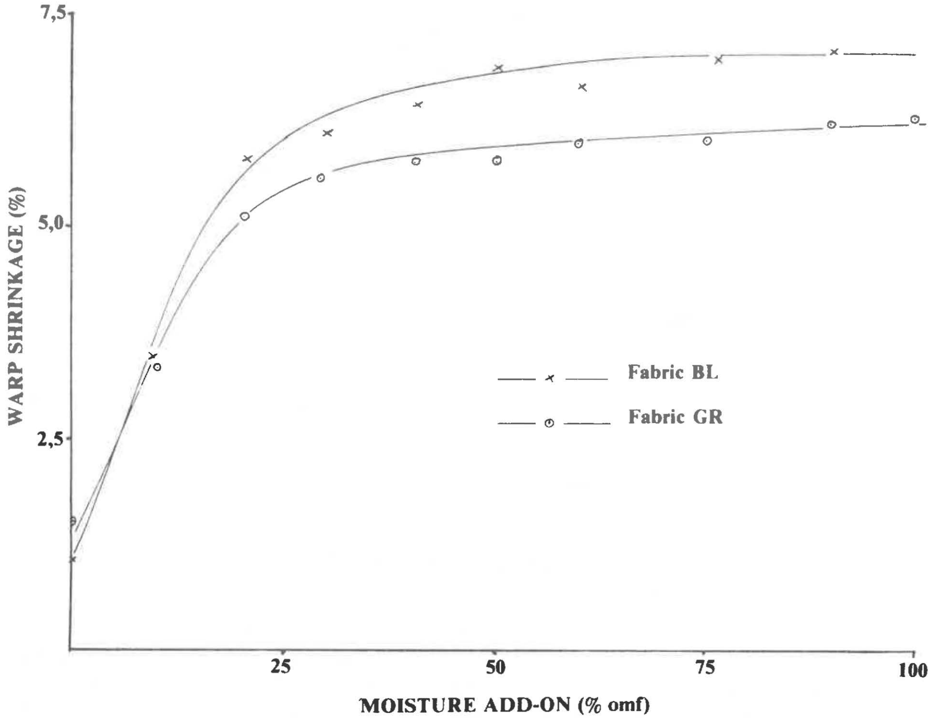


Fig. 80 Effect of added moisture on the effectiveness of heat-shock treatment.(612)

significant rôle in the dimensional stability of the laminated fabric. The degree of shrinkage of the interlining depended upon the fusing temperature, duration of fusing and upon the particular interlining. The shrinkage also depended on the atmospheric conditions under which it was measured.

Robinson *et al*[825] subsequently confirmed that the interlining played a significant rôle in determining the dimensional properties of the laminated fabric. The shrinkage of the interlining depended upon the type of interlining used and upon the direction in which the interlining was aligned, relative to the outer fabric, and to some extent, the glue itself (Fig. 81).

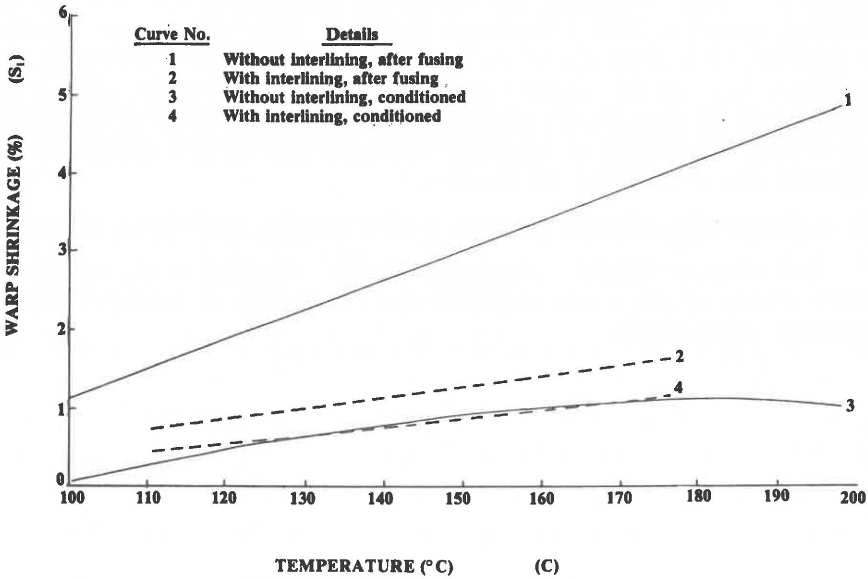


Fig. 81 Regression curves illustrating the effect of fusing temperature (C) (at constant time of 15s where applicable) on fusing shrinkage in the warp (S_1) (wool fabric).(766)

15.12 BOND PEEL STRENGTH

Robinson and Gee[857] investigated the effect of various fusing conditions and of wetting-out or dry-cleaning on the bond peel strengths of different outer fabrics fused to three interlinings.

Interlinings bonded to all-wool fabrics generally had lower bond strengths than when bonded to synthetic fabrics, the average bond peel strength being 8N/2,5cm. Fusing conditions of 165°C (machine setting), to give an actual fusing temperature of 127-132°C, 20s and 300 kPa (3 bar) pressure were suggested as a general guide for obtaining adequate bonding. Wetting-out and dry-cleaning of the laminates generally caused a decrease in the bond strength.

Robinson *et al*[886] studied the effect of industrial fusing conditions on fabric shrinkage and bond peel strength. Twenty fusing presses at eight companies were involved, the temperature, time and pressure settings being monitored. The main findings were that the average shrinkage after conditioning was at an acceptable level. However, bond peel strengths varied from very low values to acceptable levels and no individual company or type of press produced consistently good results.

Galuszynski and Robinson[903] subjected outer fabrics, interlinings, and the laminates of both to steaming and commercial dry-cleaning and found that the steaming operation hardly affected the shrinkage of the laminates and resulted in relatively low shrinkage of the outer fabrics in the case of all-wool and wool/polyester and the interlinings alone. Dry-cleaning hardly affected the shrinkage of the outer fabrics alone, but had a significant effect on the shrinkage of both interlinings and laminates. The bond peel strength changed due to steaming and commercial dry-cleaning.

15.13 KARAKUL INTERLININGS, CURTAINING AND UPHOLSTERY

Robinson and Slinger[353] investigated the use of karakul in interlinings for men's outerwear and it was concluded that satisfactory interlinings could be produced using karakul.

CHAPTER 16

DYEING AND FINISHING

16.1 CONVENTIONAL AQUEOUS DYEING

Thorpe and Veldsman[76] investigated ways of improving the levelness of reactive dyeing of South African wools, the unlevelness being due to the weathered tips dyeing more deeply than the roots. It was found that a permosulphuric acid pre-treatment promoted level dyeing but adversely affected fastness to washing. In a follow-up study[94] the efficiency of certain recommended auxiliaries for improving levelness (i.e. reducing the tip, middle and root differences in dye uptake) was evaluated.

Slinger *et al*[108] made a critical study of various recommended processes for dyeing wool below the boil in both laboratory and industrial trials, with specific reference to afterchrome black. Dyeing below the boil was generally superior to conventional dyeing in terms of fibre and yarn tensile properties, fabric abrasion resistance and spinning performance. The large effect of dyeing on fibre and yarn friction was also illustrated. Conventional dyeing reduced bundle tenacity from about 12,0 cN/tex to about 10,5 cN/tex with the value for dyeing below the boil being about 10,9 cN/tex.

Thorpe *et al*[112] evaluated and compared various levelling agents used by the local textile industry in terms of levelling action and economy and identified those that performed best for premetallised dyes, acid milling dyes and Xylene Fast P dyes respectively.

Swanepoel and Mellet[181 191 207] investigated some factors which determine the degree of fixation of vinyl sulphone (reactive) dyestuffs to wool and found that adequate fixation in commercially acceptable dyeing times could be achieved at temperatures as low as 90°C, provided that the commercial unreactive β-sulphatoethyl sulphone dyestuff was converted to the reactive vinyl sulphone derivative in a separate operation prior to actual dyeing. Activation had to be performed in such a way (e.g. over a long period at room temperature) that hydrolysis of the reactive site was restricted to an absolute minimum. Certain auxiliaries greatly improved dye levelness.

Kupczyk[196] reported on the bleeding and staining of certain dyestuffs during machine washing as well as the perspiration fastness of certain dyes, showing that bleeding was more prevalent in alkaline detergent solutions than in neutral solutions, while the reverse was true for staining. Acid milling dyes of the Benzyl, Alizarine, Coomassie and Carbolan types gave good fastness ratings to alkaline perspiration and washing. Kalinowski[246] recommended a recipe for dyeing "Baby Pinks" with good light-fastness.

Swanepoel and Van der Merwe[247] investigated the continuous pad-steam dyeing of wool using reactive dyes dissolved in concentrated solutions of urea and found that this method generally resulted in lower covalent fixation values and wet-fastness ratings than were obtained by the conventional methods. Fastness to rubbing was satisfactory and the nature of the surfactant or dye assistant did not appear to affect fixation or fastness. To ensure level dyeing, a powerful wetting agent had to be used in the dye liquor. Swanepoel *et al*[257] found the pad-batch process to result in better dye fixation than the pad-steam process although the latter offered the advantage of being a single continuous process.

Swanepoel[328] presented a paper on certain aspects of dyeing at an International Symposium on Dyeing and Finishing in Port Elizabeth. He[400] isolated and identified several derivatives formed by the reaction of urea with model compounds and showed that covalent bonds were formed between urea and the typical reactive groups present in fibre-reactive dyestuffs. Reaction of commercial fibre-reactive dyestuffs with solutions containing ^{14}C-labelled urea, in some cases lead to the formation of radio-active dyestuff derivatives. In padding methods of dyeing, however, reaction conditions were not sufficiently severe to cause the formation of measurable quantities of the dyestuff-urea products.

Van der Merwe *et al*[345] investigated the reactive dyeing of wool below the boil and developed a method to dye wool at 60°C from a solvent-assisted medium and at 80°C in the presence of a reducing agent. Strydom and Mountain[508] described a semi-continuous method for the dyeing of wool with dichlorotriazinyl reactive dyes. The wool was pretreated with a sodium bisulphite solution containing a wetting agent, followed by drying. The goods were subsequently padded with the reactive dye dissolved in a urea-sodium bisulphite solution, and fixed by baking at 100°C for 15 minutes. Unfixed dyestuff, residual bisulphite and urea were removed by rinsing in aqueous ammonia. Fastness to washing and alkaline perspiration was good and the mechanical properties of the fabrics did not suffer to a significant extent.

Roberts[704] studied the effect of three cationic agents, applied as an aftertreatment, on the alkaline perspiration fastness of several classes of dye applied to wool. An epoxy quarternary ammonium compound resulted in significant improvements in this respect, particularly when applied by a padding technique with subsequent baking. He[720] presented evidence of the benefits accruing from the use of N-2,3-Epoxypropyltrimethylammonium chloride as an aftertreatment for acid and reactive dyes on wool. A pretreatment with this compound was found to be far less effective.

16.2 CHROME DYEING

Roberts[592] showed the minimum quantity of chromate necessary for the production of deep colours of high wet-fastness on wool for four chrome dyes. Determination of residual chromium content in the spent dye liquors suggested that levels of about 1 mg/ℓ may be found although occasionally levels as high as 5 mg/ℓ may exist. A method for the removal of residual chromium based upon its reduction to the trivalent state and subsequent precipitation as the hydrated oxide, assisted by a primary coagulant and a polyelectrolyte was investigated. Laboratory results showed that the use of a sedimentation system could reduce the level of chromium to about 25 $\mu g/\ell$ while the use of a filter system could possibly achieve complete removal. The additional cost of the proposed treatment was negligible in terms of both chemicals and time. The importance of avoiding the use of excess sequestrants was stressed.

Roberts[664] subsequently achieved a saving of time in the afterchrome dyeing of wool, by commencing the dyeing at a higher temperature than normal and controlling exhaustion by means of a steady reduction in pH, the final pH being that at which chroming occurs. It was possible to avoid the necessity of reducing the dyebath temperature prior to addition of the dichromate, by its gradual addition over a period of 5 minutes, at the dyeing temperature.

Roberts[665] also determined residual chromium values after dyeing untreated, chlorinated and chlorine/ R Hercosett-treated wools with chrome dyes using various levels of dichromate. At relatively low levels of dichromate, little difference in residual chromium was found between these substrates. As the level of dichromate increased, residual chromium, in the case of the chlorine/ R Hercosett-treated wool, increased at a much greater rate than for untreated wool.

Maasdorp[777 778 839 840] showed the effect of chroming temperature, acid concentration (pH) and chrome type on the residual chromium concentration in the dye liquor and concluded that the lowest residual chromium content was attained in the lower concentration ranges for formic and lactic acid, and in the upper concentration ranges for acetic acid, or at a pH of between 3,5 and 3,8 for all the acids. He suggested[778] an alternative afterchrome technique for the chrome mordant dyeing of wool which incorporated an afterchroming temperature of ± 25°C followed by a short steaming process.

Using a scanning electron microscope (SEM) and an energy-dispersive X-ray system (EDX) to locate chromium in mordant-dyed keratin fibres, Maasdorp[839] showed that the chromium was 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).

Maasdorp[870] used a simple diffusion equation to monitor the initial fast absorption of chromium by dyed and undyed wool. The rates of absorption (diffusion) of chromium by undyed wool, showed an unusual reversal of normal reaction kinetics, an increase in chroming temperature causing a decrease in the rate of absorption. With dyed wool substrates, on the other hand, the opposite was found i.e an increase in chroming temperature caused an increase in the rate of absorption of chromium. The apparent activation energy necessary for chromium to be absorbed by dyed wool decreased with decreasing pH and was independent of acid type.

Certain aspects of the above studies were incorporated into a Ph.D. thesis[817] by Maasdorp.

16.3 DYEING OF SHRINKRESIST-TREATED WOOL

The production of pastel pink shades and fastness properties of certain dyestuffs on R Basolan (DCCA) shrinkproofed wool were investigated by Kupczyk[154 190] who found that, by and large, acid dyes, and to some extent 1:2 metal complex and afterchrome dyestuffs, had somewhat inferior wet-fastness properties on chlorinated material. This, however, was not the case for the R Remazolan dyestuffs and certain of the acid dyes and the range of R Neopolars studied. Results achieved with dyeing below the boil were generally not very satisfactory from a wet-fastness point of view. He also compared the performance of various optical brightening agents.

Swanepoel and Viviers[192] investigated the fixation of Remazolan dyestuffs on shrinkproofed wool and found that the fixation values varied from dyestuff to dyestuff depending upon the concentration of unreactive dyestuff present, but the response of the various dyestuffs, in terms of fixation, to the various treatments applied to the wool, was similar. It was also concluded that, with the exception of treatments which produced a high concentration of thiol groups in wool, the common shrinkproofing methods were unlikely to influence the rate of dyeing or the degree of fixation of R Remazolan dyestuffs significantly, although the importance of proper neutralisation of wool following reactions conducted in acidic media was emphasized.

Swanepoel and Van Rooyen[300] investigated ways of reducing the mass loss suffered when wool shrinkproofed with DCCA was dyed, by introducing cross-linkages into the protein thereby reducing the solubility of the protein. They found that the loss in mass could be reduced by applying a suitable protective agent during an aftertreatment (e.g. R Sulfix A or formaldehyde) immediately after the anti-chlor treatment.

16.4 TRANSFER PRINTING

Hayes *et al*[553] showed that all-wool fabrics could be transfer- printed under moist conditions using reactive dyes. The support medium could be prepared with paper coated with a hydrophilic film, superimposed on a hydrophobic barrier, with the dye paste being applied to the former. Prechlorination of the wool significantly assisted dye uptake and fixation. Furthermore, steaming of the printed fabric was also found to improve fixation. Subsequently[575] a poly-ethylene-paper laminate was found to have excellent dye release properties when used as a temporary support for reactive dyes, with virtually all the dyestuff on the support being utilized.

Further studies by Roberts[611] on the printing of wool by the wet transfer route showed that the quantitative transfer of colour from a commercially available poly-ethylene-paper laminate support was possible. The effect of temperature, time and wet pick-up on rates of transfer, print definition and penetration was shown and the wet- fastness characteristics attainable without a wash-off summarised.

16.5 RADIO FREQUENCY DYEING AND FINISHING

Van der Walt and Van Rensburg[781] compared the drying of wool and wool blend fabrics by dielectric and conventional heating systems and found that the energy consumption and drying energy cost in the dielectric dryer increased slightly when the fabric regain decreased to a value of about 15%, below which it increased more rapidly with further decreases in the regain. The dielectric drying energy cost increased when the distance between the electrode plates increased, but was lower than that of the conventional oven drying when drying to regain values higher than 15%.

In a number of studies at SAWTRI, Barkhuysen, Van Rensburg and co-workers[794 807 931 936] investigated the radio frequency (RF) dyeing of wool and other fibres on a pilot-scale Fastran continuous top-dyeing machine and compared it with conventional dyeing. They concluded that the RF dyeing technique compared favourably with conventional dyeing and held a number of

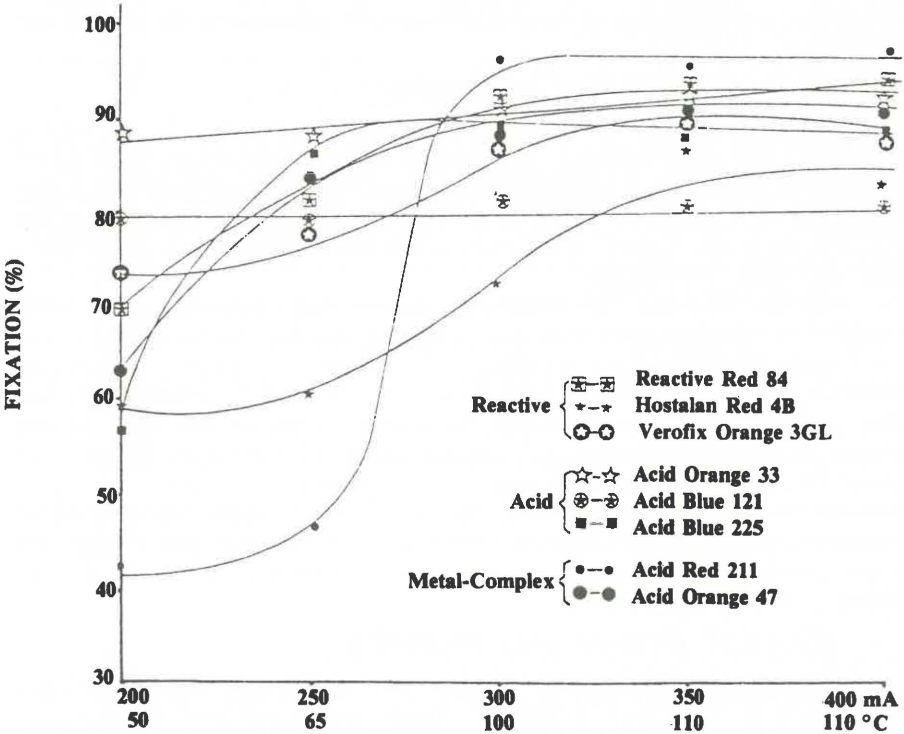


Fig. 82 Relationship between temperature and dye fixation for various dyes during RF dyeing[967]

advantages, RF dyeing in most cases producing similar or slightly better results than conventional dyeing as far as dye fixation, processing performance and yarn and fabric properties were concerned. Their studies also indicated that less fibre damage occurred during RF dyeing. Significant savings, particularly in terms of energy (as high as 80%), appeared to be possible with the RF technique when compared with conventional dyeing techniques.

Barkhuysen and Van Rensburg[967] also investigated the effect of RF generator anode current on the dyeing temperature and the effect of dyeing auxiliaries in the pad liquor on the dye fixation, fastness ratings and colour strength of wool dyed in an RF dyeing machine. It was found that acceptable dyeings were obtained at relatively low anode current settings (i.e. at relatively low temperatures — see Fig. 82). Furthermore, auxiliaries, such as urea, thickening and de-aerating agents, did not affect the dye fixation and wash-fastness ratings of RF dyed wool. More level dyeings were obtained, however, in the presence of thickening and de-aerating agents.

Van Rensburg *et al*[975] discussed and summarised the use of RF energy for the dyeing and bleaching of textiles with specific reference to the studied carried out at SAWTRI.

16.6 FOAM DYEING AND FINISHING

Van der Walt and Van Rensburg[812] reviewed the literature on low add-on techniques and foam finishing and reported on some preliminary trials on the shrinkresist treatment of wool fabrics applying R Synthappret BAP and R Hercosett 125 on a laboratory FFT (Foam Finishing Technology) machine. At low wet pick-up levels, there were differences between the resin levels on the fabric face and back, respectively.

Van der Walt and Van Rensburg[935] showed that wool and mohair fibres could be successfully dyed with metal-complex and reactive dyes using a Gaston County laboratory foam finishing (FFT) machine. Level dyeings were obtained at wet pick-ups ranging from 40% to as low as 20%, it being important that surfactants be selected having the required foaming and good wetting properties. The dye fixation and fastness ratings of foam-dyed fabrics compared favourably with those obtained by conventional techniques. It was found that for the same urea add-on level (on mass of wool), foam dyeing (reactive) produced higher covalent fixation values than conventional pad dyeing. The foam dyeing and finishing of wool and other fibres formed the basis of a Ph.D. thesis[962] by Van der Walt.

16.7 SOLVENT DYEING AND FINISHING

Swanepoel and Roesstorff[344] carried out a preliminary investigation into the dyeing of wool from a charged solvent system and described a charge consisting of a mixture of an anionic surfactant, an alkylolamide and water which could be used for the emulsification of a large number of wool dyestuffs in a perchloro-ethylene medium. Dyeings of satisfactory wet-fastness and levelness could be obtained at 90°C and recovery of the solvent was facilitated by absorption of most of the water by the wool. Van der Merwe et al[345] investigated the reactive dyeing of wool below the boil and developed a method to dye wool at 60°C from a solvent-assisted medium and at 80°C in the presence of a reducing agent.

Van der Merwe and Van Rooyen[360] showed that all-wool knitted fabrics could be stabilised in respect of both relaxation and felting shrinkage, by treatment with R Synthappret LKF in a perchloro-ethylene solution followed by autoclave steaming. They[383] described a method of dyeing wool with reactive dyes from a charged perchloro-ethylene solution. The charge consisted of water, glycerol, sodium dodecyl-benzenesulphonate and lauryl mono-ethanolamide. By dyeing at 100°C for 20 min in the charged system, the fastness properties of such dyeings were found to be similar to those obtained by means of an aqueous system. They subsequently[476] developed a method for dyeing wool with reactive dyes from perchloro-ethylene, utilizing co-solvents comprising glycerol, ethylene diglycol, sodium dodecylbenzene-sulphonate and lauryl mono-ethanolamide overcoming previous problems associated with the formation of an azeotrope. Dyeings of fastness properties similar to those of aqueous dyeings were obtained after dyeing in the solvent medium at 100°C for only 40 minutes.

Various aspects of solvent dyeing and bleaching have been studied by Van der Merwe[370] while Veldsman[365] discussed the properties of organic solvents required for use in textiles as well as their applications in the field of textiles.

Hanekom and Van der Merwe[356] investigated the shrinkresist treatment of wool with hexachloromelamine in perchloro-ethylene and found that, although effective, several disadvantages needed overcoming.

Van Rensburg[355 443 464] showed that wool could be bleached successfully in emulsions of hydrogen peroxide and optical brightening agents in perchloro-ethylene. The degree of whiteness of the wool increased when the reaction temperature, reaction time and concentration of an optical brightening agent or hydrogen peroxide increased. Provided the concentration of the hydrogen peroxide was kept reasonably low, no excessive chemical degradation of the wool was found. Van Rensburg and Scanes[387] also showed that wool could be bleached with emulsions of aqueous permonosulphuric acid in perchloro-ethylene.

Meissner and McIver[502] showed that wool could be dyed successfully with reactive dyes from a solvent system by the use of the solvent-soluble complex of dye and a cationic surface active agent, provided that small amounts of water or ethylene glycol were added to the dyeing liquor. These compounds seemed to act as fibre-swelling agents rather than as co-solvents for the dyestuff.

Roberts and Botha[541] devised a laboratory system of dyeing wool with reactive dyes from an aqueous charged perchloro-ethylene system whereby the wet-fastness properties, hue, depth of shade and brightness characteristics were comparable with those obtained by conventional aqueous dyeing and which eliminated difficulties associated with earlier methods, such as the retention of auxiliaries by the fibre and the necessity of using large quantities of emulsifying agents. The low liquor-to-goods ratio and shorter dyeing time at the boil could make a significant contribution towards reducing energy consumption.

Veldsman *et al*[546] described the solvent dyeing (laboratory and bulk) of wool using the hexadecyl pyridinium chloride derivative of reactive dyes and perchloro-ethylene in the presence of 40% water and 20% acetic acid at a wool-to-liquor ratio of 1:20.

Roberts[585] used an aqueous charged solvent system to dye a 50/50 blend of wool/Orlon. Reactive dyes were used for the wool component and cationic dyes for the acrylic component. Control of the rate of dyeing could be exercised through the use of an anionic auxiliary and a temperature arrest period.

16.8 SIMULTANEOUS DYEING AND FINISHING TREATMENTS

Van der Merwe *et al*[345] described a one-bath aqueous shrinkproofing-dyeing procedure. Subsequently Silver *et al*[512] reported on the simultaneous shrinkproofing and dyeing of a wool fabric by a padding operation. The padding liquor consisted of a polyurethane resin (its isocyanate groups converted to the bisulphite adducts), a polyacrylate resin, a reactive dye, urea and a wetting agent. After padding, the fabrics were steamed under atmospheric conditions.

Van der Merwe and Van Heerden[487] found that after a chlorination pretreatment, an all-wool fabric could be dyed and shrinkproofed simultaneously by padding with 2,8% R Revertex 275, 0,5% R Hercosett 70 and up to 2% of a reactive dye (o.m.f.) followed by steaming at atmospheric pressure and drying. The treated fabric showed hardly any felting shrinkage during washing. Although the covalent dye fixation was poorer than for the urea-dyed samples, the fastness properties were almost identical. The handle of the treated fabric was rather harsh.

Van Rensburg[599] described the simultaneous shrinkresist and flame-retardant treatment of all-wool fabrics with chlorine- R Hercosett/THPOH or chlorine-THPOH (see also ref. 621). Fig. 83 illustrates the effect of % THPOH on the Limiting Oxygen Index (LOI). The treatment produced fabrics with a very soft handle, without the use of any softening agent. He discussed the effect of the different treatments on certain fabric properties. He[678] subsequently showed that the chlorine-THPOH treatment generally reduced the rate of exhaustion of dyes onto wool although more dye could be exhausted onto wool treated in this manner than onto untreated wool. The treatment also increased covalent fixation of reactive dyes and had little effect on the light-fastness of dyed wool.

Van der Walt *et al*[844] investigated the simultaneous dyeing, flame-retardant and shrinkresist treatment of prechlorinated wool fabrics using various reactive dyes and THPOH. The process produced level dyeings and the fabrics were

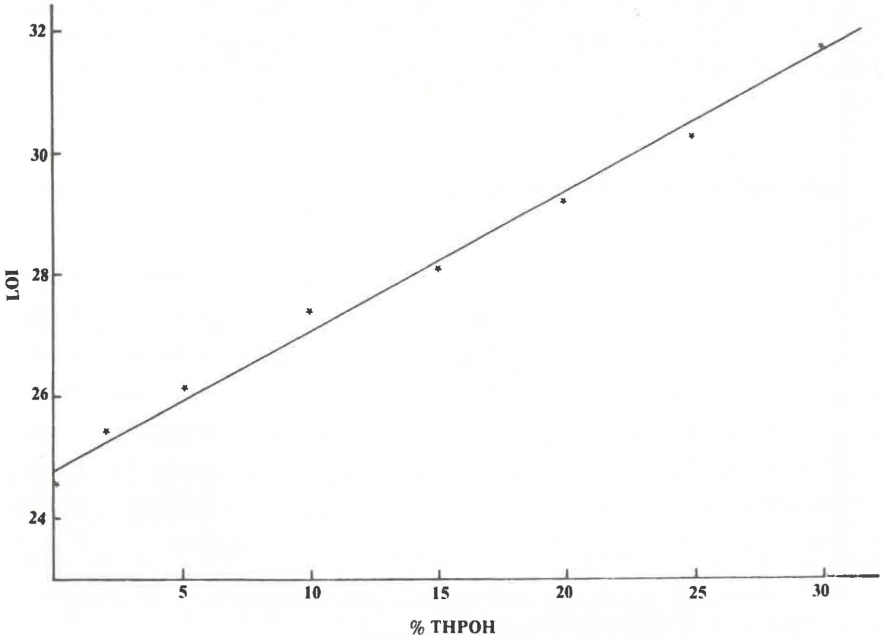


Fig. 83 The effect of THPOH concentration on the LOI values of chlorinated wool (1,5% $C\ell_2$)(599)

shrinkresistant with acceptable LOI values. Furthermore, the handle and strength of the fabrics were acceptable, but in most cases there was some evidence of ring-dyeing. In general, slightly paler shades were obtained with the dye/THPOH treatment than those obtained with conventional exhaust dyeing, using the same concentration of dye.

16.9 FABRIC BLEACHING*

Van Rensburg[382] showed that wool could be bleached successfully with hydrogen peroxide with an organic phosphonic acid (HEDP) as a stabilising agent without imparing its mechanical properties. The organic phosphonic acid derivative used, compared favourably with the conventional stabilising agents and could be used in acid as well as alkaline bleaching baths, a higher degree of whiteness being obtained under alkaline conditions. HEDP, however, also bleached the wool slightly in the absence of hydrogen peroxide in an acidic medium.

Van Rensburg[405] also showed that a new commercially available reductive

* Bleaching in solvent medium is covered under the previous section.

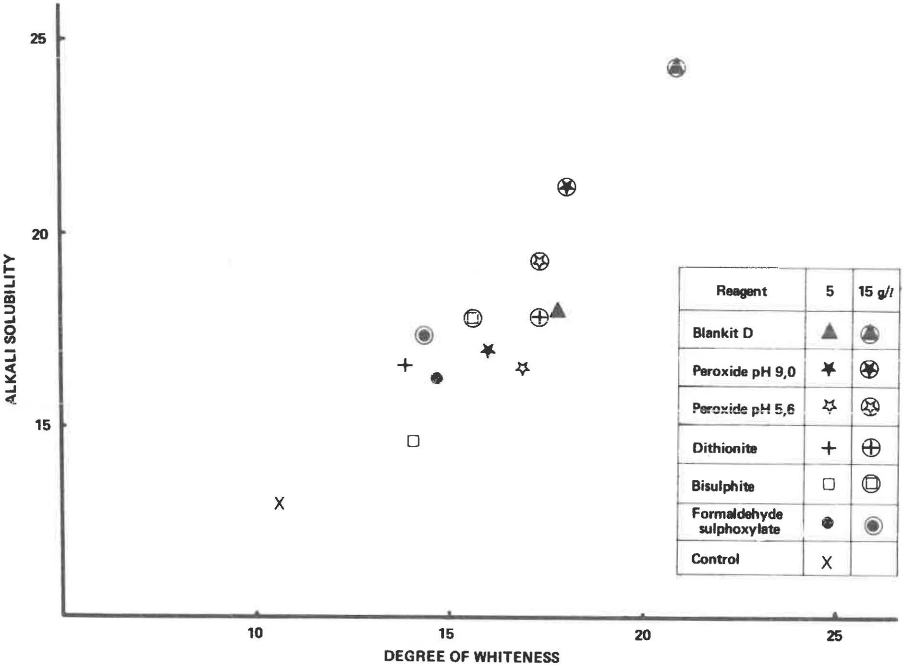


Fig. 84 The degrees of whiteness and alkali solubilities of wool samples bleached by various bleaching agents(405)

bleaching agent R (Blankit D) for wool was better than other conventional reducing agents and also compared favourably with hydrogen peroxide as bleaching agent. It also led to the whitest fabrics with the highest alkali solubility (Fig. 84).

Van Rensburg[235] studied various aspects relating to the reductive aftertreatment of peroxide-bleached wool, using either sodium dithionite or sodium metabisulphite. The dithionite treatment resulted in a whiter bleach but also more damage.

16.10 YELLOWING AND LIGHT DEGRADATION

Van Rensburg[167] investigated the artificial sunlight-yellowing of wools bleached by fifteen common bleaching methods. Best bleach, with regard to both the immediate effect and to the stability of the bleach, was obtained by successively oxidizing the wool with hydrogen peroxide and reducing with dithionite. Bleached wool irradiated in the wet state yellowed more rapidly than samples of normal regain. Application of an optical brightening agent to bleached wool seriously impaired its light-fastness. The rate of sunlight-yellowing of optically-brightened wool could be retarded by treatment with thiourea-formaldehyde or with urea-formaldehyde[279]. The protective effect obtained by these reagents could be made more fast to washing by using a catalyst.

Van Rensburg and Burroughs[234] studied the yellowing of bleached wool during dyeing and found that the use of formaldehyde sulphoxylate was beneficial in reducing such yellowing.

Van Rensburg[388] showed that, although certain research workers had found that the presence of a covalent bond between dye and cellulose led to an increased light-fastness, this phenomenon could not be substantiated in the case of reactive wool dyes. The presence of a covalent bond between wool and the dye in fact sometimes led to a decrease in the stability of the dye against degradation by light. It was found that the assumption that covalent fixation of dyes would lead to low states of aggregation approaching the monodispersed state, was not true in the case of reactive wool dyes which occurred in the wool fibre in the aggregated form.

16.11 MELANIN-BLEEDING AND BLEACHING OF KARAKUL

Kriel *et al*[275] discussed various factors involved in the bleeding of pigment from karakul wool and investigated the influence of the pretreatment history of the fibre on subsequent bleeding. They concluded that the use of alkaline media should be avoided in the processing of pigmented fibres if subsequent bleeding is to be prevented. If processing under alkaline conditions is unavoidable,

Fig. 85 Alkali solubility of bleached karakul as a function of whiteness(869)

neutralisation of the processed material was advisable. An efficient and inexpensive way of achieving this was to terminate the concluding wet process by brief treatment in dilute acetic acid solution.

Van Heerden *et al*[305] formulated a cheap but effective recipe for bleaching karakul which also resulted in limited fibre damage.

Van Rensburg and Heinrich[869] investigated various aspects of the mordant bleaching of karakul, showing that the highest degree of whiteness was obtained at a pH of about 7 and a temperature of about 50°C. Whiteness was related to alkali solubility (Fig. 85), the former increasing rapidly when the concentration of hydrogen peroxide was increased, up to a certain value, whereafter little further increase was noticed. Mordant bleaching had practically no effect on fibre tenacity and breaking extension, but increased the alkali solubility significantly. It was also found that the mordanting and bleaching liquors could be re-used.

Trollip *et al*[943] reported on the effects of pH and temperature on the ferrous mordant treatment of karakul prior to a peroxide bleach. An indirect procedure, not based on the isolation of pigment granules, was used to approximate the extent of iron reaction with the pigment. The temperature at which the best mordanting results were obtained was shown to be strongly dependent on pH and the optimum pH values and temperatures, which produced the best mordanting results without causing excessive wastage of iron via precipitation, were identified. See also ref. 991a

Maasdorp and Van Rensburg[981] described SEM and EDS studies of mordant bleached karakul. They determined the distribution of iron within medullated and solid karakul fibres and found the highest concentration of iron within the cavities (medullae) of the medullated fibres. Similar levels of iron were found within the fibres after the mordanting and bleaching stages, respectively.

16.12 MOTHPROOFING

Swanepoel and co-workers investigated the estimination of ^{R} Dieldrin by polarography[42] and the electro-reduction of ^{R} Dieldrin and ^{R} Aldrin[270]. Swanepoel[296] also investigated the use of urea solutions and the techniques used for the continuous dyeing of wool by this method, namely pad-steaming or pad-batching, in the application of mothproofing agents. ^{R} Dieldrin (Shell), ^{R} Mitin FF (Ciba Geigy) and ^{R} Eulan WA (Bayer), could be applied to wool by the urea method in the same manner as the dyestuff.

16.13 FLAME RETARDANT TREATMENTS*

Basch[666] applied various tetrakis-hydroxymethyl phosphonium chloride (THPC)-amide polymers to wool fabrics by a pad-dry-cure process. THPC-urea-ammonia produced fabrics with high Limiting Oxygen Index (LOI) val-

* Also covered under other sections.

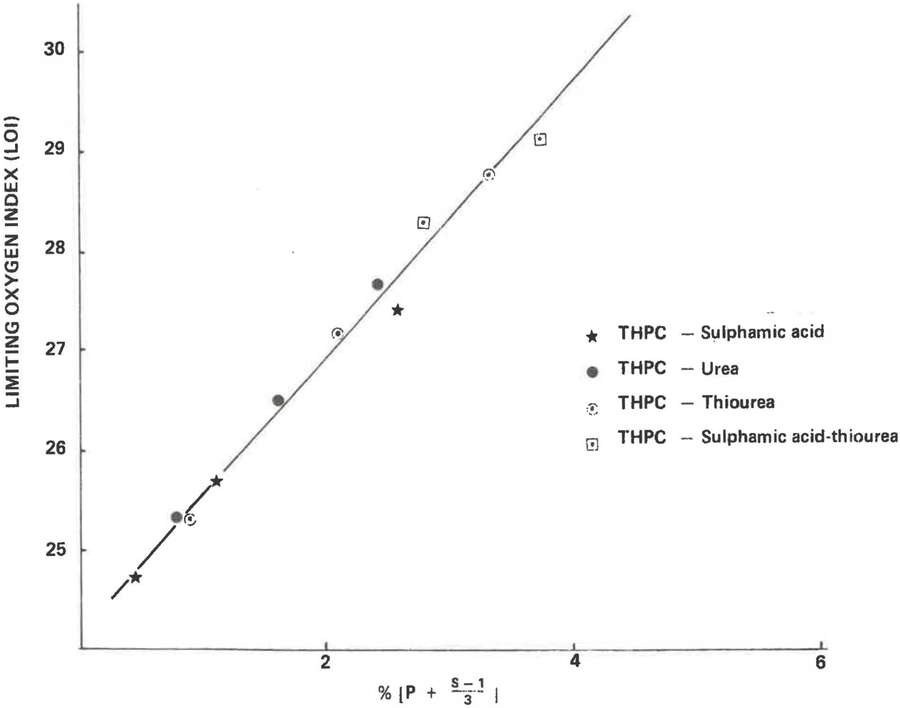


Fig. 86 The Relationship between LOI and Phosphorous and Sulphur content of solution at 100% wet pick-up(666)

ues, but increased the stiffness of the fabrics. THPC-sulphamic acid-thiourea produced soft fabrics showing little strength loss and high LOI values but inadequate fastness to washing. From the accumulated data, the efficiency of sulphur relative to phosphorus (in phosphonium form) on wool was evaluated and a relationship between LOI and the level of sulphur and phosphorous content derived (Fig. 86).

16.14 LIQUID AMMONIA TREATMENT OF WOOL*

Preliminary laboratory trials, carried out by Barkhuysen[736], indicated that wool could be dyed with a reactive dye from a liquid ammonia dyebath. In this respect, the addition of 10% water to the liquid ammonia produced more level dyeings and increased the depth of shade (K/S) values (Fig. 87). Reaction times of only a few seconds resulted in fabrics with acceptable appearance and good

* See also Chapter 19.3.

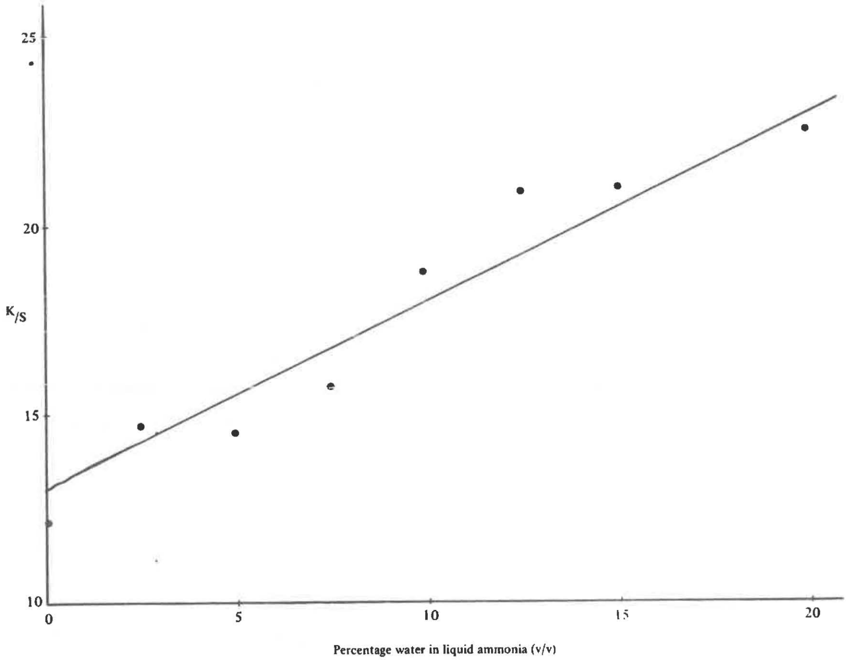


Fig. 87 The effect of various percentages of water in the liquid ammonia on the K/S values of the dyed samples(736)

dye fixation. No hydrolysis of the dye occurred. Steam removal of the ammonia was preferable to removal by heat. A chlorination pretreatment of the fabrics did not prove to be of any real advantage as far as depth of colour was concerned.

16.15 TREATMENT OF DYEHOUSE EFFLUENT

Weideman and Van Rensburg[820] studied the effect of electroflotation, using aluminium electrodes, on the chemical oxygen demand (C.O.D.), dissolved organic carbon (D.O.C.) and colour values of liquors containing acid, disperse, mordant and basic dyes in the presence and absence of wool grease. In general, electroflotation followed by sieving, filtering or centrifuging, reduced the C.O.D., D.O.C. and colour values of the liquors considerably. The presence of wool grease resulted in some improvement in colour in the case of basic dyes. Electroflotation was found superior to flocculation with aluminium sulphate.

16.16 SETTING OF YARN AND FABRIC

The use of special reagents to overcome problems of unpleasant odours associated with the use of bisulphite and urea to produce permanent creases during steam-pressing (wet) was investigated by Mellet and Swanepoel[75] who showed that the reagents introduced by the CSIRO compared favourably with the Si-Ro-Set process when the creased fabric was subjected to cold water (20°C) but compared unfavourably when the creased fabric was subjected to water at a temperature of 75°C.

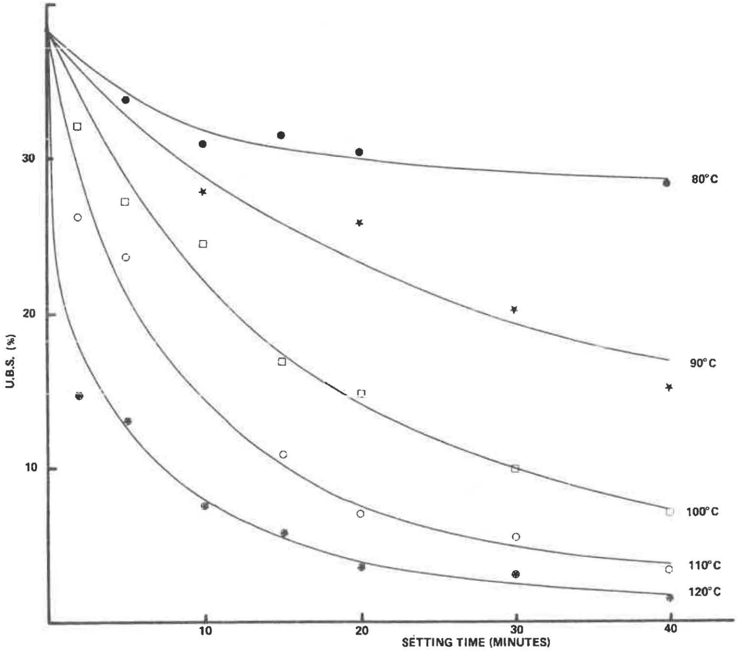
Swanepoel *et al*[71, 90] described a method and apparatus (Creasometer) for assessing the permanence (durability) of pleats (creases) set in wool woven fabrics.

Van Rensburg[552] investigated the effect of autoclave setting of yarn on the rates of exhaustion of different types of dyes (1:1 metal complex, 1:2 metal complex, acid milling, acid levelling and reactive). Setting at high temperatures (110 and 120°C) increased the rates of exhaustion of practically all the dyes. Some dyes were affected more than others. The effect of setting on the degree of whiteness, urea-bisulphite solubility (UBS), breaking strength and snarling twist of the yarn was also investigated (Fig. 88). The UBS seemed to be more sensitive to setting than did the dye affinity (Fig. 88), decreasing when setting temperature or time was increased. When the wool was set at 110°C for 5 to 10 minutes, the UBS was reduced by almost 50%. Yarn whiteness, breaking strength and extension also decreased as the setting conditions became more severe. It was found that very mild setting conditions were sufficient to reduce snarling to acceptable levels.

Van Rensburg and White[610] showed that relatively mild setting conditions (e.g. two five-minute cycles at 100 or 105°C) reduced the snarling twist of plied yarns, or yarn on large cones (1,7 kg, 20cm diameter) to acceptable levels. The rate of dye exhaustion increased when the regain of the yarn immediately prior to setting at 110° and 120°C increased. When setting was carried out at 100°C, however, the regain of the yarn had little effect on the rate of exhaustion, except when the regain was higher than 25%. Autoclave setting increased the degree of covalent fixation of certain reactive dyes, but had little effect on most other reactive dyes.

Turpie and Marsland[730] showed that both the choice of lubricant applied prior to spinning and the autoclave steaming conditions had significant effects on the resultant streakiness of piece-dyed wool fabrics.

Trollip and Raabe[986] investigated the possibility of using sulphur dioxide gas in the sulphitolysis step in a setting process for wool. It was shown that the internal pH of the wool and the presence of ionic surfactants influenced the extent of gaseous sulphitolysis. Thus, while sulphitolysis was strongly inhibited at pH's lower than about 3, two maxima in the extent of the reaction were found at pH's of about 4 and 5,5. An anionic surfactant on the wool surface



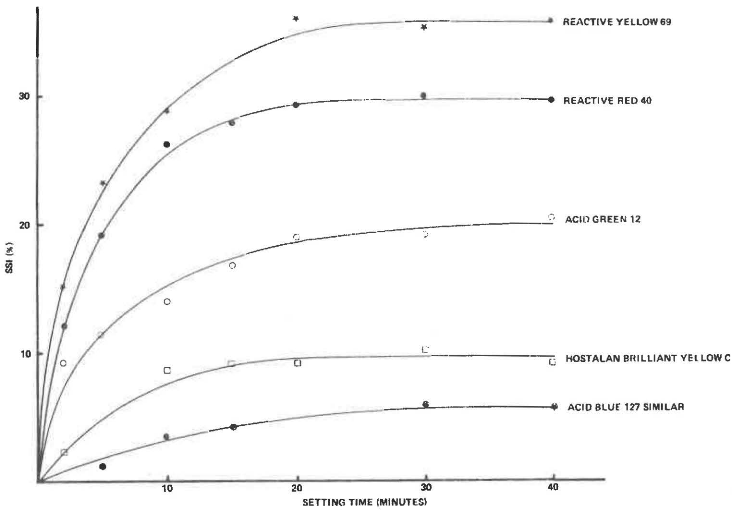


Fig. 88 The effect of setting time on urea-bisulphite solubility and on the setting sensitivity indices (SSI) of certain dyes[552]

was found to inhibit gaseous sulphitolysis while a cationic surfactant was shown to promote the reaction, which was also dependent on the water content of the samples. Good setting could be achieved following short treatments with sulphur dioxide, provided that the initial water content of the wool was sufficiently high (Fig. 89).

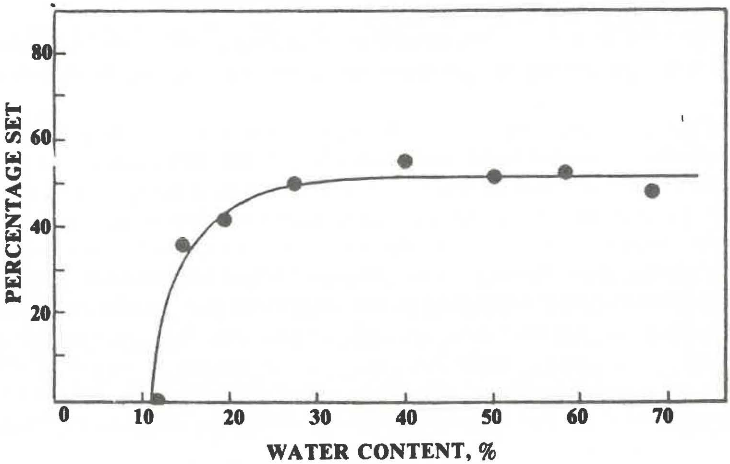


Fig. 89 Influence of water content on the set obtained (evaluated in water) following a 60 second SO_2 pretreatment and a 30 second steaming/pressing cycle[986]

CHAPTER 17

FELTING AND DESOILING BEHAVIOUR AND SHRINKRESIST TREATMENTS

17.1 DESOILING DURING FABRIC LAUNDERING

Ferreira and Van Wyk[77] showed that laundering efficiency (soil removal) improved with increasing temperature and varied according to the detergent used.

The desoiling efficiency of various household detergents, using a laboratory washing machine (washwheel) and measuring light reflectance, was studied and compared by Long and Den Heijer[145] who illustrated the effects of detergent concentration, repeated washing and using different detergents. Subsequently Den Heijer[195] studied the cleansing efficiency of various detergents in a household washing machine (Bendix). The effects of water hardness and speed of the washing machine varied according to the detergent and so did the amount of felting shrinkage which occurred. Swanepoel and Van Rooyen[256] found desoiling to be related to felting, with foam playing a much more important rôle in a rotating drum type of machine, desoiling being influenced by the liquor used and washing time (Fig. 90). Excessive foam reduced the efficiency of washing.

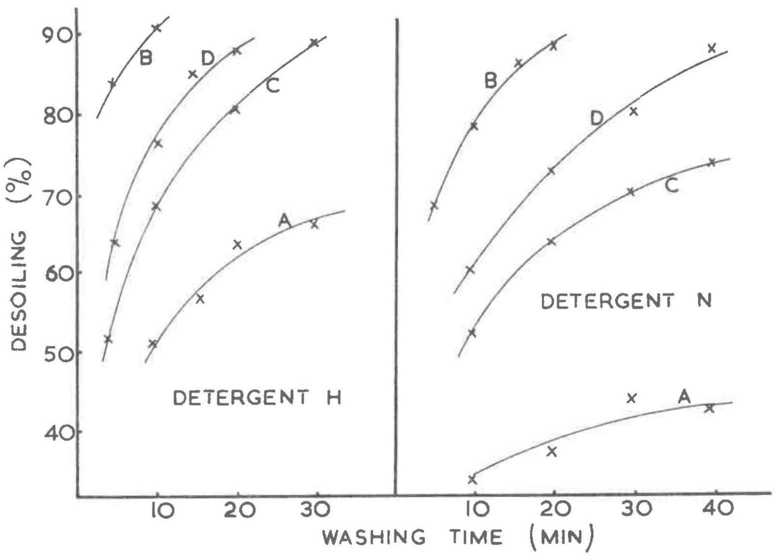


Fig. 90 Curves depicting the rate of desoiling of soiled wool samples in various machines and in two different detergent solutions(256)

Swanepoel and Van Rooyen[295] concluded that wool had superior desoiling properties to most other textile fibres, satisfying the basic requirements for good desoiling characteristics better than any other fibre, desoiling being better in alkaline detergents.

Swanepoel[272 273 282] and Cave[272 282] reported that most shrinkproofing treatments improved the already good soiling resistance of wool. Easy-care fabrics, achieved without the application of resins, exhibited improved desoiling, the opposite applying to those involving resins.

Swanepoel and Van Rooyen[332] investigated the relationship between the rates of felting and soil removal when wool fabrics were washed in domestic washing machines under various conditions of agitation, machine load, and foaming. It was shown that this relationship was a direct one for a particular detergent solution used in the machine. At higher loads, the rates of felting and desoiling were retarded, but the linear relationship was still maintained. Efficient soil removal with less felting could be obtained by the selection of a suitable detergent.

Cave[392], (M.Sc. thesis),[401] studied the improvements in the soil resistance and desoiling of wool treated with a polyamide-epichlorohydrin resin (R Hercosett 57) with and without the application of a soil-release (fluorocarbon) agent. Prechlorination improved soiling resistance while the application of a resin decreased it. The application of a fluorocarbon improved the soiling resistance.

17.2 FELTING SHRINKAGE OF LOOSE WOOL, TOPS AND FABRICS

Veldsman and Kritzinger[34] studied the felting properties of South African Merino wools and developed a laboratory technique for obtaining a relative measure of the feltability of scoured wools based upon the strength and porosity of the felt obtained. They confirmed that fine wools gave a less porous and stronger felt than coarse wools but that the change in porosity from the loose wool state to the felted state was greater for coarse wools. Undercrimped wools, particularly copper-deficient wools, had a much greater felting propensity than overcrimped wools. A change in crimp had a much greater effect than a change in diameter. Weathered wools felted more than sound wools and the effect of weathering could be greater than the effect of fibre diameter. It was shown that fibre diameter and weathering played similar rôles in the felting of Australian and South African wools. The effect of crimp variations in the Australian wools was, however, much less pronounced. Swanepoel and Veldsman[70 101] also showed that weathered wool tips behaved differently during shrinkproofing. Veldsman[259] discussed the effects of weathering and shearing time on felting.

Van Wyk[43], (M.Sc. thesis), investigated the various factors which influence the effectiveness of the shrinkproofing of wool fabrics and in one of the earliest investigations on woollen flannel fabric shrinkage during laundering with sodium sesquicarbonate, he[73] showed that, to reduce felting shrinkage, it was advisable to keep the temperature as low as possible when washing the wool fabrics under alkaline conditions. The adverse effect of increasing liquor temperature on wet and dry fabric strength was also illustrated. In a follow-up study, once again on unshrinkproofed fabric, involving eleven different household detergents, and incorporating the influence of pH, Ferreira and Van Wyk[77] showed that the effect of laundering temperature on fabric shrinkage largely depended upon the detergent used, with maximum shrinkage occurring within the temperature range of 45 to 65°C. Higher pH's during laundering appeared to be associated with lower levels of felting shrinkage. They used oil, however, to suppress excessive foaming and Faure and Hartley[119] showed that this drastically altered the felting behaviour associated with the various detergents. These workers showed that the laundering shrinkage of a woollen flannel fabric decreased with an increase in foam, the addition of an anti-foaming agent increasing felting.

In a study on shrinkresist treated (R Basolan DC) woollen flannel fabrics, Hartley and Veldsman[80] showed that maximum shrinkage occurred at between 25 and 40°C with the rate of shrinkage different for the two washing machines and lower with a lower speed of the rotating drum of the washing machine. It was concluded that a laundering temperature of 50°C was desirable for good soil removal and low shrinkage, provided the pH of the washing liquor was kept close to neutral. In a further study[92] they investigated the effects of dyeing and simultaneous dyeing and shrinkproofing (R Basolan DC and R Dylan ZB) on fabric shrinkage and found that most of the dyeings affected fabric shrinkage during laundering, the efficiency of shrinkproofing being affected by certain dyestuffs and the sequence of the treatment.

Faure[79] developed two methods (weighing ball saturated with water or measuring the average diameter of the ball) for accurately determining the volumes of felted balls when comparing the felting characteristics of loose wool by means of the felt-ball density (Aachen test) method which had been developed by the German Institute of Wool Research.

Faure[88 96 113 122 134] developed an instrument for accurately measuring the diameter of highly compressed felt-balls, speedily and easily and showed that many factors affected the felting density of the balls produced in the Aachen test and that these had to be rigorously controlled if reproducible results were to be obtained. Standard testing conditions, for reproducible test results, were arrived at for untreated top samples. He concluded, on the basis of tests on untreated and shrinkresist-treated tops and fabrics produced from them, that it was unlikely that the "Aachen felting test" could be used as a quantitative measure of fabric shrinkage during laundering, at best it was a qualitative measure. The top shrinkage test appeared better in this respect.

Faure[118] also investigated the effect of fibre length on felting propensity as assessed by the Aachen felt-ball density and top shrinkage test. Although both tests followed the same trends, no definite conclusions could be drawn concerning the effect of fibre length on felting shrinkage.

Den Heijer[177] further investigated the Aachen felting test with a view to produce maximum differences in felting rates between different types of wool (treated and untreated) and between various blends of wool and mohair. The felting rates of different breeds of wool, including an Australian cross-bred wool, were also studied.

Long and Veldsman[131] investigated the effect of washing machine loading on fabric shrinkage on two different commercial washing machines and found one machine to give much more reproducible and consistent results than the other. Overloading both machines resulted in less shrinkage but at the expense of laundering efficiency (desoiling). Low liquor-to-goods ratios resulted in higher felting shrinkage.

Faure and Long[127] investigated the effect of factors such as speed of rotation, liquor volume and temperature, concentration of detergent, total liquor to load ratio and time of tumbling on the shrinkage of a knitted fabric in the Cubex washing machine. Methods of relaxing the fabric prior to washing were also investigated. They concluded that fabric shrinkage increased with an increase in temperature up to 70°C and an increase in the rotational speed of the cube and with a decrease in liquor volume and the amount of detergent used. The addition of an anti-foaming agent had little effect on shrinkage, if anything, it increased it. Measuring shrinkage after one fixed period of time (e.g. 30 min.), instead of doing the whole shrinkage/time curve, was recommended.

The conditions required to test woven wool fabrics for machine washability were investigated by Long and Den Heijer[155] using Bendix and Cubex washing machines and suitable test conditions were evolved for the Cubex. An increase in liquor volume and a decrease in load effected a decrease in shrinkage. Cotton make-weights effected considerably more shrinkage than machine washable wool make-weights.

Swanepoel and Van Rooyen[256] evaluated the rate of felting and soil removal for domestic washing machines employing four different methods of agitation (rotating drum, impeller, vertical agitator and dunker) and two commercial detergents. Desoiling was found to be directly related to rate of felting, with foam playing a much more important rôle in the rotating drum machine than in the others. For machines in which the goods remained submerged throughout washing, the rate of felting was not significantly influenced by the liquor used, but the rate of desoiling was affected.

Van Rensburg and Barkhuysen[688] compared the dimensional changes and durable press (DP) ratings of wool, wool/cotton and other fabrics washed in four different washing machines and showed that the three local washing machines correlated significantly with the Kenmore washer, although considerable differences existed between the various machines. To obtain a significant correlation with the Kenmore washer, the washing machine and sample size had to be selected according to the type of fabric (Fig. 91).

Munden and Kerley[125] compared the felting shrinkage of a variety of wool fibres differing widely in their physical characteristics, and found little correlation between tests carried out on the loose fibre, on the fibre in yarn form, and when the yarn was knitted into a fabric. They concluded that the physical characteristics of a fibre that determine the felting shrinkage of the fabric were different from those determining the shrinkage of the loose fibre. During initial washing treatments, dimensional changes of the fabric were largely due to loop configuration changes while subsequent changes were caused by felting of the yarn itself. Godawa *et al*[142] found no definite relationship between the laundering shrinkage of knitted fabrics and yarn linear density (Constant Cover Factor) in the case of Dylan Z top treated wool.

Knapton *et al*[333] studied the felting behaviour of untreated plain-knitted all-

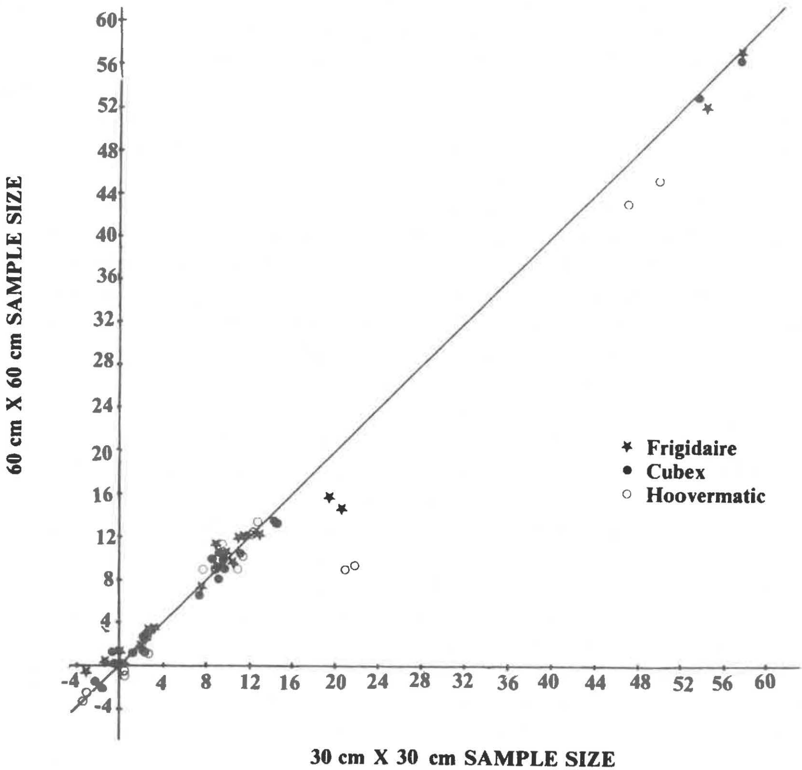


Fig. 91 The shrinkage values obtained on the 30cm x 30cm samples compared with those obtained on 60cm x 60cm samples under the same washing conditions(688)

wool fabrics and derived mathematical equations to describe the felting rate. They showed that the felting behaviour of untreated wool (not shrinkproofed) depended upon fibre, yarn and fabric variables and the complex interactions among these variables, the effect of fabric tightness predominating. They found that coarser wools had a lower felting rate than finer wools but a higher saturation felting shrinkage and ultimately produced a denser felt. Turpie and Shiloh[450] showed that an overcrimped wool felted less in the Aachen felt-ball density test but more in the sliver shrinkage test than an undercrimped wool, the felting shrinkage of the knitted fabric following the same trend as that of the felt-ball test.

Turpie and Barkhuysen[706] found that sliver carbonising involving a relatively short immersion time (15s) in the acid bath, had no material effect on compressibility or felt-ball density.

Hunter *et al*[780] investigated the inter-relationship between fibre properties, loose wool felting and fabric (knitted and woven) felting for more than 50 widely different wool lots. Fibre diameter was found to have a predominant effect on the felting shrinkage of the woven and Punto-di-Roma structures whereas fibre crimp (or bulk resistance to compression) had the predominant effect on loose wool felting and the felting of the single jersey and rib structures. Loose wool feltability by itself provided a reasonable measure of fabric felting shrinkage only in the case of the rib structure. A combination of fibre properties generally provided a better indication of fabric felting shrinkage than any of the fibre properties taken individually. The absolute level of fabric felting shrinkage, as well as the relationship between fabric felting on the one hand and loose wool felting and fibre properties on the other, were dependent upon fabric structure and yarn twist.

Van Rensburg and Barkhuysen[940] used multiple regression analysis to determine the correlation between various fibre properties such as diameter, length and crimp and the felting shrinkage of wool in the form of loose fibres, top (sliver) or fabric for wools varying widely in diameter length, and staple crimp. In general, reasonably high correlations were found between the fibre properties and the shrinkage of the wool (70-80% fit). There was a poor correlation, however, between fabric felting shrinkage and top or loose wool shrinkage. A significant correlation was found between the height of the scale edges of the fibres and fabric felting shrinkage.

17.3 SHRINKRESIST-TREATMENT OF TOPS

The continuous shrinkproofing of tops by the [R] Basolan DC process was investigated by Van Rensburg and Veldsman[93] both in laboratory and industrial trials, in terms of the concentration of the chlorinating agent, salt concentration, temperature, pH and reaction time. Optimum treatment conditions were arrived at in the laboratory trials while the industrial trials showed the process to have potential. An increase in yarn twist decreased end-breakages during spinning.

Godawa *et al*[142] compared the processing and felting behaviour of a Dylan Z shrinkresist-treated top during re-combing, drawing and spinning with that of an untreated control (50/50 Cape Australian blend 64's quality 11/12 months). It was found that there was little difference between the with-scale and against-scale friction of the treated fibres, the treatment appearing to increase the with-scale friction slightly and to reduce the against-scale friction. The shrink-resist treated wool had a poorer spinning performance than the untreated wool and the yarns were also slightly more irregular.

Swanepoel and Veldsman[70, 101] showed that weathered wool tips were more difficult to clear after the wool had been shrinkproofed by the permanganate/brine process, the $KMnO_4$ penetrating the weathered tips more deeply and reacting more quickly with the tips.

Swanepoel *et al*[315] found that the substantivity of wool towards ^{R} Hercosett after chlorination at a pH of 2 could be enhanced by dechlorinating. Thiol groups resulting from the dechlorination appeared to take part in the adsorbtion of the resin. They also described a method based upon gas chromatography which they found suitable for quantitatively determining the resin on wool. Swanepoel and Dangerfield[348] subsequently showed that polyamide-epichlorohydrin (PAE) resin reacted with the thiol- and amino-groups in wool to produce covalent grafting of the resin to the surface of the wool. The extent of the occurrence of this reaction was considered sufficiently great to play a significant part in the retention of the resin by the wool.

Van der Merwe and Van Heerden[357] reported on some factors which played an important rôle in the effectiveness of the ^{R} Hercosett treatment of tops.

Veldsman and Swanepoel[395] investigated the influence of the rate of chlorination on shrinkproofing with DCCA and found that a change in reaction rate, caused by changing the temperature or the reagent concentration, slightly affected the resistance of the treated materials to felting. A change in the pH on the other hand affected the very nature of the reactions involved and changed the efficacy of the treatment substantially.

Hanekom and Barkhuysen[495] described an improved continuous chlorination process (tops or fabrics) involving padding the wool with a solution consisting of an alkali salt of DCCA and an acid mixture of an inorganic and organic acid at pH levels between 1 and 2. Very effective and uniform chlorination was achieved with this process when padding on 1,5% active chlorine.

Weideman and Grabherr[496] used a polyamide-epichlorohydrin resin to render wool shrinkresistant employing the potassium salt of DCCA at a low pH (1,5-2,0) as a pretreatment, the wool being evenly treated using a pad mangle and four bowls. The resin could also be applied after the DCCA treated tops had been processed into knitted fabrics.

Hanekom *et al*[537] showed that tops could be shrinkresist-treated by chlorinating with a DCCA solution at a pH of 2,0 followed by treatment with an acid colloid methylolmelamine resin solution containing a polyethylene softener.

Treatment of the tops with 1,5% active chlorine, (DCCA) followed by the application of a mixture consisting of a 2% acid colloid resin and 1% polyethylene softener (o.m.f.) produced highly shrinkresistant knitted fabrics which dyed levelly in all cases. The re-combing performance of the shrinkresist-treated tops was quite satisfactory. The shrinkresist treatment was also carried out successfully on an industrial scale at a local textile mill. Hanekom and Barkhuysen[540] showed that relatively stable concentrated DCCA solutions with a low pH value were obtained by using a mixture of an organic and an inorganic acid. Different organic acids, or combinations with inorganic acids, could be used to adjust the pH of the chlorination solution and to prevent or retard the precipitation of the DCCA from the solution.

Weideman *et al*[655] studied the swelling of polyamide-epichlorohydrin (PAE) and methylolmelamine resin films in buffer solutions at various pH values as well as the shrinkage of wool treated with these polymers. The swelling of the former generally decreased with an increase in pH, while the latter resin did not appear to swell. The shrinkage of wool treated with the PAE resin increased when the pH of the buffer solution increased from 3,4 to 7,0 whereafter it decreased. Chlorinated wool without resin behaved in a similar manner. The shrinkage of PAE resin-treated wool increased when the ionic strength of the washing solution increased. The shrinkage of wool treated with the other resin, decreased almost linearly when the pH of the solution increased. A static soaking pretreatment reduced the shrinkage of chlorinated wool as well as that of polymer-treated wool.

Weideman and Van Rensburg[745] described a method whereby the presence of a methylolmelamine resin on wool could be detected by means of infrared spectroscopy after dissolving the wool in sodium hydroxide. Similar attempts to detect a polyamide-epichlorohydrin resin were unsuccessful, due to the similarity between the spectra of wool and the polyamide resin. It also appeared possible to detect the presence of a polyethylene softener on the shrinkresist-treated wool, using this method.

Van Rensburg and Barkhuysen[782] showed that wool tops and fabrics could be shrinkresist-treated successfully by chlorination and the application of an acid colloid prepared from a methylolmelamine resin. The $C\ell_2$/acid colloid treatment compared favourably with other commercially available processes.

Van Rensburg and Barkhuysen[866, 941] developed a system whereby wool tops could be continuously shrinkresist-treated on a conventional suction drum backwash using chlorine gas dissolved in water as pretreatment. The equipment was unsophisticated and the release of chlorine gas into the atmosphere was negligible. This pretreatment offered several advantages over hypochlorite/sulphuric acid and was considerably cheaper. The build-up of salts in the chlorination liquor was also lower (Fig. 92). It was used in conjunction with R Hercosett 125, R Nopcobond SWS 10 and acid colloid resins to produce shrinkresistant wool. The treatment could also be carried out on loose stock on a modified

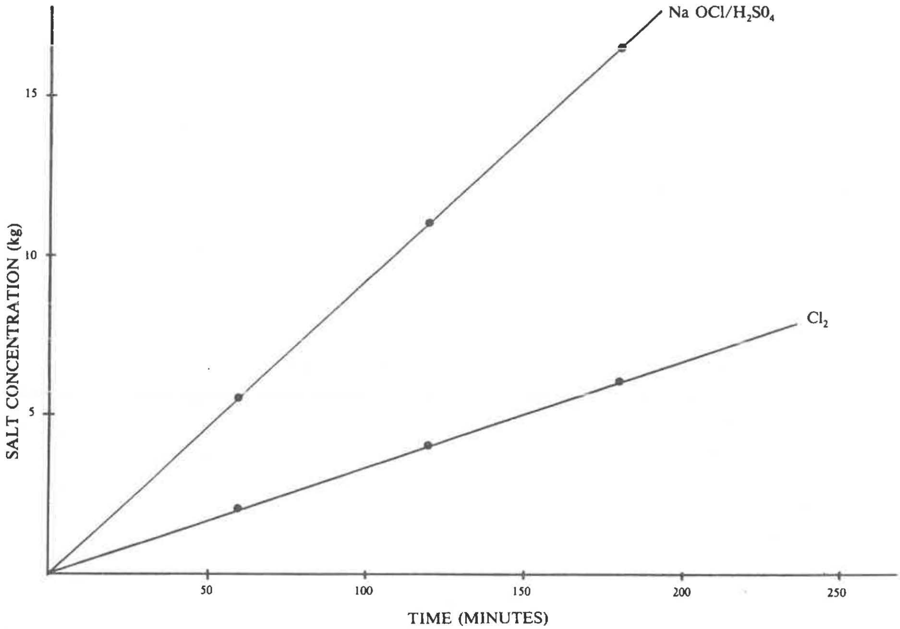


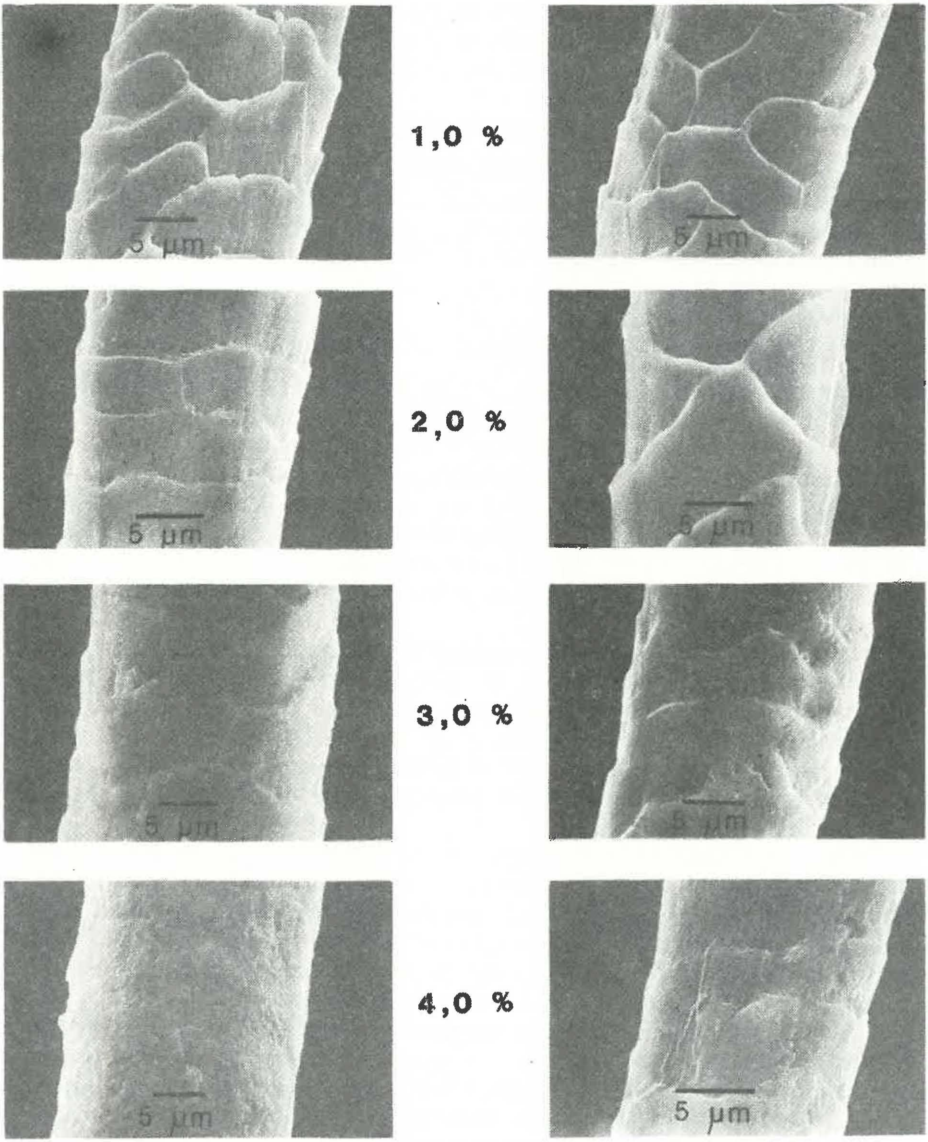
Fig. 92 Theoretical build-up of salt in chlorination liquor(866)

suction drum machine. At relatively high chlorine levels (4 to 6%) the lustre of wool and other keratin fibres increased.

Van Rensburg *et al*[876] showed that the treatment of wool with chlorine gas dissolved in water caused less fibre damage than a treatment with sodium hypochlorite and sulphuric acid, progressively more scale being removed from the fibre as the reagent concentration increased (Fig. 93).

17.4 SHRINKRESIST-TREATMENT OF HAND KNITTING YARNS

Swanepoel and co-workers[315 350] investigated the R Hercosett 57 resin treatment (2 to 2,5%) of hand-knitting yarns, and found that although effective shrinkresist effects were obtained in most cases, there were instances when felting occurred because of unlevel deposition of resin on the wool. Den Heijer and Swanepoel[200], investigating the dyeing and shrinkproofing of locally available commercial hand-knitting yarns, concluded that hand-knitting yarns of sufficient dimensional stability to washing in household washing machines, could be obtained by shrinkproofing with DCCA of sufficient strength to give 3,3% active chlorine on the mass of the wool. The sequence of shrinkproofing and dyeing of the yarn influenced the dimensional stability of the end-product



Na OCℓ + H_2SO_4 | Cℓ$_2$ gas in water

Fig. 93 Effect of chlorination on scale structure[876]

but whichever sequence was employed, special care had to be exercised to ensure that the goods were subsequently neutralised properly. Cilliers *et al*[251] and Smuts *et al*[427] found that adequate shrink-resistance of hand-knitting yarns could be achieved with 4,5% DCCA.

17.5 SHRINKRESIST-TREATMENT OF HOSPITAL BLANKETS

Van Wyk[74] shrinkproofed 36 blankets by five different methods after milling and scouring and subjected the blankets to user trials at a large hospital. He concluded that on the basis of effectiveness, general appearance and handle, the permanganate/salt and R Basolan DC (BASF) processes were superior to the other treatments applied.

17.6 SHRINKRESIST-TREATMENT OF FABRICS

The treatment of wool fabric (doctor flannel) with dichloroisocyanuric acid (DCCA) prior to shrinkresist-treatment with Primal K3 polyacrylate resin was investigated by Du Toit and Louw[143], it being concluded that this shrinkproofing sequence used low-cost chemicals and gave improved abrasion resistance and little or no adverse effect on handle or yellowness.

Den Heijer[174] investigated the effect of various wetting agents on the Basolan DC (BASF) shrinkproofing of fabric and found that they differed in their effects on the stability of the solution, exhaustion of Basolan and shrinkproofing effectiveness.

Den Heijer and Abrahams[199] compared various commercial DCCA products in terms of chlorine content, solubility in water, effectiveness of shrinkproofing, handle and yellowing of shrinkresist-treated woollen fabric materials. No difference in shrinkproofing effects was observed provided the concentrations were such that equal strengths of active chlorine were obtained. Differences in handle and yellowing were obtained, these depending upon the pH used during treatment.

Swanepoel and Becker[238] reported on the shrinkproofing (DCCA) and reduction bleaching (sodium formaldehyde sulphoxylate with and without fluorescent brightening agent) of wool. The application of a resin to improve the light-fastness of fluorescent brightened wool material was also studied. Recipes were formulated for shrinkproofing and bleaching of easy-care wool fabrics in pastel or bright shades as well as in undyed whites.

Swanepoel and Handley[227] discussed the prevention of wool shrinkage by polymer treatments. Hanekom *et al*[385] investigated the shrinkresist-treatment of wool fabrics with an alkylated methylolmelamine resin R (Aerotex M3) and found that adequate shrinkresist properties could be imparted by the application of methylolmelamine resin-polyethylene mixtures without significantly affecting the handle of the fabrics. Pretreatment of the wool fabrics however, was essential. Acid colloid resin-treatment of the fabrics proved to be especially effective. Results indicated that resin add-on levels of 1 to 2% were sufficient to impart the required resistance to felting shrinkage to most woven and knitted wool fabrics.

Den Heijer[254] investigated the effectiveness of various pretreatments in terms of resin (Primal K3) deposition on wool fabrics and recommended either sodium hypochlorite or DCCA. Weideman and Grabherr[497] found that a woven wool fabric could be rendered shrinkresistant in a continuous process using 2% DCCA (1,2% active chlorine) and 0,3% polyamide-epichlorohydrin resin (PAE resin), when chlorinating at a pH of 1,5 or 2,0. When a mixed resin (PAE/polyacrylate) was used, 1% DCCA (0,6% active chlorine) was sufficient as a pretreatment to produce a shrinkresistant fabric.

Van Rensburg[534] studied some factors affecting the shrinkresist-treatment of wool fabrics by chlorination followed by a treatment with a polyamide-epichlorohydrin (PAE)-polyacrylate dispersion and found that the addition of certain polyacrylates to the PAE polymer reduced the degree of shrinkage of the chlorinated fabrics. The minimum concentration of PAE required for successful shrinkresist-treatment depended on the level of chlorination, and increased with decreasing levels of chlorination (Fig. 94). Some PAE/polyacrylate dispersions

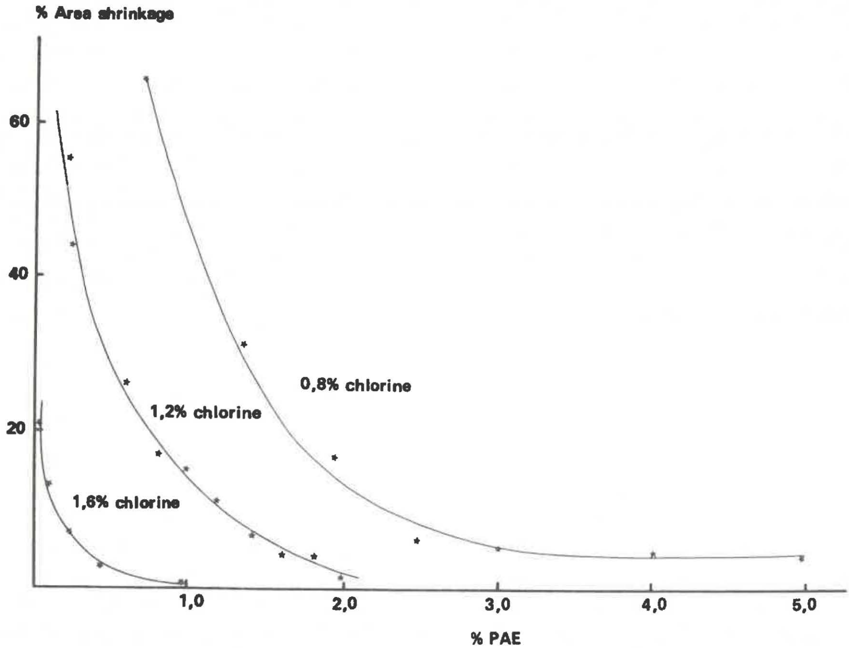


Fig. 94 The percentage area shrinkage of wool treated with different concentrations of active chlorine and PAE polymer(534)

were unstable and coagulated.

Weideman and Grabherr[531] employed the potassium salt of dichloroisocyanuric acid (DCCA) at low pH values (1,8 — 3,4) in a pad mangle to increase shrinkresistance of wool fabrics. The influence of the temperature of the DCCA solution in the pad mangle on the degree of shrinkresistance obtained, was studied as well as the effect of various softeners on the shrinkresistance of fabrics treated with a polyamide-epichlorohydrin resin. They also investigated[580] the effect of the degree of chlorination and various additives in the resin bath on the shrinkage of R Hercosett-treated woven wool fabrics. Some additives appeared more sensitive to the level of chlorination, while others were more sensitive to the level of resin.

Weideman *et al*[779] found that the addition of water to various organic solvents affected the degree of shrinkage of wool fabrics (untreated, chlorinated and resin-treated) washed therein in different ways, the shrinkage sometimes being higher in solvent-water mixtures than in solvent or water only. The shrinkage curves of chlorinated and resin-treated wool differed from that of untreated wool.

CHAPTER 18

WOOL/MOHAIR BLENDS

18.1 YARN AND FABRIC PRODUCTION AND PROPERTIES*

Cilliers[157] reported on the processing of different wool/mohair blends on a modified continental system followed by spinning on a double apron ring frame and showed that long coarse mohair fibres migrated preferentially to the yarn surface and the shorter fine wool fibres to the yarn centre. He[179] also investigated the spinning of different wool/mohair blends on the French (Continental) system and determined the influence of yarn linear density, composition, twist factor and spinning speed on spinnability, yarn breaking strength, elongation at break and levelness. In general, the coarser yarns could be spun more satisfactorily. The number of ends down during spinning was lowest for the 20% mohair blend. Indications were that yarns containing more mohair, should be spun with a higher twist factor to obtain a reasonable spinning performance. Yarns containing smaller amounts of mohair could be spun at higher speeds than those with more mohair. Spinning waste was of the order of 1 to 3%. Yarn hairiness was found to be related to mohair content. Cilliers[287] also compared the spinning performance (French system) and yarn properties of wool blended with artificially crimped mohair, the latter being crimped by the method used to crimp wool fibres artificially.

Den Heijer[177] found that the shrinkage of wool/mohair blends, as determined by the Aachen felt-ball density test, decreased with increasing mohair content.

Slinger and Godawa[175] and Bowring and Slinger[197] investigated the yarn properties and light-weight tropical fabric properties of different blends of a 64's quality wool and a BSFK quality mohair. They reported conflicting results for crease recovery and wrinkling tests and recommended wearer trials to resolve the difference. Nevertheless, it appeared that the effect of the finishing procedure overshadowed any trend due to mohair content. In a follow-up study, Slinger and Robinson[264] found that different wool/mohair blends had no apparent effect on laboratory measured crease and wrinkle recovery, with the coarser fibres producing stiffer fabrics as expected. The crimped wool fibres gave fabrics with greater elasticity than that of the mohair fabrics, with increased yarn crimp improving AKU wrinkling.

Hunter and Kruger[403] investigated the frictional properties of yarns containing different percentages of mohair and found that friction increased with increasing mohair content. By scouring or extracting the yarns with a solvent

* Wool/mohair fabrics are also dealt with in Chapter 21.

prior to waxing, the yarn friction, subsequent to waxing, could be reduced considerably. It was therefore suggested that it was not inherent differences between the mohair and wool fibres, as such, which influenced the yarn friction, but that it was the ether extractable matter present on the mohair which adversely affected lubricating efficiency of the paraffin wax.

The minimum friction of the waxed yarns was found to be correlated with the ether extractable matter content of the yarns[403] (Fig. 95).

Hunter *et al*[423] investigated the dimensional properties and washing shrinkage of various blends of mohair and wool single jersey fabrics and showed that felting shrinkage of the unshrinkproofed fabrics decreased with increasing mohair content and was very close to zero for the pure mohair fabrics. On the other hand loop distortion (cockling) increased considerably with increasing mohair content. Fabric distortion was particularly bad under severe conditions of sol-

Details of Blend	Leomin KP	Topsol	Durosil	Lissapol NX	Eutectal
100% Mohair	●	×	○	□	
80% Mohair/20% Wool	▲				
70% Mohair/30% Wool	▼				
100% Wool					*

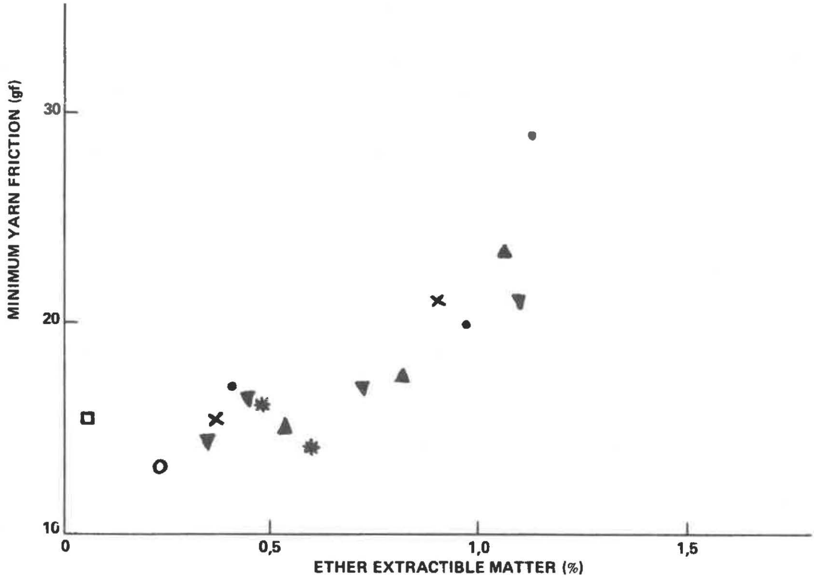


Fig. 95 Minimum friction of waxed yarns vs. ether extractable matter prior to waxing for certain unscoured, scoured and extracted yarns (melting point of wax 63°C)(403)

vent dyeing. By treating the fabrics knitted from untreated yarn with Synthappret LKF followed by autoclaving, or alternatively autoclave-steaming the fabrics knitted from 4½% DCCA treated yarns, reduced cockling and shrinkage to an acceptable level provided the irregularity and mohair content of the yarns were not excessive.

Hunter *et al*[735, 952] established and quantified the effects of mohair fibre diameter and length on the physical properties of wool/mohair suiting type

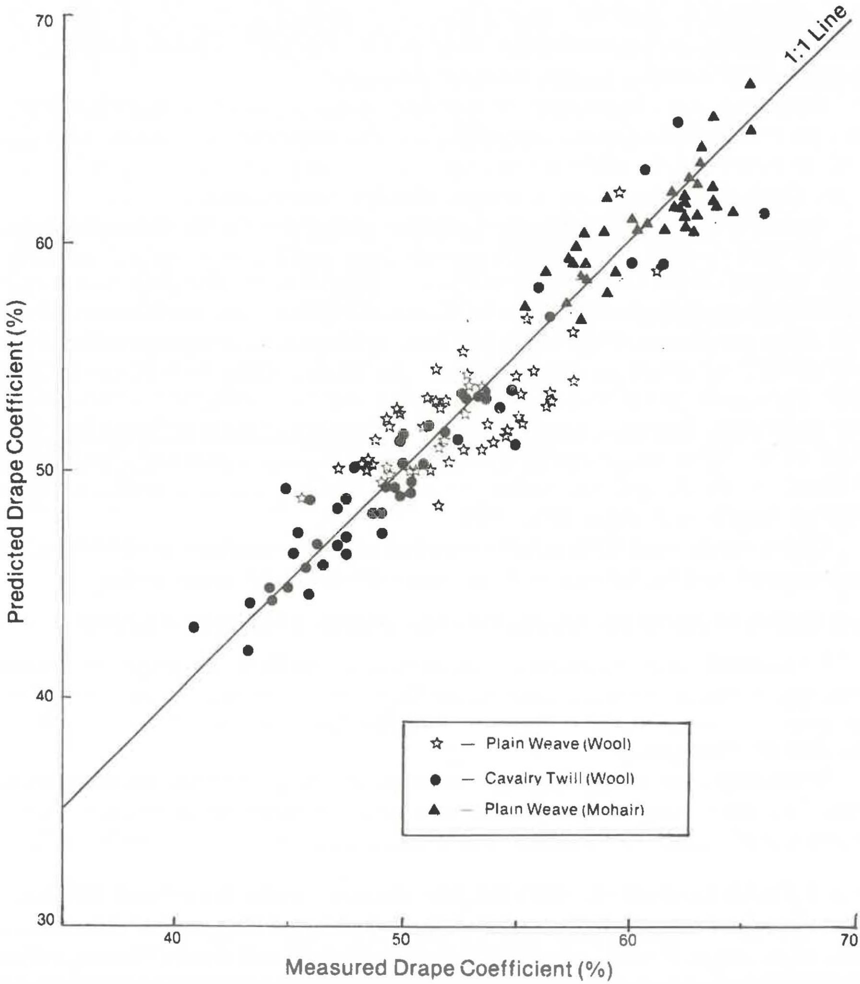


Fig. 96 Predicted vs Measured Drape Coefficient[884]

woven fabrics. They illustrated the large effect of ageing on wrinkle recovery and that of fibre diameter. The effect of mohair on wrinkle recovery was found to depend upon the particular test method used to assess wrinkle recovery (see section dealing with wrinkling).

Smuts and Hunter[819] measured various physical properties of some sixty wool/mohair woven fabrics (mainly plain weave suiting fabrics) with the main objective to establish "average" values for the physical properties of such fabrics which could be used as a basis of reference when similar fabrics were being evaluated in practice. The results were plotted against fabric mass and average values were calculated and tabulated for the various fabric properties to facilitate their use for quality control purposes.

Shorthouse and Robinson[897 983] reported on the affect of mohair fibre diameter, yarn twist, oil content and dyeing on the properties of mohair loop and brushed loop yarns containing a wool/nylon yarn as ground and wrapper as well as on their performance in a woven blanket construction.

Smuts *et al*[884] studied the effect of fibre properties on the shear properties of plain and cavalry twill fabrics woven from wool and wool/mohair (wool warp, mohair weft) lots varying widely in fibre length, diameter and crimp. The fibre properties generally only had a small effect on the fabric shear. Of the wool fibre properties, fibre crimp (or bulk resistance to compression) had the most significant effect on shear stiffness, the latter tending to increase as fibre crimp increased. Shear hysteresis appeared to be little affected by variation in fibre properties. For these fabrics, the small changes in shear stiffness had little effect on the fabric drape coefficient. Drape coefficient was mainly determined by bending length, and the former could be fairly accurately predicted from bending length and shear (Fig. 96).

Galuszynski and Robinson[999] reported on the making-up properties of wool/mohair suiting fabrics and on ways of reducing seam pucker.

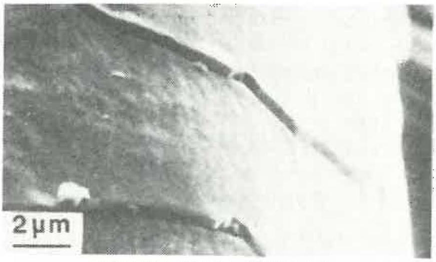
18.2 SCRATCHINESS ASSOCIATED WITH COARSE FIBRES

Swanepoel and Veldsman[280] described a method of reducing fabric scratchiness which involved treating the fabric with sodium bisulphite and either ethylene glycol or polyvinyl alcohol, the latter providing a finish which was fast to laundering.

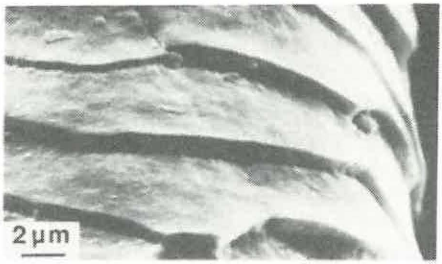
Maasdorp and Van Rensburg[909] used a scanning electron microscope to show that wool and mohair fabrics assessed subjectively as prickly, had a percentage of coarse fibres protruding a short distance from the fabric surface.

18.3 DISTINGUISHING BETWEEN WOOL AND MOHAIR FIBRES

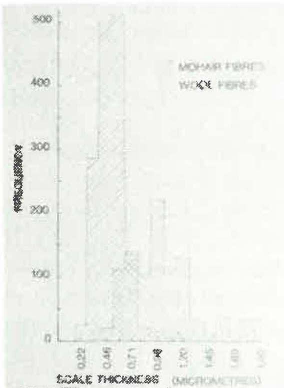
Scheepers[204] suggested using the fibre profile, as determined microscopically, to distinguish wool from mohair while Slinger and Smuts[406] proposed the use of differences in against-scale fibre friction as a way of distinguishing wool from mohair. Smuts *et al*[760] subsequently used the fact that mohair generally had



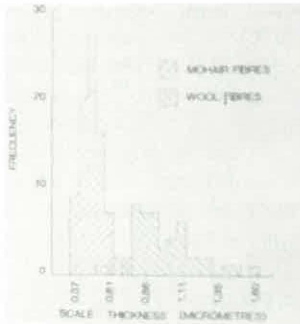
MOHAIR FIBRE SURFACE



MERINO WOOL FIBRE SURFACE



HISTOGRAMS OF SINGLE SCALE THICKNESS VALUES



HISTOGRAMS OF FIBRE SCALE THICKNESS VALUES

Fig. 97 Scanning electron microscope results for wool and mohair scale thickness (height)[951]

a lower against-scale fibre coefficient of friction than wool as a criterion for separating the components of a wool/mohair blend. It was found that the frequency distribution curve of the single fibre friction of a diverse range of mohair was displaced from that of wool, although overlapping occurred. For fibres in the undyed and unprocessed state, the differences between wool and mohair fibre friction were more distinct than for fibres removed from finished fabrics. The frictional force depended slightly on the fibre diameter and crimp. Weideman and Smuts[951] showed fibre friction to be related to scale height.

Subsequently, considerable work was carried out by Weideman *et al*[985, 988, 1000] on the scale height method (developed by the Deutsches Wolforschungsinstitut) whereby the heights of scales, as measured on a scanning electron microscope, are used to distinguish wool from mohair (Fig. 97). It was shown that there was a significant overlap in the heights of wool and mohair scales, although the scale height of wool was generally higher (greater) than 0,7 µm and that of mohair less than 0,6 μm (Fig. 97). The scale height distributions of a number of wool and mohair samples, originating from various parts of the world, were measured so as to build up data for assessing the scope and accuracy of the scale height method.

18.4 A COMPARISON OF WOOL AND MOHAIR DYEING BEHAVIOUR

Kriel *et al*[186] compared the dyeing behaviour of wool and mohair and discussed possible reasons for the differences they observed.

Swanepoel[236] compared the dyeing behaviour of wool and mohair and concluded that the rate of dyeing was greater for mohair than for wool of the same diameter. The rate of dyeing of both wool and mohair decreased with increasing fibre diameter and the depth of shade increased with increasing fibre diameter at the same concentration of dyestuff. Mohair appeared deeper in colour than wool of equal average diameter containing the same concentration of dyestuff, due to differences in fibre surface structure (lustre). Later Roberts and Gee[644] compared the dyeing characteristics of mohair with those of lustrous Corriedale wool of similar fibre diameter and also found the rate of dyeing and equilibrium exhaustion for the mohair to be greater than those for wool. Instrument and visual assessments of depth of shade indicated little differences between respective fibres dyed to the same nominal depth. Fastness to washing, rubbing, and perspiration were also similar[719]. Their results also indicated that the lustre associated with the mohair fibre was responsible for its apparently greater depth of shade when compared with other less lustrous wools, supporting the findings of Swanepoel[236]. Van Rensburg[767] dyed various keratin fibres which differed significantly in lustre, such as mohair, Corriedale, Falkland and Merino wool with 12 different dyes and then exposed them to Xenon light for various periods. It appeared that lustre had no effect on the light-fastness ratings or the rate of fading.

CHAPTER 19

WOOL/COTTON BLENDS*

19.1 PROCESSING ON THE WORSTED SYSTEM

Turpie[499] investigated the processing of wool/cotton blends on the worsted system and found that scoured 6/7-month wool and mechanically opened cotton could be successfully carded, gilled and combed in blends of 70/30 and 50/50 wool/cotton. In the latter case the production rate was about 50 to 60% of that for wool alone. Significant improvements in performance were possible by applying 0,5% lubricant prior to carding (Fig. 98). The improvement in the performance of the cotton component due to lubrication was more pronounced than that of the wool. Drawing and spinning of re-combed tops composed of

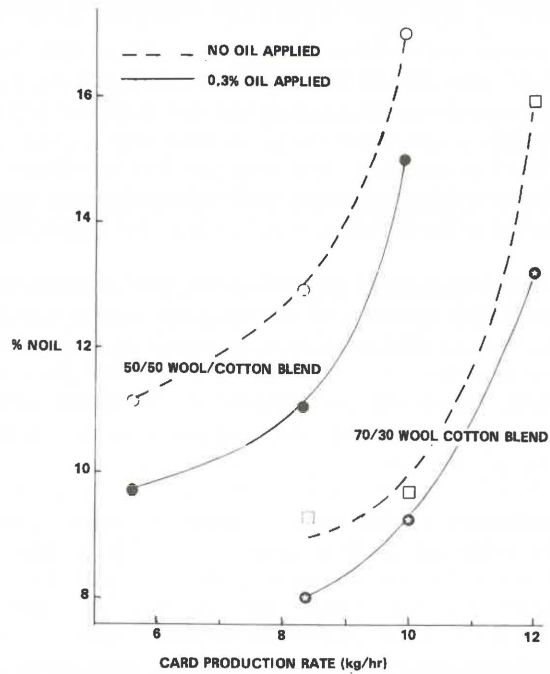


Fig. 98 The effect of card production rate on the percentage noil obtained during combing 70/30 and 50/50 wool/cotton blends(499)

* Wool/Cotton blends also feature in Chapter 20.

55/45 wool/cotton were successfully carried out on conventional worsted equipment.

Schmidt and Turpie[577] studied the effect of different grades of cotton, lubrication and card production rate on nep formation during the carding of 50/50 wool/cotton blends, best results being obtained with about 0,5% lubricant on the wool component of the blend. Nep formation was found to increase with increasing carding rate.

Turpie and Marsland[634] carried out spinning trials on ring and Repco spinners using rovings prepared from a combed 55/45 wool/cotton blend and an uncombed 67/33 cotton/wool blend and found that the wool-rich blends (prepared on worsted system) could be spun satisfactorily alone on the worsted ring frame, and on the Repco with the assistance of a nylon multifilament core and binder thread. The ring-spun yarns almost matched an average all-wool worsted ring yarn (containing short wool) in physical properties (excepting for extension) but the Repco yarns were generally of a poorer quality.

19.2 PROCESSING ON THE COTTON (SHORT STAPLE) SYSTEM

Blends of cotton and wool containing from 20 to 60% wool, were processed by Aldrich[522] into 20 and 30 tex carded type yarns on a standard cotton system, using three methods of blending and four different types of wool. The strength (Fig. 99) and extension of the yarns decreased linearly with an increasing percentage wool in the blend. The irregularity of the 30 tex and the cotton-rich 20 tex yarns compared favourably with standard carded type cotton yarns. The waste extracted in the blowroom and at the card depended on the type of wool used.

Aldrich[572] also investigated the processing performance of 67/33 cotton/wool blends using three methods of blending (blowroom, card and first draw frame) and wool in three different forms, (scoured, open top and top). Combed cotton sliver was also blended with wool top at the first drawframe to produce *combed type* yarns. Processing performance of the blends offered no serious problems, the number of end-breaks being in each case well below the commercial level. When scoured wool was blowroom blended, the card waste was slightly higher than when using open top or when processing the cotton component alone. Amongst the carded yarns the blowroom blend of open top and raw cotton generally produced the best quality yarn. The combed type yarn was only slightly stronger than the strongest carded type yarn, but was far superior in yarn irregularity and nep content and was also less hairy. Fabric tensile properties, abrasion resistance and air-permeability were largely insensitive to the method of blending or to the type of wool used. Blowroom blending offered the advantage of using a standard production line.

Veldsman *et al*[617] investigated the effect of various parameters on the rotor spinning of a 38mm lambswool into 60 tex yarn. With metallic wire opening rollers, a speed of 6 000 r/min and a rotor speed of 35 000 r/min were found

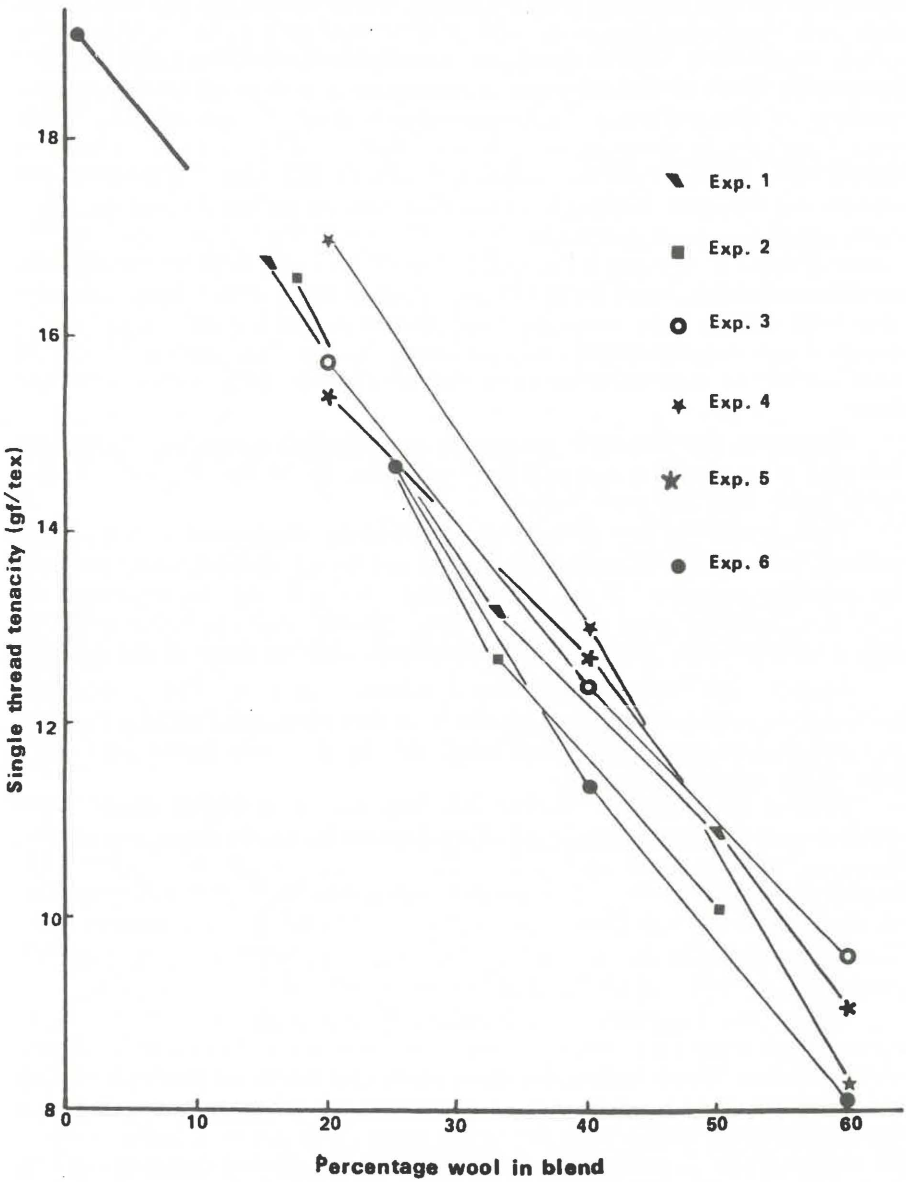


Fig. 99 Yarn tenacity versus blend ratio(522)

beneficial towards resultant yarn properties. Tenacities of the resultant 60 tex yarn were lower when compared to those of worsted-spun yarns and irregularity values were low by IWTO standards. Subsequently, Veldsman and Taylor[686] studied the effects of various machine parameters as well as lubrication on rotor spinning of all-wool and a 75/25 wool/cotton blend. Pinned opening rollers were found best for spinning, the type of lubricant making no real difference on spinnability. Pinned opening rollers with speeds less than 7 000 r/min and smooth nozzles were preferable in terms of yarn properties, two of the lubricants improving yarn properties. For 75/25 wool/cotton sliver, spun on the cotton system, an opening roller speed of less than 7 000 r/min was preferable, no difference being found for the 55 and 65mm diameter rotors. Relatively high yarn twist factors were generally used. Robinson and Layton[687] found that a standard size mix performed better on coarse than on fine yarns and better on wool/cotton and wool/polyester yarns than on all-wool yarns (a short wool was used).

Robinson and Layton[694] compared the physical properties, sizing and weaving of wool/cotton ring and rotor yarns and found the ring yarns to perform better than the rotor yarns.

Spencer and Taylor[708] showed that artificial de-crimping of wool by backwashing in a solution of sodium bisulphite and drying under tension improved the spinning properties of the fibres during rotor spinning but weakened the yarn. Backwashing alone and drying under tension produced better spinnability, a stronger yarn and other yarn properties close to those of the control.

Spencer and Taylor[718] found that a minimum of about 25% cotton was necessary to enable wool/cotton blends to be processed satisfactorily into laps in a cotton blowroom. This blend could also be spun into coarse yarns on a rotor (OE) spinning machine.

Spencer and Taylor[727] studied the removal of vegetable matter from scoured wool during the processing of wool/cotton blends on the cotton system. Relatively short scoured wool with moderately heavy vegetable content could be processed successfully, when blended with cotton in 75/25 and 50/50 ratios, on standard cotton machinery, the preferred route being via a tandem card. There appeared to be no necessity to comb the wool when spinning relatively coarse yarns. Rotor spinning appeared to be limited to coarse yarns.

Hunter and Toggweiler[849] investigated the processing of wool and wool/cotton blends using chute feeding to the card. Yarns were spun on both ring and rotor machines. Chute feeding overcame problems sometimes experienced with lap formation at the scutcher. Lapping and low web cohesion occurred during the carding of the 100% wool, the blends generally performing better. Vegetable matter (burrs in particular), was a source of problems, especially during rotor spinning. Fig. 100 illustrates the effect of blend level on ring and rotor yarn tensile properties.

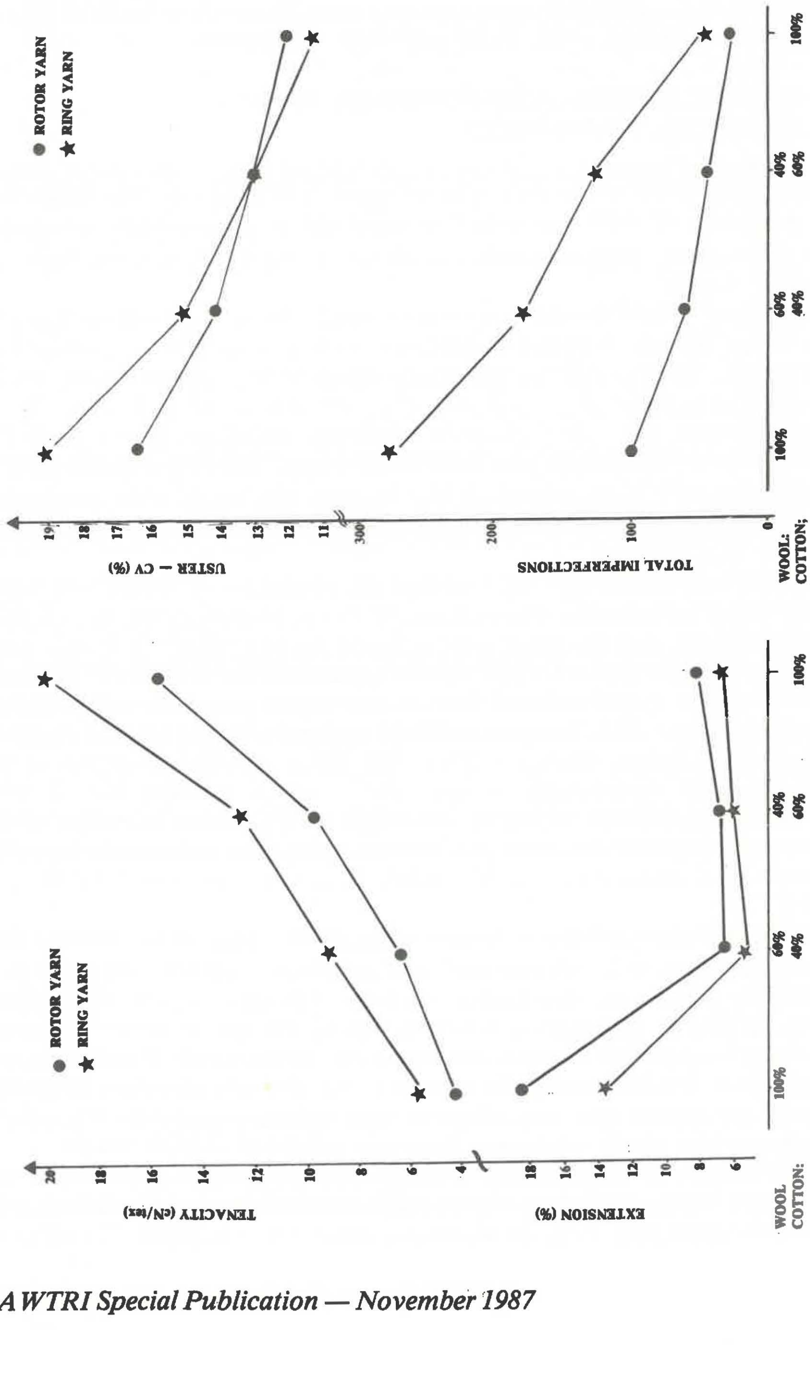


Fig. 100 Yarn tensile and evenness properties vs blend composition (62,5 tex yarn)(849)

Hunter *et al*[883] compiled some average values for the physical properties of rotor yarns, including wool, from published information.

19.3 FABRIC DYEING AND FINISHING AND PHYSICAL PROPERTIES

Shiloh *et al*[404] treated a 55/45 wool/cotton blend fabric with various quantities and types of resin and cross-linking agents and found that the wash-and-wear properties of the fabric could be improved to commercially acceptable levels although dry wrinkle recovery could not be improved, washing improved the fabric handle.

Hanekom *et al*[428] treated wool/cotton blend fabrics with various types of resins in an attempt to obtain satisfactory durable press (DP) properties and found that the fabrics could be chemically treated to provide satisfactory wash-and-wear and mechanical performance, even at low levels of application. When properly blended, the cotton component inhibited shrinkage, but to obtain DP performance, resin treatment was generally essential. The polyurethane resin (R Synthappret LKF) applied from solvent medium was found to be promising. The relationships between the wrinkling performance and various other properties were also reported.

Shiloh and Hanekom[462] also studied the properties of cotton rich blend fabrics. Three fabrics were woven from 30/70 wool/cotton yarns, two of plain weaves (200 g/m^2 and 140 g/m^2) and the third a poplin (200 g/m^2). It was found that different fabric structures and masses required different levels of DP treatments to achieve a good balance between mechanical properties and wrinkling performance (Fig. 101). The heavier fabric required a higher level of resin ($\simeq$ 10%) than the lighter fabric ($\simeq$ 5%). The major physical properties of the fabrics were not significantly changed after a severe washing test. Durable press treatments reduced pilling by apparently slowing down migration of the fibres to the surface of the fabric. An increase in the wool component improved the mechanical performance of DP treated blends and decreased the flexural rigidity.

Leigh[560] investigated the hydrogen peroxide bleaching of wool/cotton fabrics using conventional cold-pad-dwell and pad-steam methods under both acid and alkaline conditions. The highest whiteness per unit of peroxide applied, without significant degradation, was obtained by the use of silicate-stabilised peroxide in an overnight cold-pad-dwell process. Subsequently Barkhuysen and Leigh[637] found that sodium chlorite was not a very effective bleaching agent and that reducing agents were less effective than hydrogen peroxide. Pad-dwell, pad-bake or pad-steam treatments generally produced similar results.

Van Rensburg[586] showed that THPOH-ammonia and an oligomeric vinyl phosphonate flame-retardant produced flame-retardant wool/cotton fabrics with LOI values higher than 27,0, the treatments being fast to washing. The effect of

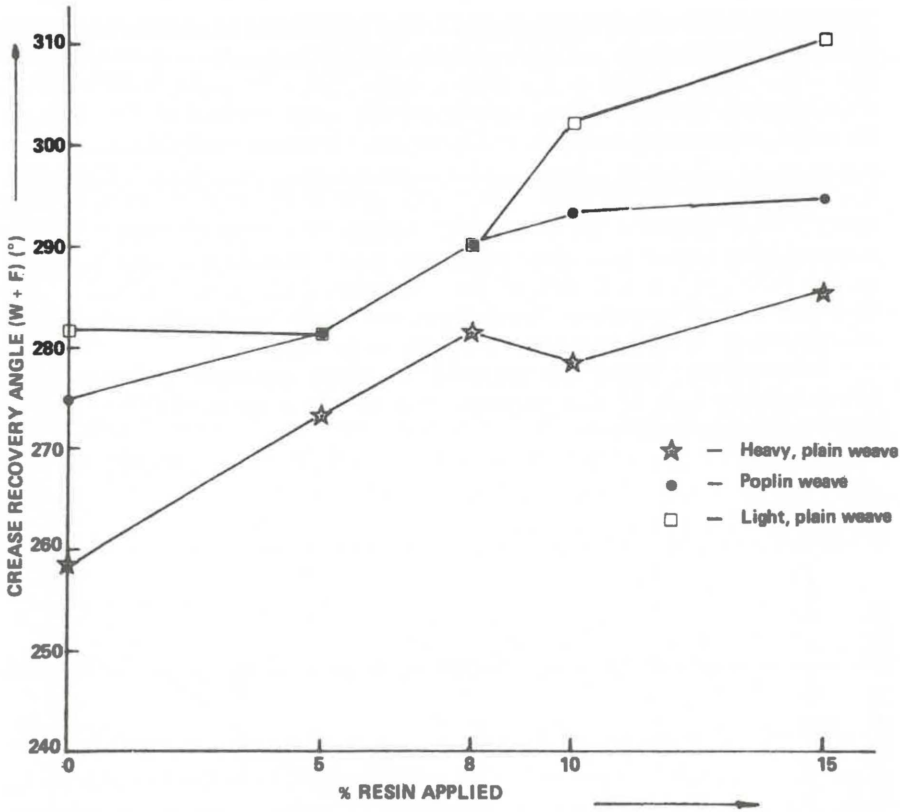


Fig. 101 Crease Recovery Angles vs Percentage Aerotex M3 + Fixapret CPN applied (30/70 Wool/Cotton)(462)

various shrinkresist treatments on the LOI values of the fabrics was also studied, slightly higher LOI values being obtained when the fabrics were first flame-retardant treated and then shrinkresist treated, than when the order of treatment was reversed.

Barkhuysen and Van Rensburg[581] investigated the effect of liquid ammonia and DP resins on the dimensional stability and crease recovery angle of 30/70 wool/cotton blended fabrics. A pretreatment with liquid ammonia, and the subsequent removal of ammonia by hot water, followed by a resin treatment, produced fabrics which changed less than 2% in area after a two-hour wash test. They also investigated[595] the effect of THPOH and liquid ammonia on the LOI values and certain physical properties of the fabrics. It was found that a treatment with THPOH, followed by a treatment with liquid ammonia produced fabrics with LOI values higher than 27. The LOI values were, however, lower than those obtained by the conventional THPOH/ammonia vapour treatment. The wool/cotton and all-cotton fabrics were found[648] to differ significantly in their response to liquid ammonia and durable press treatments. For example, the addition of certain silicones to aminoplast resins increased the crease recovery angle of all-cotton fabrics, but decreased that of the wool/cotton fabric. Also treating the wool/cotton fabric with DMDHEU type resins resulted in lower crease recovery angles and DP ratings than treating with melamine-formaldehyde type resins. Pretreating the wool/cotton fabrics with liquid ammonia increased the strength of the resin-treated samples, but had a slight adverse effect on DP ratings. Strength retention at different curing temperatures was inversely related to crease recovery (Fig. 102).

Barkhuysen[607] found that the effect of liquid ammonia on fabric dimensional stability and physical properties was lower for all wool fabrics than for 33/67 wool/cotton fabrics.

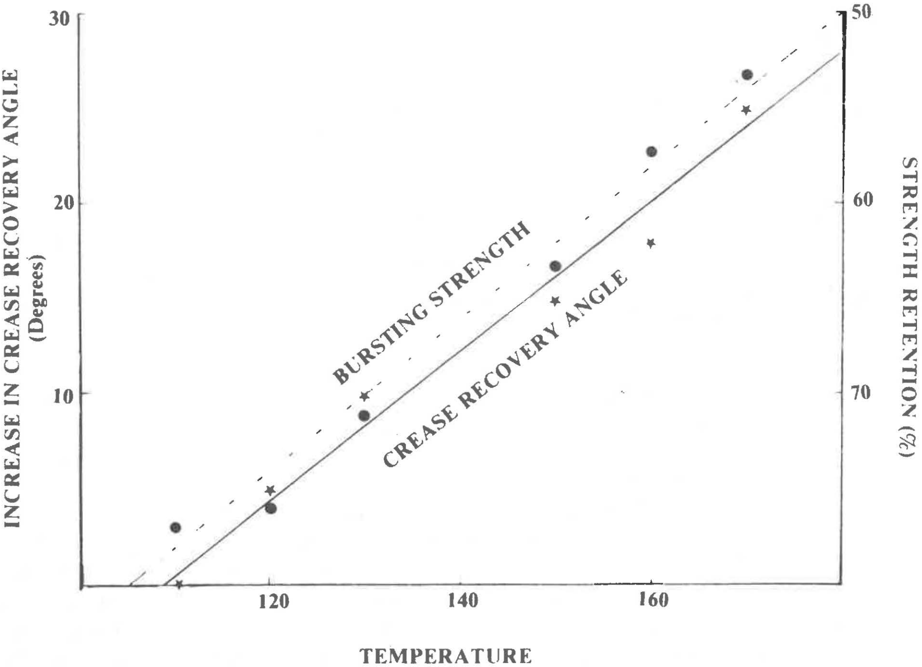


Fig. 102 The increase in crease recovery angle and the percentage strength retention of resin-treated wool/cotton fabrics as a function of curing temperature(648)

Van Rensburg[709] found that the properties of light-weight fabrics, comprising a cotton warp and a wool or mohair weft, compared favourably with those of intimately blended 55/45 wool/cotton fabrics, the crease recovery angles and strength loss of the fabrics generally increasing when resin concentration or curing temperature increased. For the same level of resin, the cotton warp of the wool/cotton blends contained about 40% more resin than the cotton warp of the all-cotton fabric. Care should therefore be exercised during the resin treatment of wool/cotton blends not to damage the cotton component in the blend by the application of too high a level of resin.

Van Rensburg and McCormick[717] studied the simultaneous dyeing and DP treatment of 55/45 and 33/67 wool/cotton fabrics using DMDHEU resin, ammonium nitrate catalyst and direct, acid or reactive dyes. For the direct and acid dyes unlevel dyeings were obtained, the dyes showing a higher affinity for the cotton. Certain cotton reactive dyes behaved in a similar manner. However, a number of wool reactive dyes gave level dyeings, with similar uptake of dye by the wool and cotton. The crease recovery angles and the percentage dye fixation increased with increasing resin. Resin level did not seem to have an effect on alkaline perspiration fastness, wash fastness and dry rubbing fastness, these generally being good. The wet rubbing fastness of the samples was somewhat lower.

Robinson[851] discussed the production of seersucker fabric constructions and specifications for new constructions based on differential shrinkage of wool and cotton, were given in detail. Fabric details and samples were given.

CHAPTER 20

WOOL/SYNTHETIC BLENDS

20.1 THE PRODUCTION AND PROPERTIES OF RING-SPUN STAPLE YARNS

Aldrich and Grobler[454] compared the properties of wool, wool/polyamide, wool/polyester and wool/acrylic intimately blended yarns. The addition of 25% acrylic fibre or more, reduced the elongation at break, but increased tenacity compared to pure wool yarns. The twist for maximum yarn strength was lower for wool/polyester and wool/acrylic blended yarns than for wool/polyamide (Fig. 103). Wool/polyester and wool/acrylic fibre blends showed inferior elastic recovery properties from elongations of 4, 8 and 12% when compared with pure wool and wool/polyamide yarns (Fig. 104).

Hunter and Turpie[500] investigated the influence of polyester types (normal, low pilling and high bulk) in wool/polyester blends, and of different additives

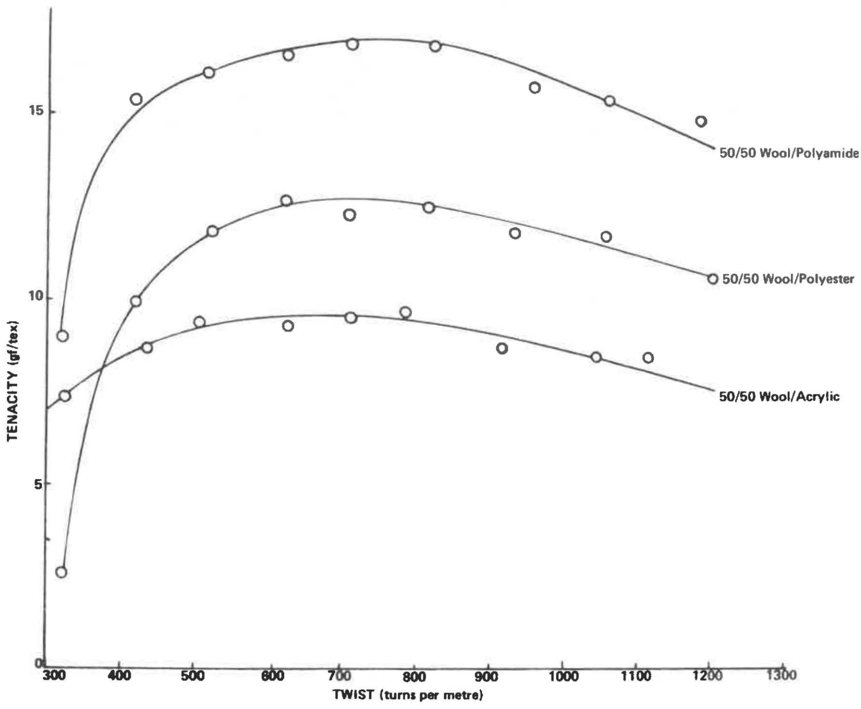


Fig. 103 Yarn tenacity versus twist (t.p.m.) (Yarn count = 26 tex)[454]

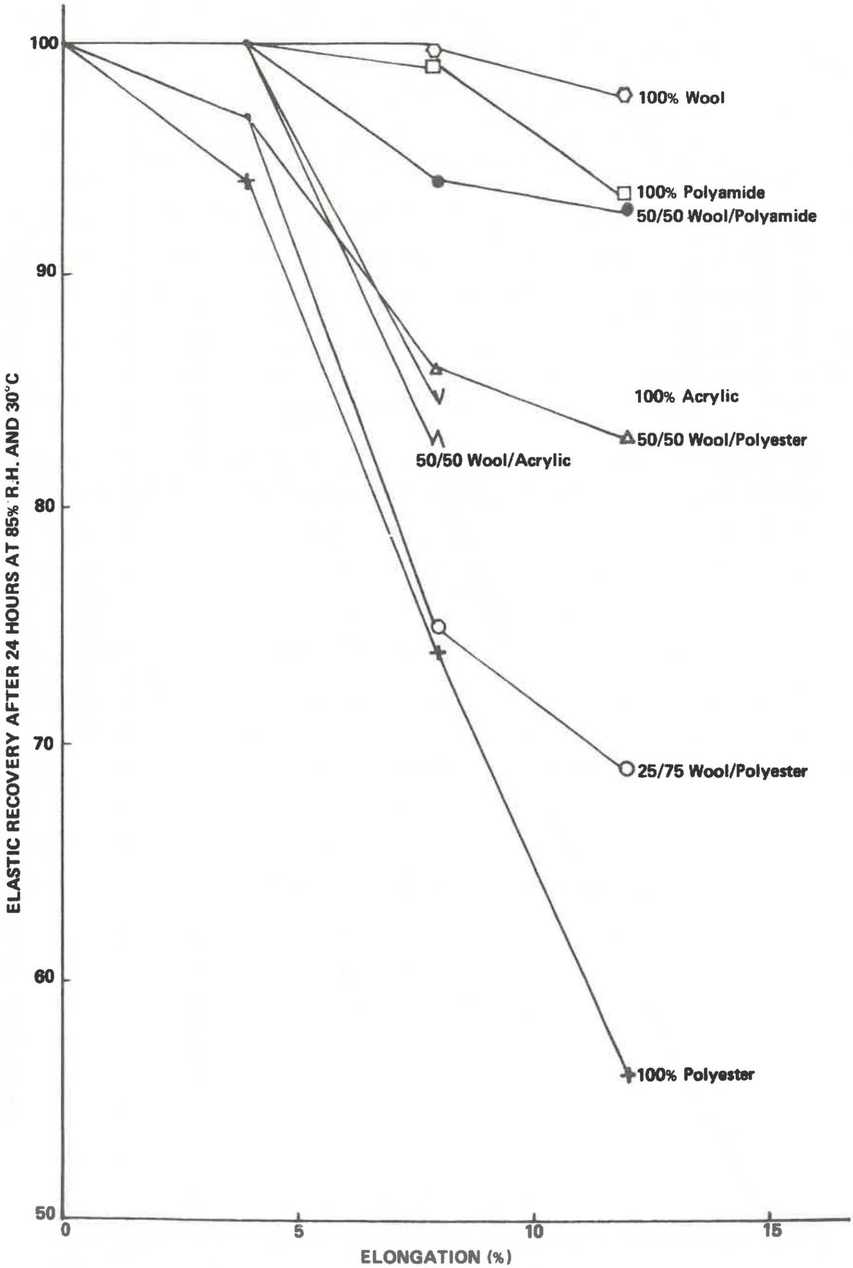


Fig. 104 Elastic recovery after 24 hours at 85% r.h. and 30°C versus elongation[454]

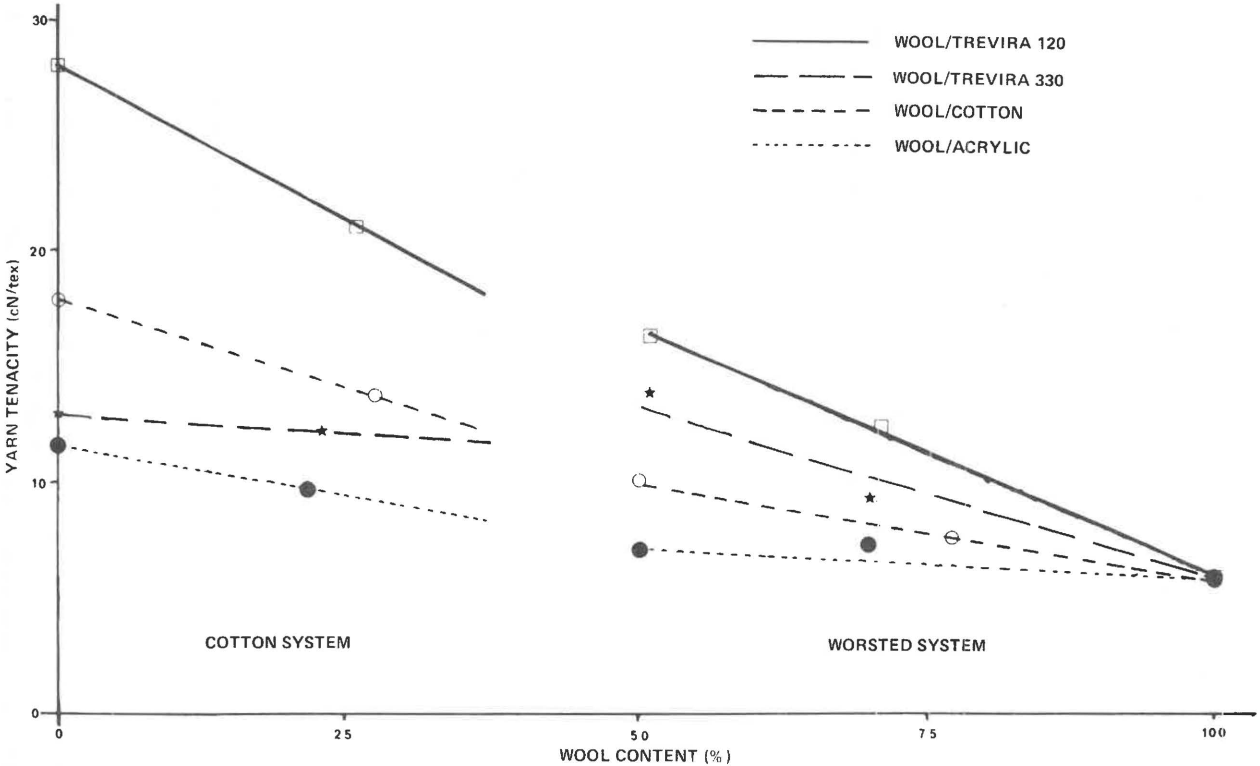


Fig. 105 Relationship between yarn tenacity and blend composition for a 24 tex yarn, spun on both cotton and worsted systems[632]

on the end breakage rate during spinning and on the yarn physical properties. The effects of the type of polyester and additive and of polyester level on the end breakage rate during spinning were not large while certain of these variables had a very pronounced effect on some of the yarn properties.

Robinson *et al*[632] obtained the following graph (Fig. 105) for the tenacity of different yarns.

Strydom[856] conducted spinning trials on blends of two polyester fibres and different wools ranging in fibre diameter and length and found that spinning potential, as measured by the mean spindle speed at break technique (MSS), was determined solely by yarn tex (or fibres in the yarn cross section) in the case of the polyester-rich blend (Fig. 106). The spinning potential of the wool-rich blends was lower than that of the polyester-rich blend, but the difference was smaller for the finer and longer wool component. The effect of variations in wool diameter and length on MSS was found to be roughly only one-half to one-third of the effect previously observed for 100% wool worsted yarns. The

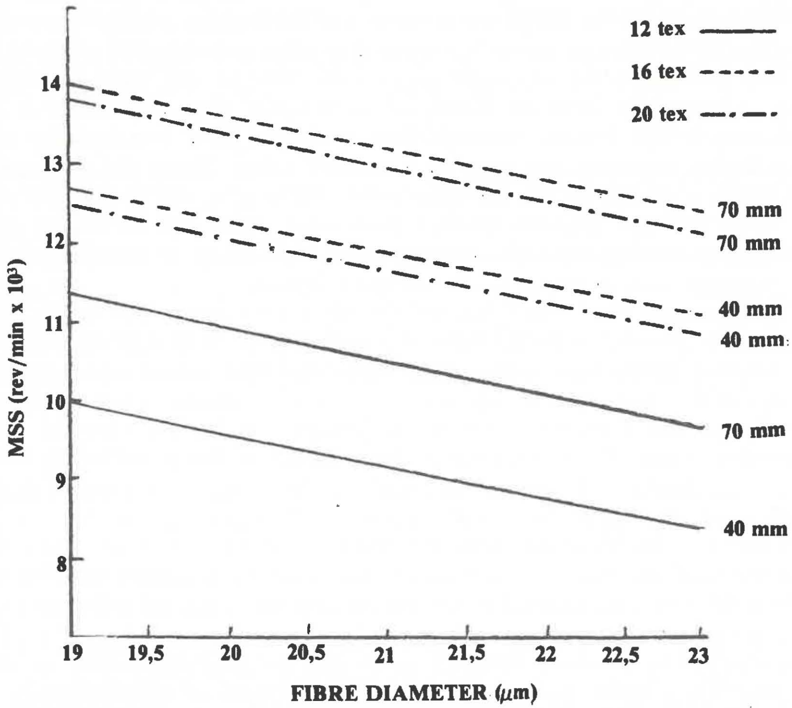


Fig. 106 Regression curves for MSS as a function of mean fibre diameter of wool component (60/40 wool/polyester)[(856)]

wool fibres, being shorter and coarser than the polyester fibres in general, migrated to the yarn surface.

20.2 PHYSICAL PROPERTIES OF COMMERCIAL WOOL/POLYESTER YARNS

Hunter and Andrews[603] measured the tensile properties and irregularity of 90 commercial wool/polyester yarns (40% wool/60% polyester to 60% wool/40% polyester) and presented the results graphically. The graphs could be used in practice for reference purposes i.e. by a quality control laboratory for determining how a particular wool/polyester yarn compared with other yarns having a similar linear density and composition. Recently Hunter and Gee[991] also presented average values for the physical properties of wool/polyester two-ply ring and Repco yarns.

20.3 CORE-SPUN RING YARNS

Kruger[376] studied core-spinning of wool using a 22 dtex textured multi filament nylon as core. The physical properties of the core-spun yarns were better than those of the 100% wool yarns and the knitting performance of the core-spun yarns was also better. Compared to intimately-blended yarns of staple nylon and wool, the core-spun yarns were stronger and more resistant to pilling, whereas the intimate blends showed better abrasion resistance.

Robinson and Smuts[441] reported that core-spun yarns required less warp tension during weaving than pure wool worsted yarns. Sizing did not improve the weaving performance of core-spun yarns, but waxing did. Core-spun yarns were much stronger than the unsized pure wool yarns and performed much better during weaving although stripping of the wool could be a major problem. Knot slippage was a major cause of warp breaks.

Subsequently Robinson[469] applied various additives to wool during drawing, prior to spinning or to the yarns during beaming. Both core-spun and all-wool worsted yarns were subsequently spun and then woven into a standard shirting fabric. Weaving trials showed that certain additives improved weaving performance, and even improved the weavability of all-wool yarns to a level comparable to that of core-spun yarns. Some additives decreased felting shrinkage to some degree. Aldrich and Grobler[458] made a study of the tensile properties of wool core-spun yarns with various multifilament yarns as cores and found that the tenacity of the yarns depended on the strength of the core and the wool/core ratio, an increasing wool/core ratio resulting in a lower yarn tenacity. Whether the core was textured or not did not have any apparent influence on the tensile properties of the yarns. The tenacity and breaking energy of a 24 tex core-yarn, having a core of either 22 or 44 dtex textured polyamide, increased with increasing twist showing a maximum strength at approximately 800 turns/m. The percentage increase in tenacity, however, depended on the wool/core ratio.

Shiloh[432, 474] also investigated the yarn and fabric properties for all-wool and wool/nylon, core-spun and wool/polyester staple fibre blend yarns (see Chapter 20.7). Robinson and Marsland[907] described the spinning of core-spun and wrapped core-spun yarns on a conventional ring spinning machine and compared their properties with those of conventional all-wool worsted yarns (Fig. 107). The former yarns appeared to have considerable potential for both weaving and knitting.

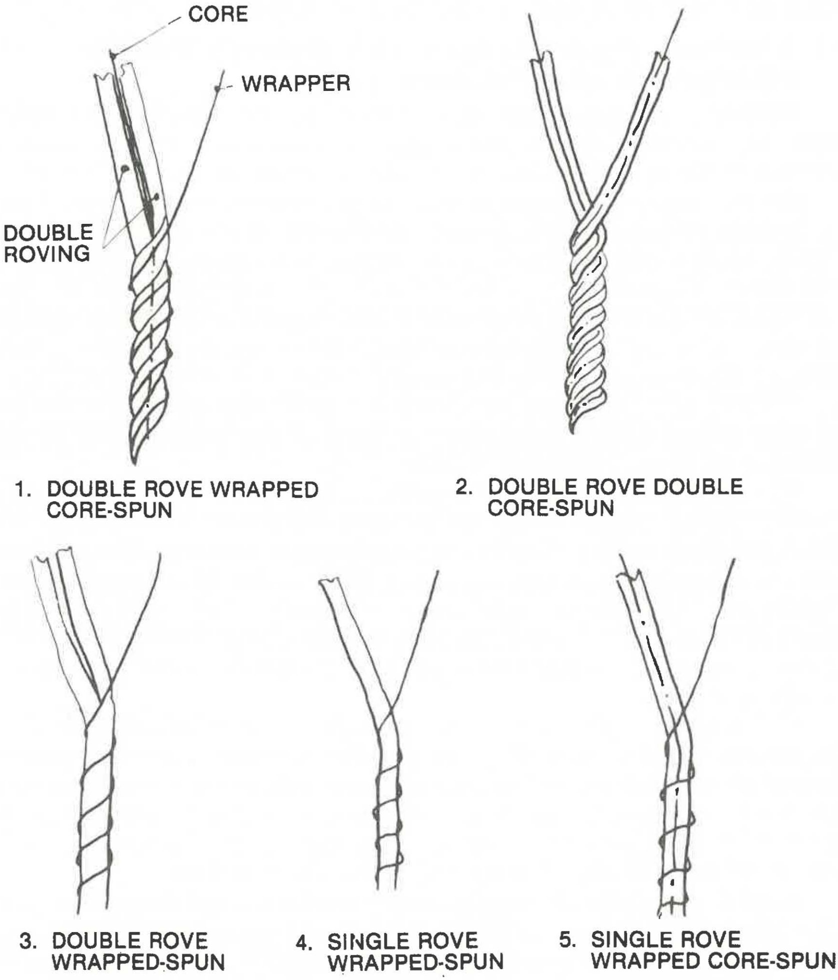


Fig. 107 Schematic diagram of core and wrap yarns[907]

20.4 STRETCH YARNS

Strydom[814] produced two worsted-type stretch yarns (wool and 45/55 wool/polyester) by assembly-winding two ends of each of these with an elastomeric component, followed by conventional uptwisting. The wool stretch yarn proved to be about half as strong as the wool/polyester stretch yarn but its extension at break test results were approximately 50% higher. The extension values were found to increase with an increase in elastomer linear density and stretch ratio and an increase in the level of uptwisting.

20.5 KNITTING PERFORMANCE AND KNITTED FABRIC PROPERTIES OF RING-SPUN YARNS

Wolfaardt and Buys[379] described a technique for manufacturing double-jersey fabrics containing low percentages of nylon flat filament in which the wool was plated onto both sides of a synthetic ground structure or "scrim". In this way the unique advantages of wool were combined with the more beneficial physical properties of the synthetic component. The resulting fabrics could be knitted with higher efficiency and performed better during washing, than all-wool fabrics of equivalent mass and tightness. In a subsequent study Wolfaardt *et al*[414] studied the knitting performance and physical properties of intimate, core-spun and plated wool/polyamide blend fabrics and the influence of fabric tightness, finishing procedures and shrinkproofing. It was found that 22-gauge plated fabrics which had been autoclaved and decatised and for which the wool had been treated with a shrinkproofing agent (R Hercosett or DCCA) were preferable to fabrics produced in other ways.

Van der Merwe and Silver[429] described a sequence of processes by means of which plated double jersey fabrics (Punto-di-Roma) knitted from wool (80%) and nylon (20%) could be rendered machine washable. The processing sequence comprised autoclave decatizing (KD) of the fabric, treatment with R Synthappret LKF (Bayer), autoclaving and finally winch dyeing. Total processing shrinkage i.e. from machine state to finished state did not exceed 8,5% in area for wool/nylon plated fabrics and 14% for fabrics knitted from wool/nylon core-spun yarns.

McNaughton *et al*[455] investigated the production of wool rich warp knitted (Queenscord) fabrics on a 36 gauge Raschel machine, a textured polyester filament on the front bar and an intimate blend yarn of wool and nylon on the back bar giving a fabric containing 60% wool, proved to be superior to other fabrics made from polyester on the front bar and wool/nylon core-spun on the back or intimate blends of wool and nylon on both bars.

Buys *et al*[492] produced "semi-locknit" fabrics through feeder blending of either untreated wool yarns or DCCA-treated wool yarns, with either polyester (continuous filament) or cotton yarns. For untreated 70/30 wool/polyester filament fabrics or 50/50 wool/cotton fabrics, autoclave decatising followed by a 1,5% R Synthappret LKF treatment produced machine

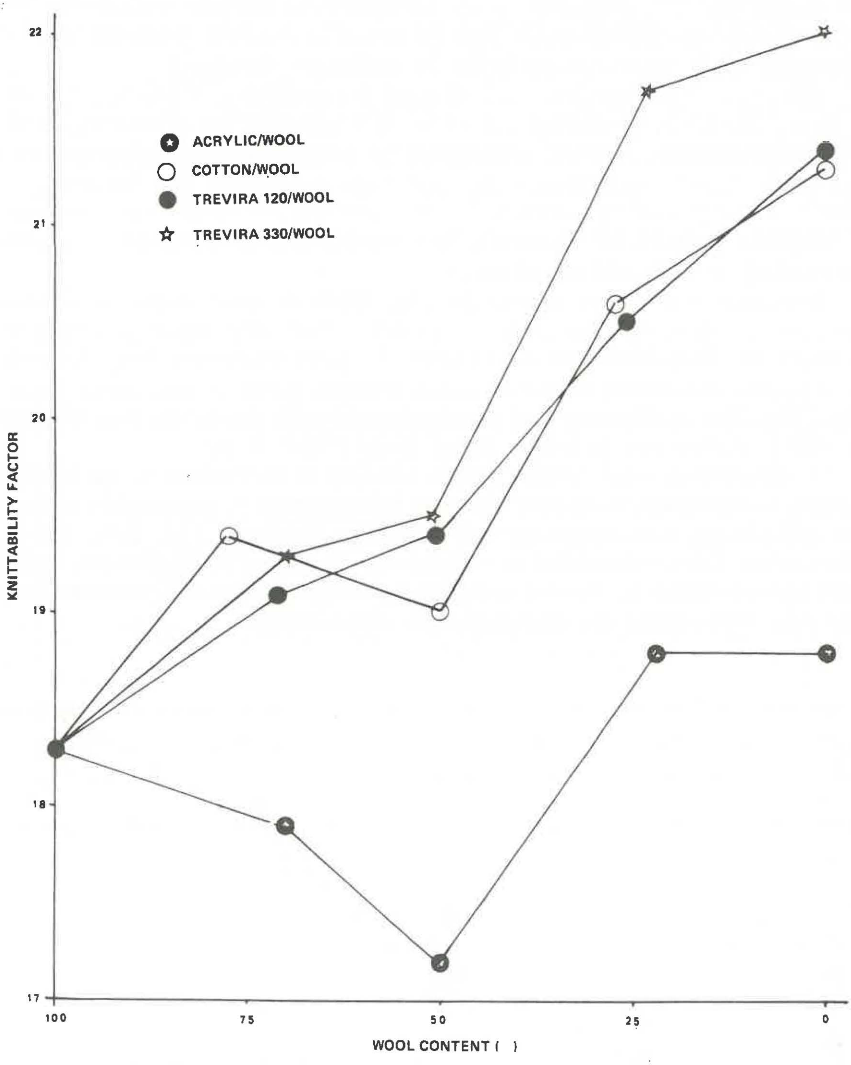


Fig. 108 Knittability factors vs percentage composition of blend yarns for the plain structure(632)

washability. For DCCA-treated wool/polyester fabrics, autoclave decatising, or heat-setting plus 2% aminoplast resin, also produced machine washability. The 50/50 wool/cotton blends could also be rendered machine washable after an aminoplast resin treatment preceded by autoclave decatizing.

Silver and Van Heerden[518] investigated the stabilising of wool/acrylic single jersey fabrics to laundering using untreated and chlorinated wool tops and a resin (polyurethane, silicone, aminoplast or polyamide-epichlorhydrin). In a later study Silver[571] determined the best finishing routine for dimensionally stable wool/acrylic fabrics using feeder-blended textured acrylic yarns followed by scouring (solvent or aqueous), heat-setting and shrink-resist treatments (aminoplast or polyurethane resins).

Robinson *et al*[632] investigated the knittability of short staple wool blend yarns (wool/cotton, wool/polyester and wool/acrylic) on a 28-gauge single jersey machine. They found that the wool/acrylic yarns performed relatively poorly, in some cases worse than that of the all-wool yarns of the various blends (Fig. 108). The wool/cotton and wool/polyester yarns performed best although the 100% cotton and polyester yarns knitted best of all.

A decrease in wool content mostly resulted in an increase in the bursting strength and abrasion resistance of single jersey fabrics[675], and slightly reduced their pill ratings, ease of sewing and relaxation shrinkage (Fig. 109). The K_1-values of the fabrics depended on whether the blend was predominantly hydrophilic (giving higher K_1-values) or hydrophobic (giving lower K_1-values). Polyester was well suited for blending with short wools.

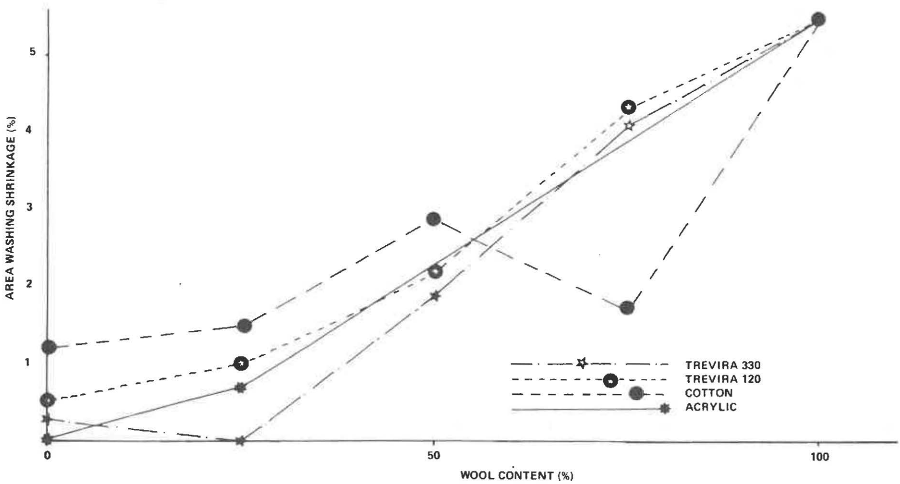


Fig. 109 Relationship between Blend Composition and Fabric Relaxation Shrinkage(675)

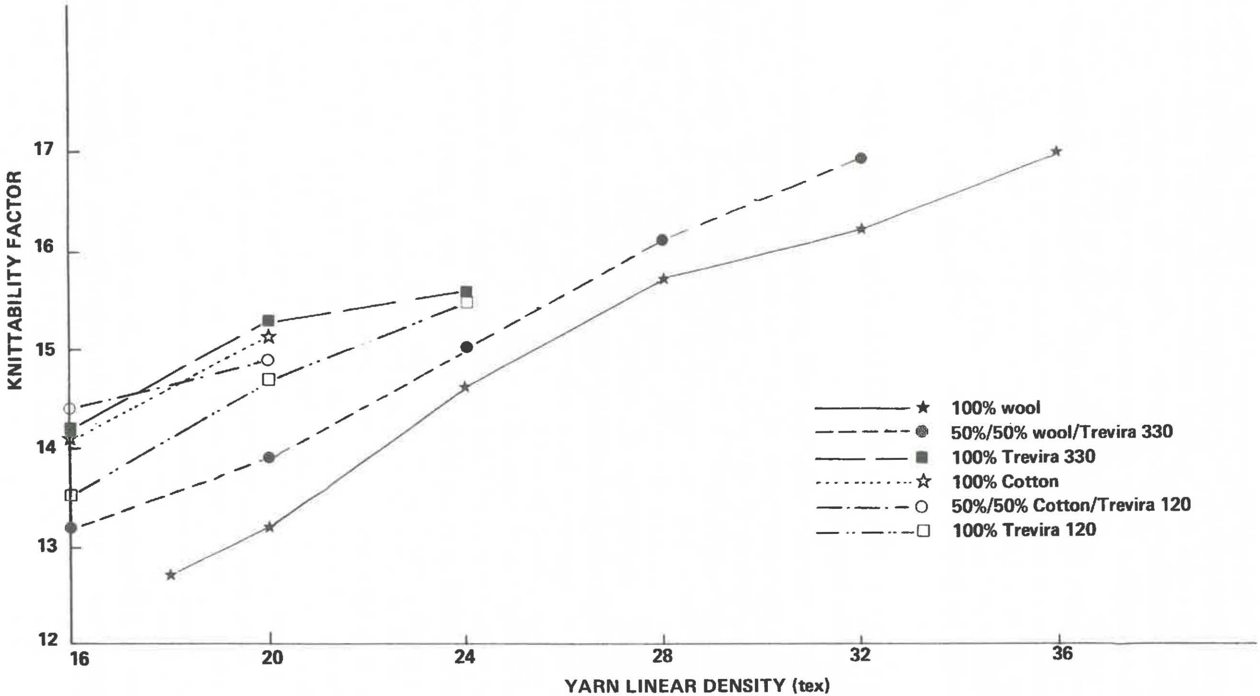


Fig. 110 Knittability factor vs yarn linear density for the satin stitch structure(700)

Hunter *et al*[700] spun yarns to various linear densities from cotton, 50/50 cotton/polyester, polyester on the cotton system as well as from wool, 50/50 wool/polyester and polyester on the worsted system, and knitted them into various single and double jersey structures. When the knitting performance of the yarns was assessed in terms of machine tightness factor (MTF), the knitting performance generally improved with an increase in yarn linear density (Fig. 110). However, when knitting performance was assessed in terms of stitch length (SCSL), the knitting performance deteriorated with an increase in yarn linear density, at the relatively high MTF's employed. This meant that coarser yarns could be knitted to higher machine tightness factors whereas finer yarns could be knitted to shorter stitch lengths, confirming the findings of earlier studies.

20.6 REPCO (SELF-TWIST) SPINNING AND YARN AND FABRIC PROPERTIES

Robinson and Turpie[640] described the concept and principles of spinning Repco Wrapped Core-Spun (RWCS) yarns (initially developed by Robinson *et al*[606] with specific reference to the spinning of fine mohair yarns and their use in light-weight mohair/wool fabrics), their properties as well as those of the fabrics knitted from them. Fig. 111 illustrates the principle of spinning RWCS yarns. In the initial studies the yarns were subsequently uptwisted.

Robinson *et al*[650] showed that fine (RWCS) yarns could be spun and knitted successfully into light-weight double jersey fabric. The properties of the yarns and fabrics were compared with similar yarns and fabrics knitted from spun polyester yarns and found to offer certain advantages.

Turpie and Marsland[643] showed that the use of nylon filaments improved the evenness characteristics of Repco-spun wool yarns which were spun at or beyond the designated spinning limit of the wool, the 'wrapped core' technique enabling 64's quality wool to be spun into yarns as fine as 9 tex (Fig. 112).

Turpie and Marsland[667] investigated the influence of various spinning conditions on RWCS yarn properties and concluded that the apron roller groove depth and the creel position should be normal and that normal light rovings should be used. Low roller loadings were found to be of some advantage from a nep frequency point of view. Very low uptwist factors were successfully used in the trials. Turpie and Marsland[690] described how the Repco Mark I Spinner could be modified so that eight ends of RWCS yarns could be produced simultaneously (i.e. production doubled) without undue adverse effect on yarn properties and spinning performance.

Robinson and Marsland[691] compared the properties of fabrics produced from grandrelle or twist yarns spun on the ring system, the Repco system and by the RWCS system. The RWCS yarns performed best in weaving and produced fabrics equal to, or better than, those produced by the two other yarn types.

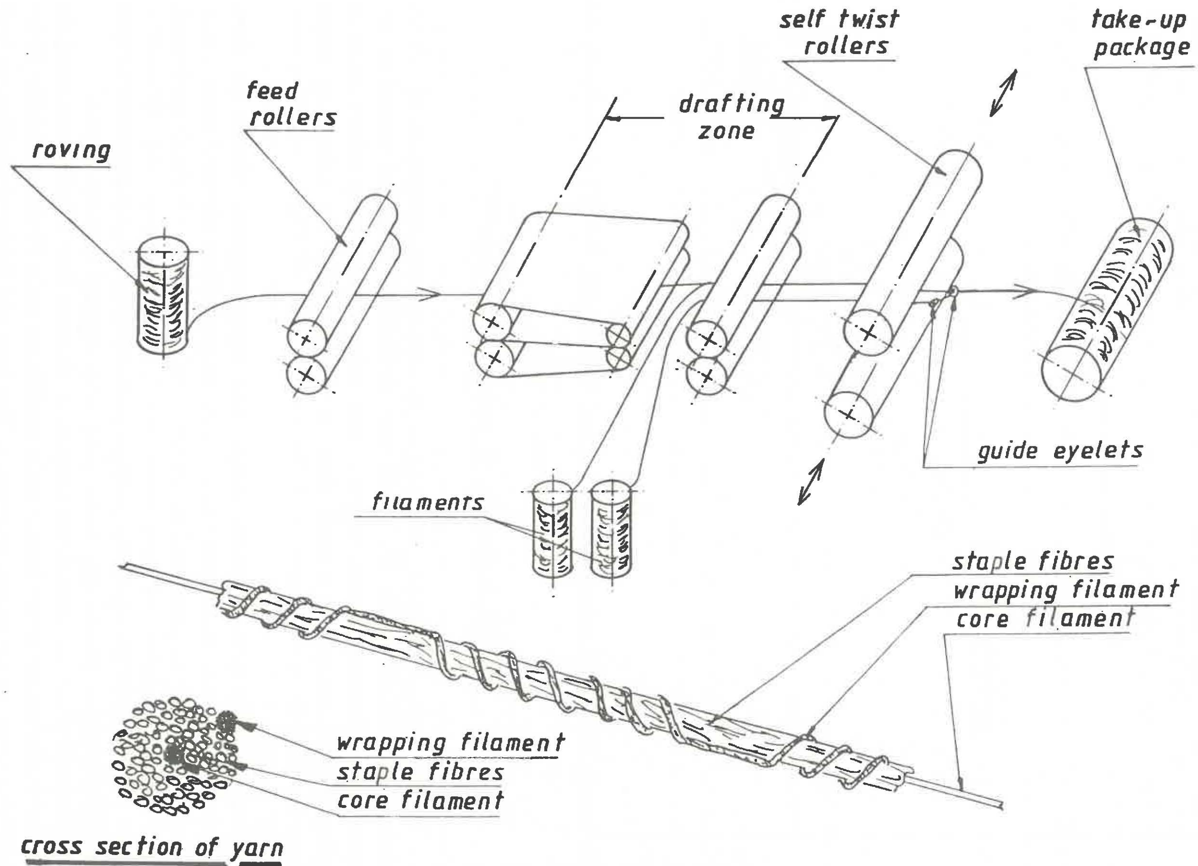


Fig. 111 RWCS System.

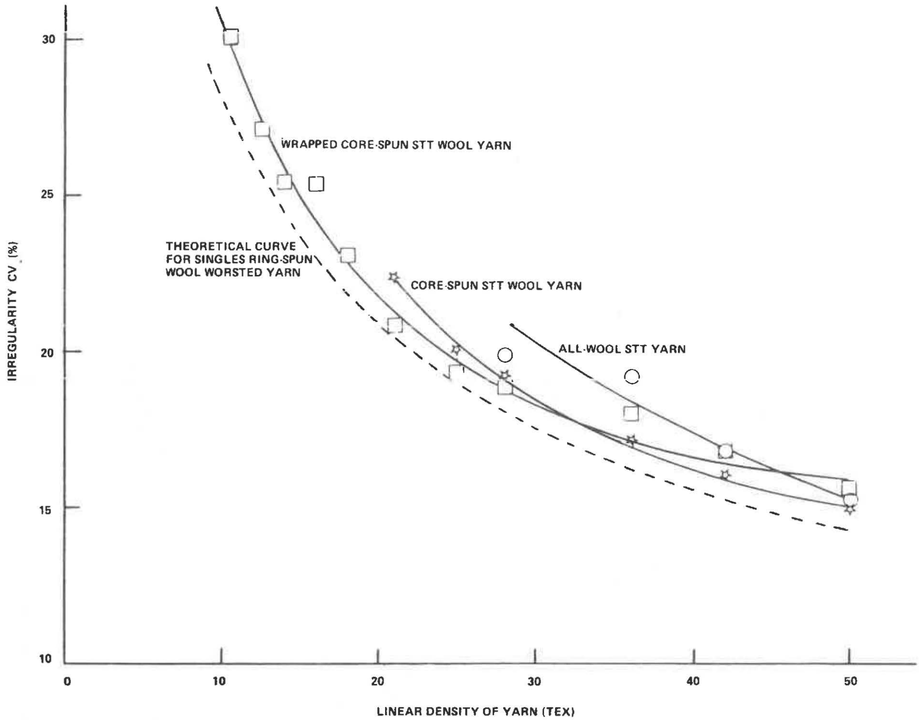


Fig. 112 Irregularity of Various Repco Yarns(643)

Turpie[721] investigated the effect of staple crimp on the properties of fabrics knitted from RWCS yarns. He found that an increase in crimp tended to decrease fabric air-permeability slightly. The other effects were either small or negligible and, taking an overall view, it appeared that the effects of staple crimp on the physical properties of the fabrics were of little practical consequence.

Robinson *et al*[743] produced single and double jersey fabrics in 60% wool/40% polyester in different ways, viz. intimate fibre blended yarns, core-spun yarns, plying of yarns and by feeder blending during the knitting process. The physical properties of both yarns and fabrics were assessed. Generally, blends produced in the spinning process gave the most acceptable fabrics with the RWCS yarns giving the most even and regular surface effect.

Cawood *et al*[775] discussed the properties of some fine RWCS yarns and the knitting performance under commercial conditions on a 28-gauge double jersey machine as well as the fabric properties. The yarn and fabric properties, as well as the knitting performance of RWCS yarns spun on a modified Repco using short wools of differing length and diameter, were statistically analysed.

Strydom and Marsland[757] described the spinning of a range of short wools (32 to 44mm) by the RWCS technique as well as the preparation of these wools on the short staple (cotton) system. The tenacity and irregularity of the yarns spun on the modified Repco compared favourably with those of Repco wrapped core-spun yarns spun on an unmodified Repco using long wools, and those of other comparable short staple all-wool yarns.

Shorthouse and Robinson[816 865] and Robinson *et al*[806] described the use, performance and advantages of RWCS yarns and variations of such yarns, e.g. Repco wrapped-spun (RWS), Repco core-spun (RCS), in men's socks, most of these yarns being knitted without being uptwisted. The yarns were spun with various different filaments, textured or flat filament nylon or polyester, and appeared to offer advantages above conventional yarns in certain cases. The wear performance of the socks was also evaluated and compared with commercial products.

Shorthouse and Robinson[916] spun Repco wrapped core-spun (RWCS) and Repco wrapped spun (RWS) wool yarns, having textured nylon or polyester as the filament component, to limiting counts and knitted them into medium and fine gauge double jersey fabrics (Punto-di-Roma and Interlock). The yarns knitted satisfactorily, direct from the spinner's package, in self-twist (ST) uncleared and unwaxed form and the fabrics had acceptable handle and appearance.

In an extension of the work,[927] yarns were spun to a range of linear densities from three different tops; viz. (1) polymer treated tops pretreated by the sodium hypochlorite/sulphuric acid process, or (2) polymer treated tops pretreated by the new SAWTRI gaseous chlorine process and (3) untreated. The yarns knitted satisfactorily, direct from the spinner's package, into medium and fine gauge double jersey fabrics. After dyeing, the untreated fabrics were shrink-resist treated in fabric form.

20.7 WOVEN FABRIC PROPERTIES*

Shiloh and co-workers[432 474] compared the mechanical properties and wrinkling of light-weight wool-rich fabrics woven from wool/nylon core-spun yarns (textured or untextured nylon multifilament cores), wool/nylon and wool/polyester staple intimate blend yarns, and all-wool yarns, respectively. In one case a fumed aluminium oxide (Alon) was applied to the wool tops, prior to spinning, so as to increase fibre cohesion. This product increased the yarn tensile properties and the fabric frictional couple (Mo). The wool/polyester intimate blend fabric had better wrinkle recovery than the fabric containing the wool/nylon core-spun yarns. The twill fabrics generally performed better than

* Wrinkling is mostly dealt with in a separate section (Chapter 21).

the plain weave fabrics in terms of wrinkle recovery but worse in terms of pilling and certain mechanical properties. The fabrics containing the core-spun yarns appeared to offer certain advantages, in terms of pilling propensity for example, but did not have as good resistance to abrasion and bagging as the fabrics containing the staple blends. Autoclave decatising was found to be advantageous provided the fabrics had not been heat-set. No one particular fabric showed overall superiority to the other fabrics.

Shiloh and Slinger[437] reported on the consequence of blending wool with three different types (normal, low-pilling and high bulk) of polyester in different proportions and concluded that increasing amounts of polyester improved most of the mechanical performance of yarns and plain weave fabrics, with the breaking strength and the efficiency of transfer of fibre properties to the yarns and the fabrics being best for the normal polyester and worst for the high-bulk polyester. It was found, that the 60% wool and 40% low-pilling polyester blend fabrics were very satisfactory in all tests. When the fabrics were autoclave-decatised it was found that 40% polyester was sufficient for obtaining satisfactory durable press performance with untreated wool blends.

In a follow-up study[445] shrinkproofed wool was used to blend with polyester and converted into plain and 2/2 twill weave fabrics. It was found that by increasing the polyester component, the mechanical properties were improved, and by comparing the results with those obtained for untreated wool and polyester blends, it was found that the DCCA treatment resulted in a considerable reduction in the tensile properties of the blends. A significant decrease in area shrinkage also occurred when the polyester component was increased, together with an improvement in crease recovery under conditions of high humidity.

Hunter and Smuts[527] studied plain weave light-weight (200g/m^2) fabrics woven from wool/polyester intimate blends using two polyester types (low-pilling and normal) and six blend levels. The strength, abrasion resistance, flexural rigidity, dimensional stability and D.P. ratings of the fabrics increased with increasing polyester content. The fabrics containing the normal polyester type in most cases performed slightly better than the low-pilling types. Autoclave-decatising decreased fabric flexural rigidity and improved wrinkle and crease recovery, dimensional stability and appearance after washing. In a follow-up study Smuts and Hunter[565] applied two polymers (polyurethane and silicone) from solvent systems to wool and wool/polyester plain weave light-weight fabrics. Both polymers reduced the felting and improved the appearance after washing of the wool-rich blends to levels similar to those of the polyester-rich blends. Polymer treatment also slightly reduced the relaxation shrinkage of all fabrics. Fabric stiffness and tear strength were increased by both polymers. Bursting strength and flat abrasion deteriorated slightly when the silicone polymer was applied.

Smuts and Hunter[582] investigated the woven (plain and 2/2 twill 190g/m^2) fabric properties of a range of wool/acrylic blends. Increasing levels of acrylic reduced flex abrasion but improved certain other fabric properties, the twill weave being worse than the plain weave in terms of pilling and abrasion resistance. The wool/acrylic blend fabrics generally compared unfavourably with wool/polyester fabrics studied previously. The yarns containing a finer (3,3 dtex) acrylic were in most cases superior to those containing a coarser acrylic (4,9 dtex). As would be expected, in view of the wool being untreated, washing shrinkage decreased with increasing levels of acrylic. Treating the fabrics with a polyurethane polymer (solvent system) and a mixture of the bisulphite adduct of a polyurethane and a polyacrylate polymer (aqueous system) reduced the relaxation and felting shrinkage of the wool-rich blends to levels similar to those of the acrylic-rich blends[628]. Both treatments increased fabric stiffness and the resistance to flat abrasion of the 2/2 twill fabrics. They concluded that the wool/polyester blend fabrics were generally equal or superior to the wool/acrylic fabrics and that a blend level of approximately 60/40 wool/polyester may be the best combination from the point of view of comfort and durability, although a resin treatment would still be required to reduce felting shrinkage if the fabric was to be given a severe wash. This could be achieved with 2% polyurethane or 5% silicone resin, the latter appearing to be preferable. They also applied[645] a polyurethane and a polyurethane/polyacrylate polymer mixture, from solvent and an aqueous system, respectively, to the fabrics. The low-pilling polyester produced fabrics with inferior tensile properties compared to normal polyester, although in other respects there were no significant differences. The main advantage of the polymer treatments was to reduce the felting shrinkage and to improve the appearance after washing.

Galuszynski[1003] discussed fabric cover factor and tightness and recommended the use of tightness, rather than cover factor, as a measure of fabric structure, particularly when different weaves are being compared.

CHAPTER 21

WRINKLING OF WOOL AND WOOL BLEND WOVEN FABRICS

21.1 CREASE AND WRINKLE RECOVERY TESTS

Various laboratory tests (Shirley and Monsanto crease recovery angles, IWS Thermobench, AKU and FRL) have been used at the Institute for assessing crease and wrinkle recovery.

Slinger and Smuts[301] developed a method of quantifying the wrinkle severity of a fabric containing random wrinkles (e.g. AKU and FRL tests) whereby a light stylus traversed the surface contours of a wrinkled fabric (resting lightly on the fabric), its movement being transferred via a spring to the load cell of an Instron where it was converted into an electrical signal and analysed. Later this system was modified and improved (by for example replacing the load cell with a rotary variable differential transducer)[602], eventually leading to the self-contained SAWTRI Wrinklemeter.

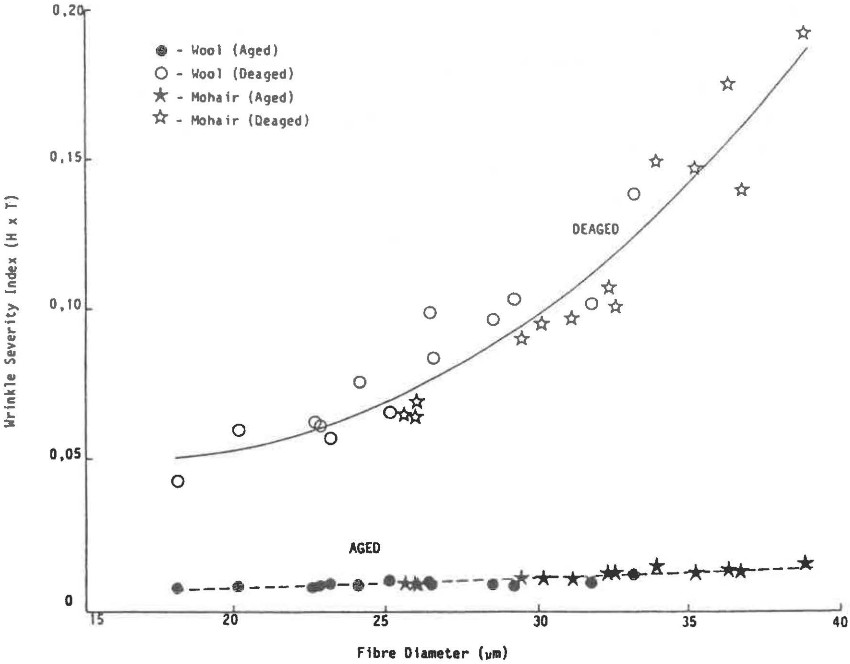


Fig. 113 AKU Wrinkle Severity Index vs Mean Fibre Diameter (Plain Weave: Weft Direction)(946)

Slinger carried out a comprehensive study on the crease and wrinkle recovery and other mechanical properties of wool fabrics and presented the work as a Ph.D. thesis[311].

21.2 EFFECT OF FIBRE PROPERTIES

In the case of both mohair and wool, Hunter, Smuts and co-workers[733 735 791 893 932 952] found a trend for wrinkle recovery to deteriorate with an increase in mean fibre diameter, the trend being least pronounced and often absent for the Monsanto test. For the IWS and Monsanto tests, the wool/mohair fabrics (i.e. 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 test methods can produce contradictory trends. The above-mentioned trends are illustrated in Figs 113 and 114. It was found that the different atmospheric test conditions generally produced similar trends in terms of fibre diameter.

Staple crimp[733 776 791 832 893 932] (or bulk resistance to compression) and breed

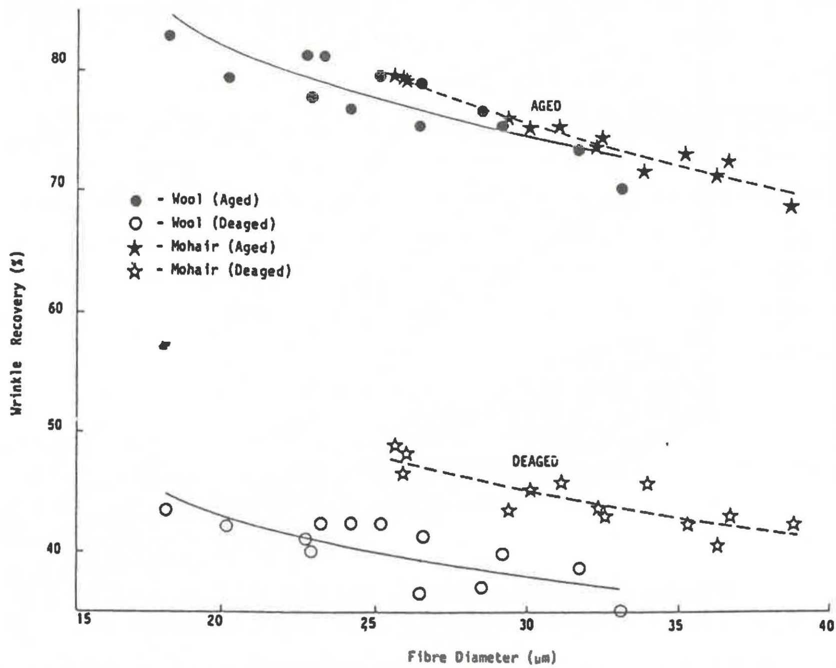


Fig. 114 IWS Thermobench Wrinkle Recovery vs Mean Fibre Diameter (Plain Weave: Weft Direction)(946)

of sheep (Merino and allied breeds) appeared to have little effect on fabric wrinkle recovery as assessed by the various test methods.

21.3 EFFECT OF BLENDING WITH SYNTHETIC FIBRES

Wool/Polyester: Studies[437 445 527 565 645 656] involving different types of polyester (normal, low-pilling and high bulk) showed that these polyester types differed little in their wrinkling properties, the low-pilling polyester possibly being marginally better. Increasing polyester content tended to improve the wrinkle recovery of deaged fabrics (and sometimes also of aged fabrics) as assessed by the FRL, AKU and IWS Thermobench tests, but had neither a large nor a consistent effect on Shirley and Monsanto crease recovery angles. Figs 115 to 117 illustrate some of the trends.

Wool/Acrylic:[582 628 656] Little difference was found between FRL wrinkle

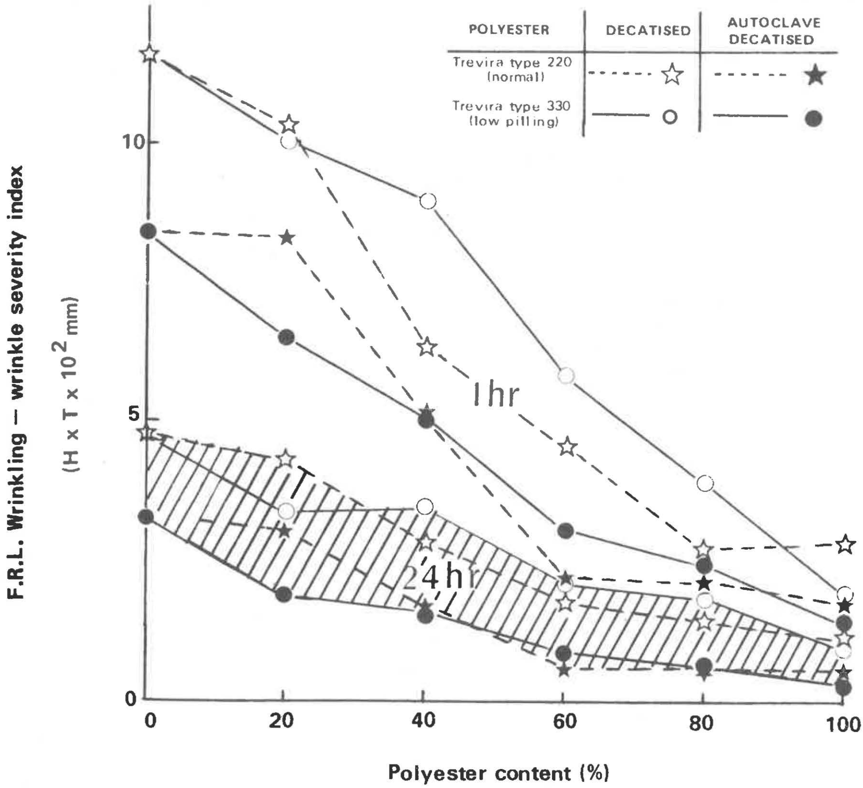


Fig. 115 The relationship between wrinkle severity index (H x T) and polyester content(527)

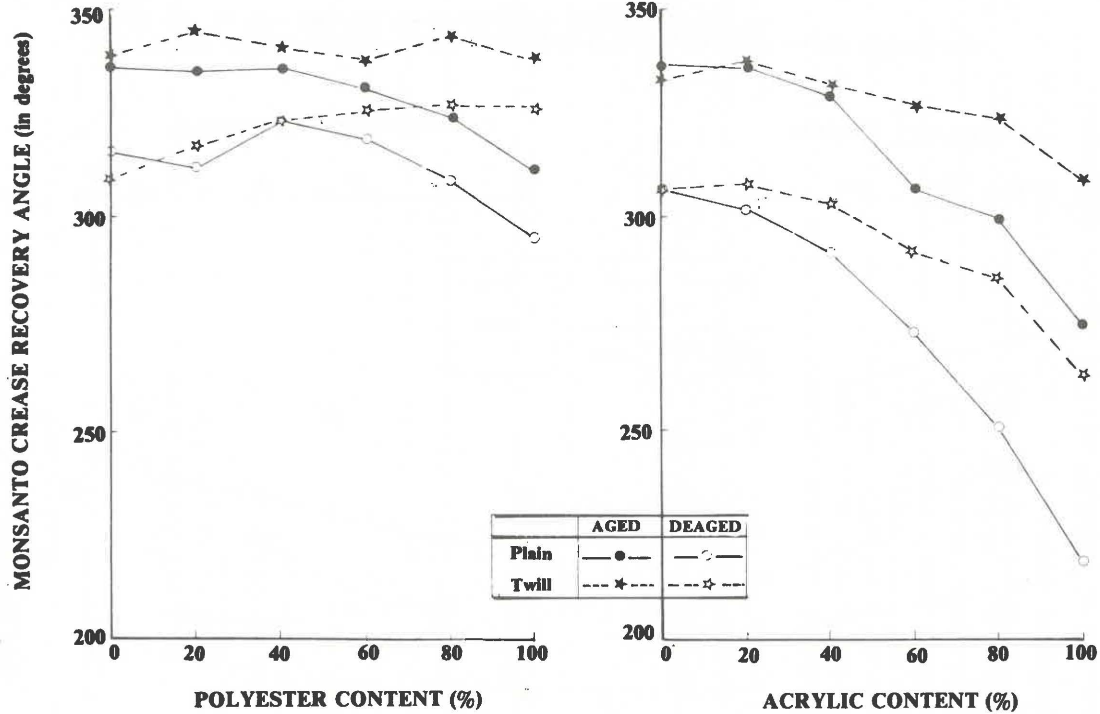


Fig. 116 The effect of synthetic fibre content on the Monsanto crease recovery angle obtained for the two different fabric structures and "states" (fabrics creased and recovered at 20°C/65% RH)(656 946)

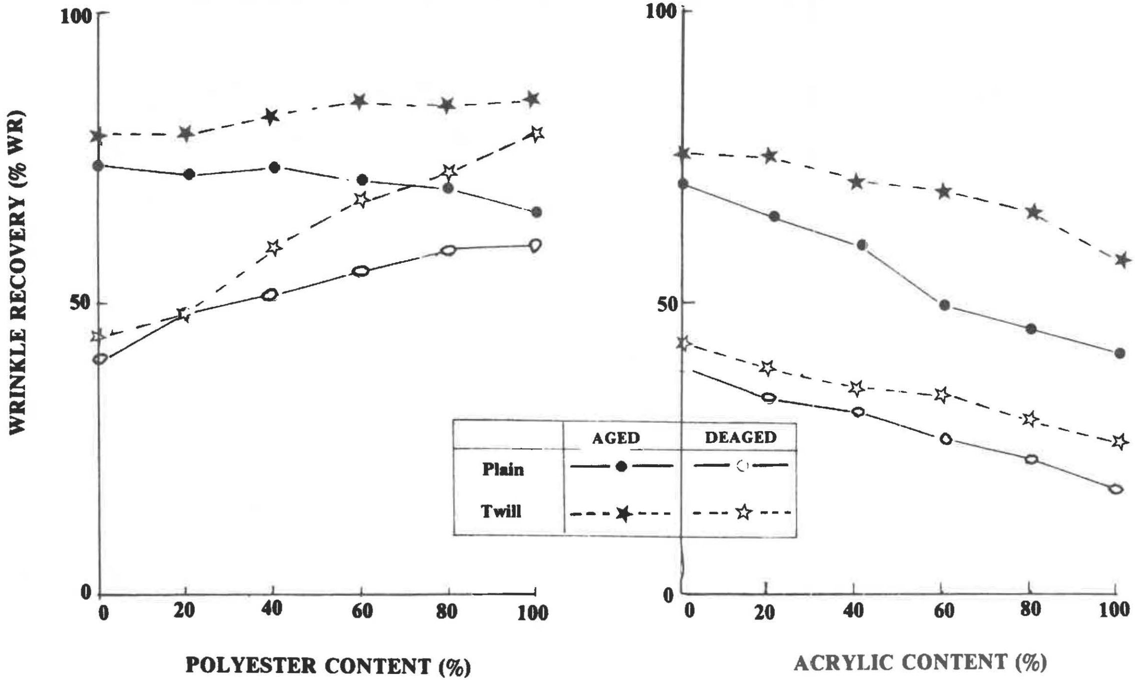


Fig. 117 The effect of synthetic fibre content on the IWS Thermobench wrinkle recovery test results for the two different fabric structures and "states"(656 946)

recovery and crease recovery (Monsanto) of blends involving 3,3 dtex acrylic and those involving 4,9 dtex acrylic. Monsanto crease recovery of aged and deaged plain fabrics and of deaged 2/2 twill fabrics deteriorated with increasing acrylic content (Fig. 116), the effects generally being more pronounced for the plain weave than for the twill weave. For the IWS Thermobench test, the general trend for the plain weave fabrics (aged and deaged) was also for wrinkle recovery to deteriorate with increasing acrylic content (Fig. 117), whereas for the twill weave fabrics, acrylic content had no apparent effect except when the test was carried out under standard conditions in which case wrinkle recovery once again deteriorated with increasing acrylic content. For the AKU test, wrinkle recovery also deteriorated with an increase in acrylic content in the case of the deaged fabrics while it either remained constant or improved in the case of the aged fabrics. On the other hand the wrinkle recovery, as assessed by the FRL (aged and deaged) method, generally tended to improve with increasing acrylic content. Certain of the above trends are illustrated in Figs 116 and 117. The fabrics containing polyester generally performed better than those containing acrylic and appeared best of the synthetic fibres from the point of view of wrinkle recovery.

Shiloh and co-workers[432 474] compared the wrinkling and mechanical properties of wool-rich plain and twill-weave fabrics containing all-wool, wool/nylon core-spun and wool/nylon and wool/polyester intimate blend yarns. No one particular fabric consistently performed better than the others although the presence of the synthetic component offered some advantages in terms of fabric wrinkling and certain mechanical properties.

21.4 YARN AND FABRIC STRUCTURAL VARIABLES[126 311 358 380 407 858 902]

In one of the earliest studies, Smuts *et al*[126] found AKU wrinkle recovery to improve with fabric sett until it reached a maximum after which it decreased. Smuts *et al*[368] observed better wrinkle recovery for fabrics woven under high warp tension (giving a relatively high weft crimp).

Slinger and Gouws[407] found that for plain weave fabrics, involving fabrics varying in pick density and yarn linear density, Shirley and FRL crease recovery values improved with an increase in fabric thickness.

In some limited trials on 2/2 twill-weave wool fabrics, in which only fabric sett was changed, Slinger and Robinson[358] found that fabrics with a mass of 262g/m^2 and a cover factor of 25,5 performed slightly better during wear and Monsanto and FRL wrinkling than either the tighter (and heavier) or looser (and lighter) fabrics.

In a study on wool fabrics, involving four different weave structures and two-ply yarns differing in twist direction (i.e. SS, SZ, ZS and ZZ) and different scouring, crabbing and cropping conditions, Smuts *et al*[380] found that weave structure had the main effect on wrinkle recovery, both FRL and Shirley wrinkle recovery values improving with an increase in float length. Smuts[402] was awarded an M.Sc. degree for his work on the mechanical and wrinkling properties of woven wool fabrics. Slinger (Ph.D. thesis)[311] found that the thickness of a series of plain weave was a better indication of wrinkle recovery than were the other fabric parameters, thicker fabrics wrinkling less. High plying twist in the weft yarn also affected wrinkling beneficially.

Studies[445 555 582 628 656 733] involving plain and 2/2 twill light-weight (200g/m^2) wool, wool/polyester and wool/acrylic fabrics showed that in most cases the 2/2 twill fabrics had superior wrinkle and crease recovery properties as assessed by the Shirley, IWS, AKU and FRL tests. For the Monsanto test differences between the twill and plain weave fabrics were insignificant for 100% wool but generally increased as the percentage polyester, or acrylic, particularly the latter, increased, being as high as 50° for 100% acrylic. Smuts *et al*[126] found higher yarn twist beneficial. The direction of the plying twist appeared to have little effect[368 380].

Smuts and Hunter[858 902] also investigated the effects of yarn parameters, such as singles and plying twist factor, plying twist balance and yarn type (singles, two-ply or fresco) and fabric parameters, such as weave structure and cover factor, on wrinkle recovery. It was found that these parameters generally only had a very small effect on fabric wrinkle recovery, the effect of ageing being far larger. The two test methods used (AKU and IWS) showed contradictory trends in a number of cases. For the AKU test, the fabrics containing the fresco yarns tended to have slightly better wrinkle recovery than those fabrics containing the unbalanced two-ply yarns (two-ply twist = singles twist), these fabrics in turn being slightly better than than the fabrics containing the balanced two-ply yarns (two-ply twist = 0,67 x singles twist) or singles yarn. For the IWS test, the fabrics containing the fresco and singles yarns performed similarly, and were slightly better than the fabrics containing the unbalanced twist yarns, the fabrics containing the balanced twist yarns performing worst. The effect of weave structure was not the same for the two wrinkling tests and neither were the effects of fabric mass and thickness.

21.5 CORRELATIONS BETWEEN DIFFERENT WRINKLING PARAMETERS AND TESTS[251 527 573 946]

From the above discussion it is evident that different laboratory tests for wrinkle or crease recovery give contradictory trends and it was therefore decided to investigate the correlation between the different test methods and parameters in more detail. Earlier studies[251 527 573] indicated a poor correlation between AKU results on the one hand and multiple-pleat and Shirley results on the other, the latter two being reasonably well correlated when the tests were carried out under the same atmospheric conditions. Generally[946] AKU parameters, SD, H and H x T, measured after 1 hr, were highly correlated with each other, a correlation of 0,95 being obtained for a wide range of wool, mohair, synthetic and blend fabrics (n = 84). The values obtained for these parameters under the (20°C/65% RH) test conditions, were also highly correlated (r = 0,9) with those obtained under 'non-standard' (27°C/75% RH) test conditions.

The Monsanto values obtained on aged fabrics with the 'standard' test were highly correlated (r = 0,96) with those obtained with the 'non-standard' test, the correlation (r = 0,66) being lower for deaged fabrics. The Monsanto results (standard test) obtained on aged fabrics were highly correlated (r = 0,98) with those obtained on the deaged fabrics.

The correlation between IWS values obtained on aged and deaged fabrics was 0,78 for the 'standard' test and 0,93 for the 'non-standard' test, while the correlation between the 'standard' and 'non-standard' test results was 0,97. The correlation between IWS and AKU results was about 0,7, conducting the two tests on fabrics having the same regain not improving the correlation to any marked extent. There was a better correlation between the IWS and Monsanto values for aged (r = 0,9) than for deaged fabrics (r = 0,7), the correlation generally being lower when the tests were carried out under 'non-standard' conditions.

It was concluded[946] that, although the results obtained with the different test methods (AKU, IWS and Monsanto) were correlated, the correlation coefficients were generally not high enough for the different tests to consistently rank different fabrics in the same order in terms of wrinkle recovery or to give similar trends.

21.6 EFFECT OF FINISHING CONDITIONS

Smuts *et al*[126] found that chemical setting caused a deterioration in dry wrinkle recovery but improved wet wrinkle recovery and that good wrinkle resistance did not necessarily imply good wrinkle recovery.
Slinger and Smuts[301] investigated the effect of setting, by vacuum steaming fabrics of different constructions and densities and found that in most cases wrinkling and crease recovery properties were adversely affected, cloth shrinkage also with increasing vacuum steaming, followed by formaldehyde treatment which also had an adverse effect on fabric wrinkling.

Smuts *et al*[368 380] investigated the effects of crabbing, scouring and cropping variables on the mechanical properties and wrinkling of wool worsted fabrics. Of these variables only the pH of the scouring liquor had a significant effect. From a consideration of the Mo results it appeared that crabbing under high roller pressure followed by scouring under low roller pressure was the best. After weave structure, scouring pH influenced the fabric properties, notably wrinkle resistance and Mo, the most. The change brought about was consistent with the notion of increased set (and better wrinkle recovery) at high pH of scouring liquor. Weaving at relatively high warp tension and decatizing for long periods gave optimum (best) fabric wrinkling but at an economic disadvantage[368]. Slinger (Ph.D. thesis)[311] found that autoclave decatizing had a beneficial effect on wrinkle recovery. He established the preferred decatizing conditions, as far as wrinkle recovery was concerned. The beneficial effect of autoclave decatizing was also observed in other studies[527].

Kelly and Hunter[555] compared the wrinkle recovery and certain other properties of light-weight all-wool plain- and twill-weave fabrics treated with either a silicone resin or a polyurethane resin. The fabrics treated with a commercial silicone polymer showed good dimensional stability and increased flexural rigidity without any loss in bursting strength. The treatment appeared to impart some resistance to deageing in wool fabrics prior to wrinkling. The fabrics treated with 10% silicone performed best in terms of wrinkle recovery. Smuts and Hunter[565] also found silicone to improve the dry crease recovery of wool and wool blend fabrics. They found that treating wool/acrylic[582, 628] and wool/polyester[645] fabrics with a polyurethane polymer and a mixture of the bisulphite adduct of a polyurethane and a polyacrylite polymer, generally only had a small effect on fabric wrinkle recovery.

21.7 WRINKLING AND BENDING OF FUSIBLE INTERLININGS

Shiloh[430] studied the wrinkling and bending of fusible interlinings in which a series of apparel fabrics were bonded both to a cotton base cloth and to a worsted base cloth and their wrinkle severity determined by means of the Sivim Wrinklemeter. Buckling and cantilever tests were also done, and the wrinkling behaviour and bending performance were compared. Fabric wrinkling in the wet state was about 50% higher than in the dry (65% RH) state, the fused and unfused fabrics behaving differently and also depending on whether the fabrics were fused to wool or cotton. Fusing inhibited the recovery from deformations, probably due to larger frictional restraints. In that particular study wrinkle severity was correlated with flexural rigidity and the bending and wrinkling of the corporate fabrics were affected more by the lining fabric than by the face fabric.

21.8 WEARER TRIALS

Slinger and Van der Merwe[409] reported on some wearer trials carried out on trousers treated with R Synthappret LKF and stated that the resin improved the smooth-drying and wet wrinkling properties of the fabric but caused a deterioration in wrinkling.

Slinger and Robinson[358] reported on the physical properties of 2/2 twill weave fabrics differing in sett and woven from an R42 tex/2 yarn. Wearer trials were also carried out on trousers produced from the fabrics, with specific reference to wrinkling. They concluded that the fabric (260g/m^2) with an intermediate sett (30,4 ends/cm x 27,1 picks/cm) performed best in terms of laboratory and wear wrinkling.

CHAPTER 22

INSTRUMENT AND MACHINE DEVELOPMENTS

22.1 TOP SAMPLING MACHINE

Mandel *et al*[111] developed a top sampling machine to eliminate the very difficult and time consuming process of the traditional top "squaring" or "worsted draw" technique. It produced an unbiased sample from a top in a relatively short time.

22.2 WITHDRAWAL FORCE TESTER[146, 152, 210, 215, 216, 217, 329, 408, 421, 433]

Kruger[215-217] described an apparatus, called a Withdrawal Force Tester (Fig. 118), by means of which the force necessary to withdraw a tuft of fibres from a sliver inserted in pins could be measured so as to investigate fibre movement during gilling and combing and the forces involved in each case. An account was given of the use of this apparatus in investigations of withdrawal-force variations for different sliver weights and withdrawal speeds and to determine the extent of fibre alignment and cohesion in slivers. There was a relationship between withdrawal force and percentage noil. In most cases, the withdrawal force per fibre was well below the fibre breaking load. Fibre breakage obtained in rectilinear combing was ascribed to bad fibre alignment and fibre entanglement.

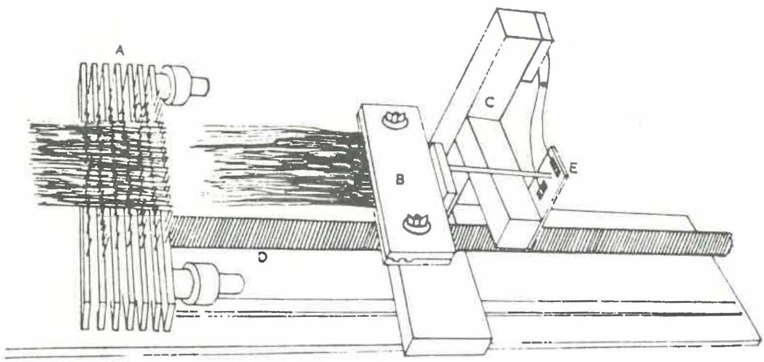


Fig. 118 Essential parts of the apparatus for measuring withdrawal forces. A — stationary pin-bed; B — jaws; C — pillar; D — lead screw; E — metal plate with strain gauges.

22.3 COMPRESSIBILITY TESTER[188, 285]

A simple apparatus was designed (Fig. 119) for measuring the resistance to compression of a randomized sample of loose wool. It consisted of a cylindrical brass chamber in which a conditioned sample of wool is compressed for exactly a minute under a load of 1 kg, the height to which the wool is com-

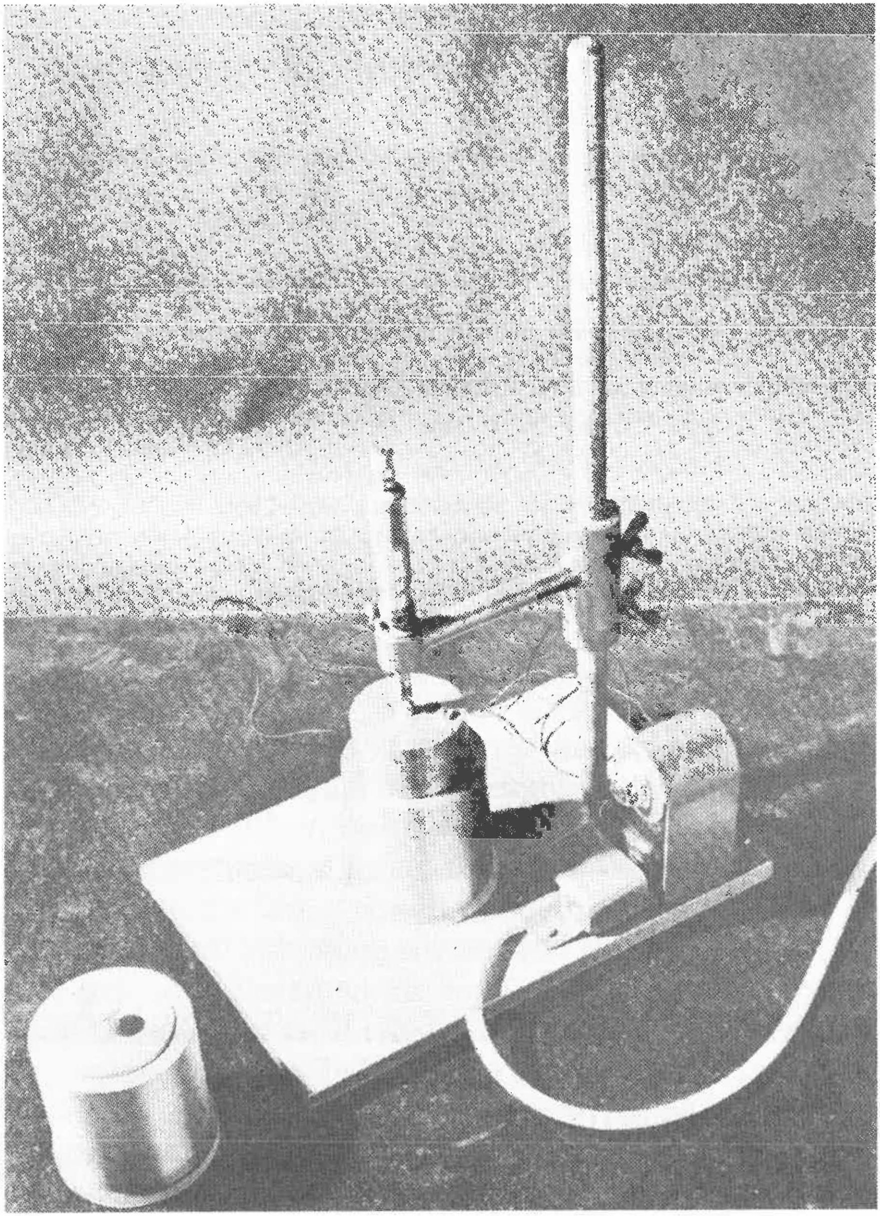


Fig. 119 SAWTRI Compressibility Tester.

pressed providing a measure of resistance to compression (RC) and fibre crimpiness.

22.4 YARN FRICTION TESTER

The SAWTRI Yarn Friction Tester was developed in 1967[226 281 314] which used strain gauges to measure the tension generated in a yarn due to friction. An updated (modernised), lighter and more compact instrument, called the SAWTRI Yarn Friction Meter, was subsequently designed by Frazer (Fig. 120). An input tensioner and associated tension measuring head were added.

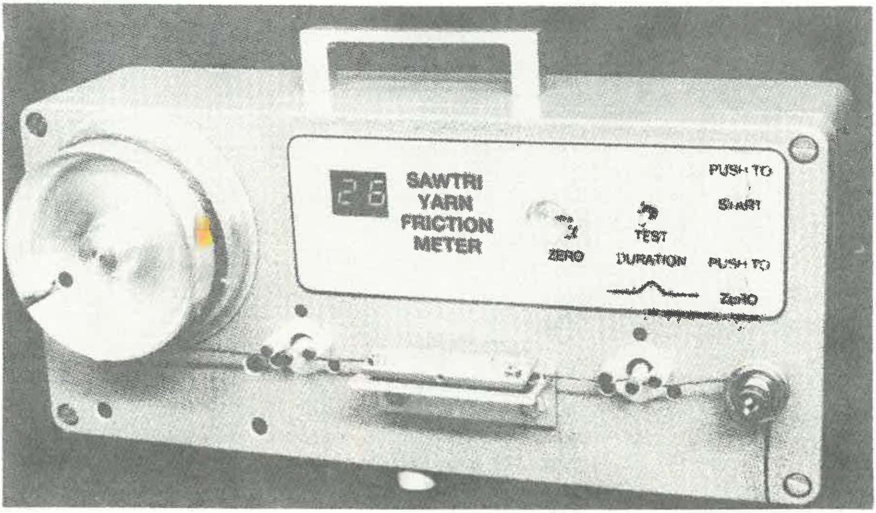


Fig. 120 SAWTRI Yarn Friction Meter.

22.5 SCOURED WOOL ENTANGLEMENT METER[362 410]

Kruger[362 410] described an instrument capable of determining the degree of entanglement of scoured wool. The results obtained with it correlated well with the carding and combing performance of the wool. Fibre length was found to be directly related to the entanglement reading. A parameter called the entanglement factor was defined to give a measure of the state of entanglement.

22.6 MIKRONMETER[374]

Boshoff and Kruger[374] described a relatively simple and inexpensive portable instrument, called the Mikronmeter, developed by the National Physical Research Institute of the CSIR in collaboration with SAWTRI, by means of which an estimate of wool fibre diameter could be obtained rapidly, and which was based upon the diffraction of white light, the diameter of the fibre sample determining the size of the circular diffraction pattern (Fig. 121).

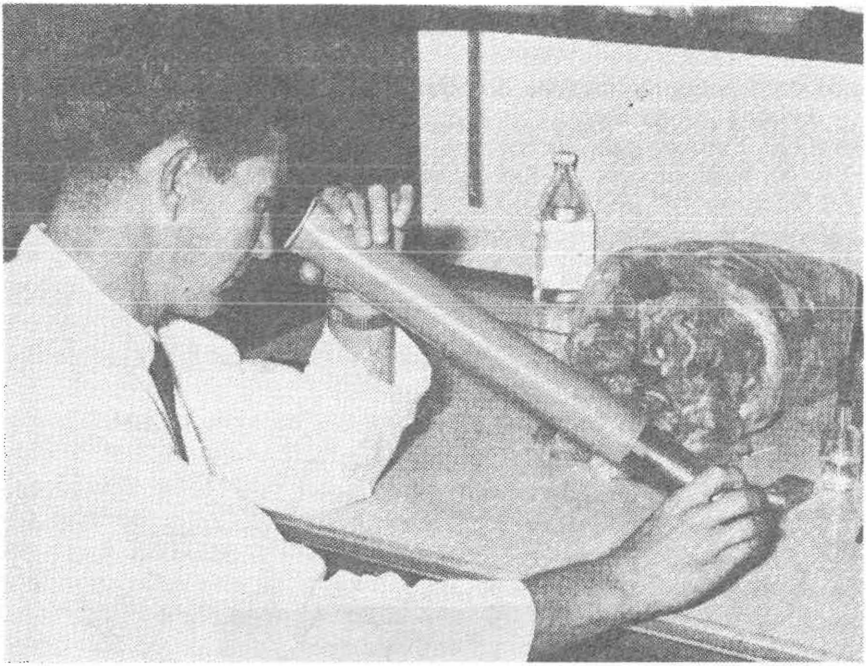


Fig. 121 The Mikronmeter.

22.7 ROTOR GILL BOX

In 1973 SAWTRI unveiled its rotor gill box which at that time was one of the fastest gill boxes in the world. It was exhibited by Messrs Petrie McNaught at the 1975 ITMA exhibition (Fig. 122). An M.Sc. thesis was prepared on the engineering aspects and design of the gill box by Klazar[524].

22.8 WRINKLEMETER[602]

Kelly[686] described some developments aimed at automating the FRL and AKU wrinkle recovery measurements by using an instrument to measure and compute the severity of wrinkling. Later developments led to the construction of an instrument, called the SAWTRI Wrinklemeter (Fig. 123). This instrument, which incorporates a micro-computer and video-monitor, measures the wrinkles inserted in a fabric and automatically subjects the results to computer analysis, from which is then obtained a print-out of the severity of wrinkling, including the average height and slope of the wrinkles.

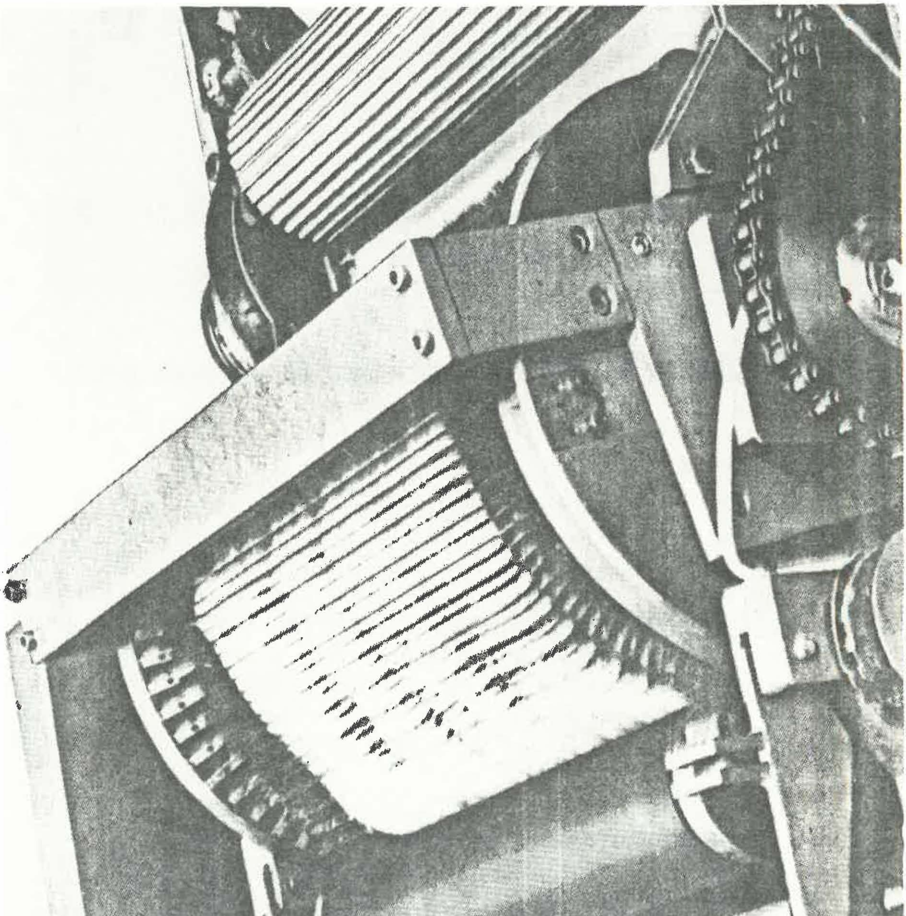


Fig. 122 Rotor Gill Box.

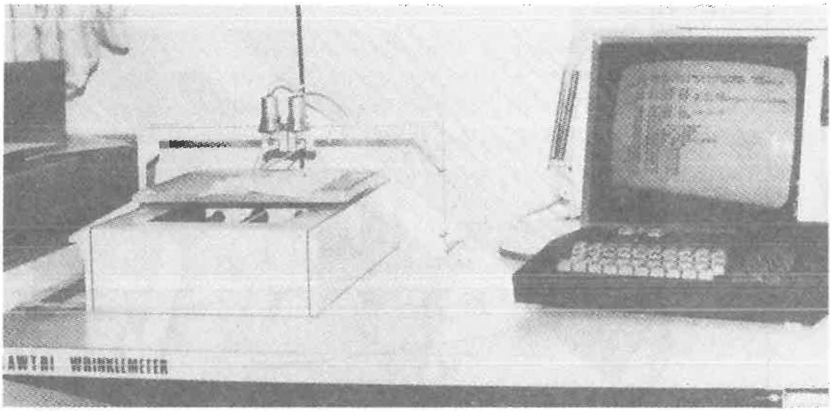


Fig. 123 SAWTRI Wrinklemeter.

22.9. SLD MONITOR

Klazar *et al*[681] developed the SAWTRI Sliver Linear Density (SLD) Monitor, which when fitted to the output of the most modern type of gill boxes, successfully monitored sliver linear density variations at delivery speeds of up to 300 m/min. Its concept allowed continuous and on-line monitoring. Off-limit variations could be detected rapidly by the SAWTRI SLD Monitor, which could be set to either illuminate a warning light or to stop the machine. Variations in sliver linear density of less than 1% were readily detectable and the monitor was useful for checking machine settings. An improved model (Fig. 124) as well as some industrial trials were reported later by Maskrey and Currie[754].

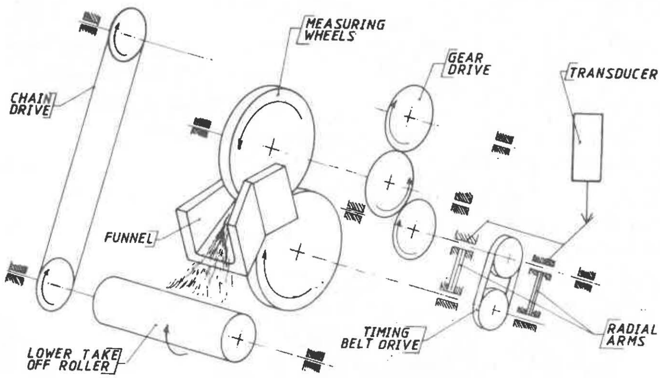


Fig. 124 SLD Monitor Mk3-Schematic Layout.[754]

22.10 COMB[770]

Turpie *et al*[770] described a working model of a novel high-production comb intended for combing fibres on the long staple system (Fig. 125). Novel features of the comb included its modular design, continuous linear action, low noise level and the fact that it lent itself to automation.

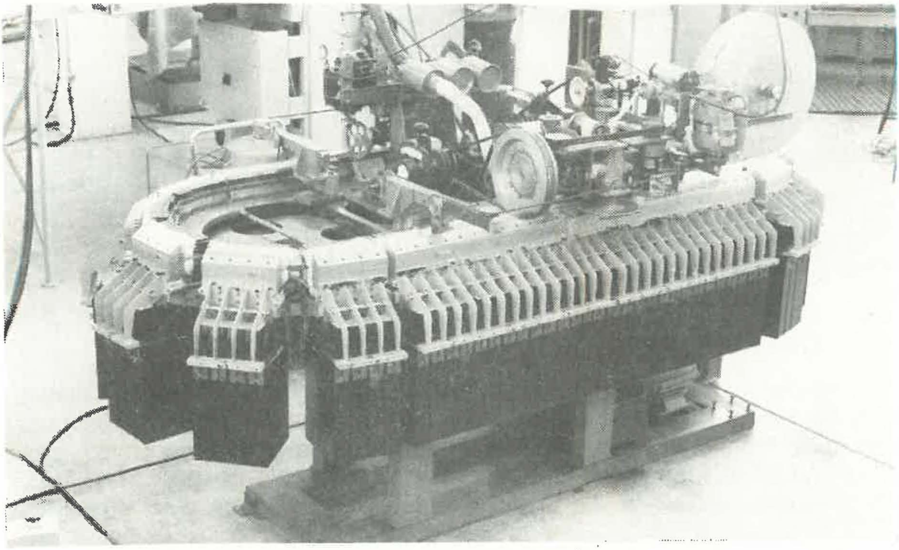


Fig. 125 SAWTRI Comb.

22.11 AUTOCREEL

A major effort led to the development of the SAWTRI Autocreel (Fig. 126), a highly sophisticated advanced automatic feeding machine for feeding slivers into a gill box[973]. It was designed by Klazar and Cizek with some assistance from the National Electrical Engineering Research Institute of the CSIR, and is being manufactured under licence by Messrs Cognatex, a member of the SAVIO Group in Italy. At the last ITMA in 1984, this firm exhibited an integrated two-stage gilling operation featuring robotics as the connecting link between the two stages, and the SAWTRI Autocreel as an integral part of the second stage. The unique feature of the SAWTRI invention in this application is the path taken by the cans of slivers during feeding and the way in which the feed mechanisms can accommodate that path. This invention enables virtually uninterrupted feeding, automatically splicing-in any replacement slivers when they run out or break, and resulting in extremely high operating efficiencies.

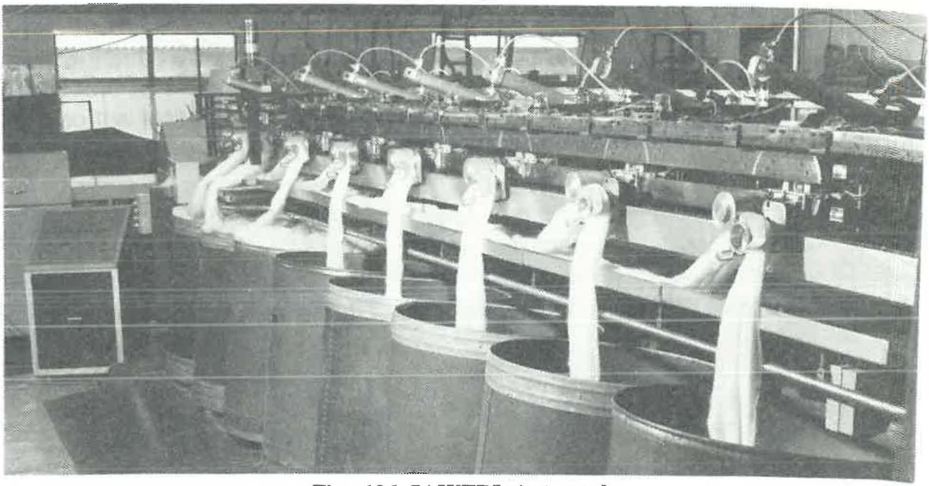


Fig. 126 SAWTRI Autocreel.

22.12 DEFRIBBER[824]

Research at SAWTRI showed that the degree of "fribbiness" (largely very short staples and second or double cuts) of raw wool played a significant rôle in the amount of fibres which was rejected as waste during topmaking and a method involving a hand operated laboratory defribbing apparatus was devised to obtain a reproducible estimate of the fribbiness of the wool (Fig. 127).

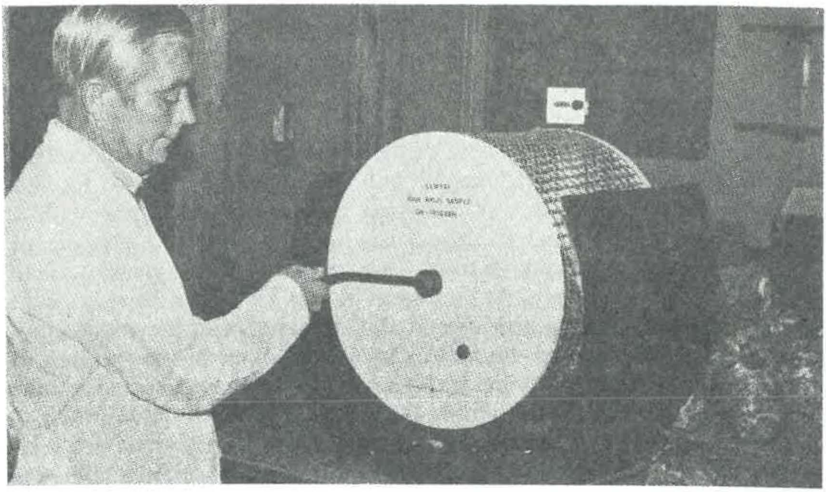


Fig. 127 The Defribber.

22.13 WOOLLEN WRAP-SPINNING DEVELOPMENT

Van der Merwe and co-workers[898 905 974 989] modified a woollen card so as to allow wrap-spun yarns to be produced directly on the card (Fig. 128). Subsequently Brydon and Van der Merwe[974 990 992 993 1001] described a separate machine which they had constructed for wrap-spinning of woollen slubbings (Fig. 129).

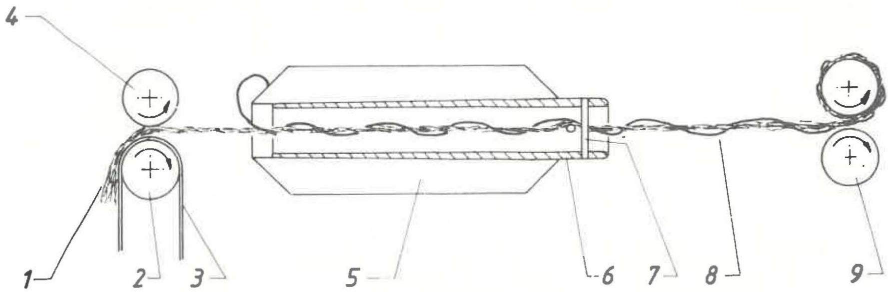


Fig. 128 The production of wrap yarn on a woollen card without rubbing aprons.

1. Fibre ribbon
2. Tape roller
3. Tape
4. Counter roller
5. Filament package
6. Hollow spindle
7. False twist cross
8. Wrap yarn
9. Condenser winding drum

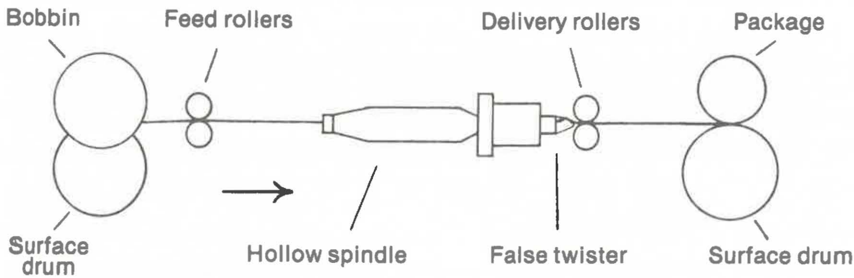


Fig. 129 Apparatus for drafting woollen slubbings.

22.14 CONTINUOUS SHRINKRESIST TREATMENT PROCESS

Van Rensburg and Barkhuysen[866] developed a process whereby wool tops are shrinkresist-treated on a continuous basis on a modified suction-drum backwashing unit (Fig. 130) using chlorine gas for the prechlorination stage. This stage is followed by the application of a polymer to complete the shrinkresist treatment.

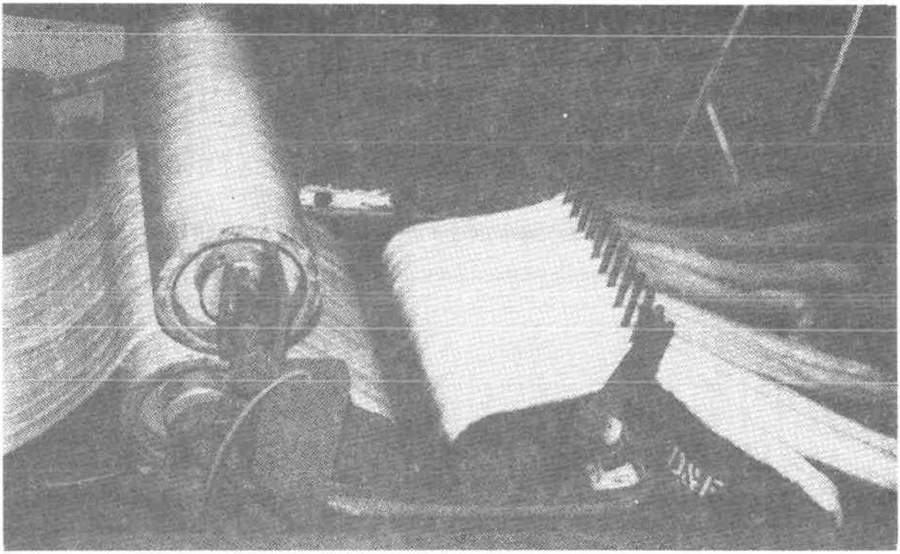


Fig. 130 Wool tops being passed through a suction-drum backwashing machine for chlorination.

22.15 AUTOMATIC STAPLE LENGTH/STRENGTH TESTER

Cizek and Turpie[912 924 939 973 995] and Turpie *et al*[973a] described the SAWTRI Staple Length/Strength Tester for the routine automatic measurement of the cross-sectional profile and length of a wool staple, the position and cross-sectional area of its thinnest place, its tenacity and the work required to break it (Fig. 131). Strength measurements can be carried out at the maximum practical gauge and/or at short gauge. The instrument can also be used for length and profile measurements of mohair. The information provided was shown to have useful application in the prediction of combing performance, the strength measurements at short gauge providing useful additional information in respect of percentage noil. It was also shown that collective information on staple profiles could have useful application in the prediction of the length distribution in wool and mohair tops.

Fig. 131 The SAWTRI Staple Length/Strength Tester.

22.16 HIGH-SPEED YARN TENSILE TESTER[971, 973]

Cizek (Patent Application No. 86/2796) developed and constructed a very high speed automatic yarn strength tester which can test yarn at a speed of some 10 000 breaks per hour. Hunter *et al*[971, 998] gave some results obtained with the prototype instrument and showed that its results correlated well with the weavability of worsted yarns etc. (Fig. 132)[973].

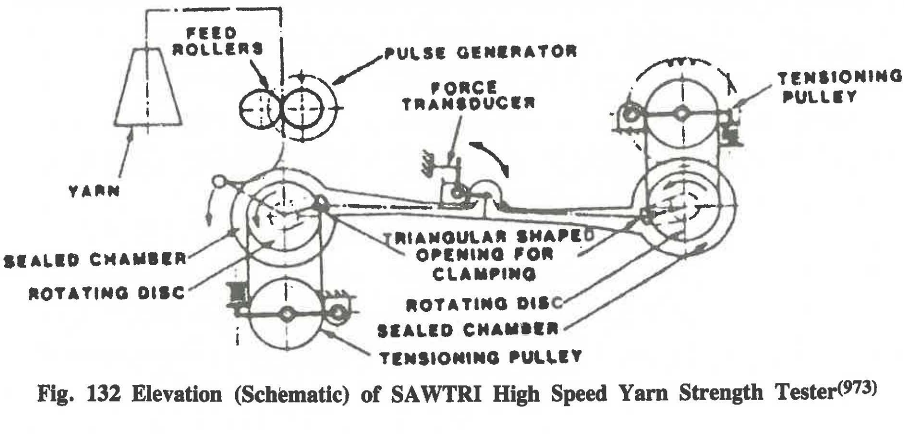


Fig. 132 Elevation (Schematic) of SAWTRI High Speed Yarn Strength Tester[973]

22.17 PUCKERMETER

Galuszynski[977, 979] developed a relatively simple apparatus, called the SAWTRI Puckermeter (Fig. 133), for quantifying the degree of seam pucker, the lengths of a seamed fabric sample measured tensionless (i.e. in its puckered state) and under tension (puckering just removed) respectively, being used to arrive at a measure of pucker.

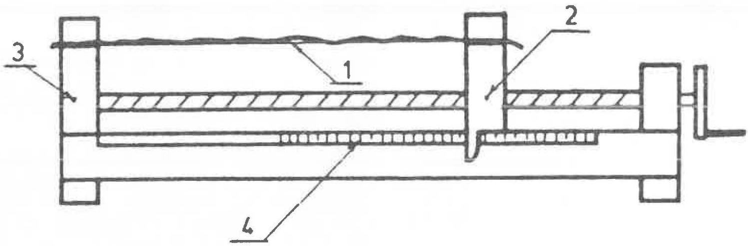


Fig. 133 SAWTRI Puckermeter.

CHAPTER 23

PUBLISHED REVIEWS

Various SAWTRI staff members have over the years undertaken reviews on diverse subjects, some comprehensive and detailed while others were more limited in their scope. Some reviews dealt purely with SAWTRI's research activities and facilities while others covered research done in different parts of the world on a specific subject. The ones dealing with wool and wool-related subjects are briefly listed below in two groups, namely reviews which dealt solely with SAWTRI's studies and those which were more general, covering research carried out globally. For the sake of having a complete bibliography, articles dealing with SAWTRI's wool-related activities and facilities are listed.

23.1 SAWTRI'S WORK

Veldsman[49, 220, 228, 308, 342, 367, 412, 452, 489, 490, 491, 545, 662, 674, 755] regularly reviewed various aspects related to SAWTRI's research activities and facilities. In certain cases he dealt with specific topics including wrinkling[291], pollution resulting from textile wastes[330], processing behaviour of South African wools[180, 715], machine washability[159], shrinkresist treatments[559], knittability[601], cockling[620], dyeing and finishing[716], chemical modifications (shrinkresist treatments, dyeing, bleaching, durable press) and wrinkling[605].

Den Heijer *et al*[244] gave a synopsis of work carried out at SAWTRI on DCCA shrinkproofing, including aspects of yellowing.

Strydom[600] and Veldsman[670] discussed the advantages of ammonia treatment and briefly referred to the flame retardant treatment and mercerisation of wool/cotton blends.

Strydom[638] briefly referred to some of SAWTRI's research achievements while Vogt[968] and De Wet Olivier[420] briefly described some of the facilities and activities of the Institute and the latter also discussed[268, 293, 411] various aspects related to the Co-We-Nit system of producing fabrics. He also summarised work done on the use of fibre friction for distinguishing between wool and mohair[442].

Turpie[765, 890] discussed the historical background, and some research activities and findings of the Institute and also described[973] some of the achievements, machines and instruments which had been developed at the Institute while Maasdorp and Van Rensburg[976] described new analytical techniques and instruments available in the field of textile chemistry.

Turpie[921] reviewed recent studies carried out at SAWTRI, and related the raw wool properties that count most in textile processing while Vogt[425] discussed changes in the South African wool clip related to the relative importance of various wool fibre properties in textile processing. Hunter *et al*[872] summarised some of SAWTRI's research on the effect of wool fibre properties on woven and knitted fabric properties. Van der Merwe and Veldsman[349] briefly reviewed some of SAWTRI's research on karakul and Robinson[917] that in the field of fusing. Brydon[992 993 1001] reviewed studies at SAWTRI on the production and properties of woollen spun wrap yarns.

23.2 GENERAL

Veldsman[132 144 158] gave a detailed review of the weathering of wool in a series of articles.

Van Wyk[63 67] reviewed the factors which play a rôle in the felting of wool and the research carried out in various parts of the world in this particular field. He also briefly reviewed methods for rendering wool fabrics shrinkresistant[98].

Swanepoel[41] briefly surveyed the current position as far as durable creasing of wool fabrics was concerned while Louw[29] gave details of the Si-Ro-Set and Immacula processes of durable creasing and pleating of wool fabrics and compared their advantages, disadvantages and chemical reactions. Swanepoel and Handley[227] reviewed the application of polymers to wool to prevent felting shrinkage. Veldsman[160 172 373] reviewed developments in the fields of dyeing and finishing of wool and achieving dimensionally stable fabrics[231].

Van Rensburg and Mozes[758] reviewed current legislation and mill practice in South Africa with respect to wool scouring effluents and gave the specifications for effluents to be discharged into streams, rivers and municipal sewers, as well as some tariffs charged by certain municipalities for the discharge of effluents.

Tworeck, Ross and Van Rensburg[892] discussed the use of reclaimed water in the textile industry.

Veldsman[669] briefly discussed some important basic facts in the carbonising of loose wool with minimum damage to the fibres while Mozes[963] reviewed the carbonising of raw wool and the treatment and purification of wool and mohair scouring wastes[835].

Van Rensburg[451 818a 836 881 882] briefly reviewed the latest trends in making fabrics flameproof and discussed the toxicology of fires and burning textiles, including statistics related to burn injuries and the factors which cause death. Veldsman[554] also briefly discussed the importance and economics of flame resistant treatments.

Louw and Boshoff[168] reviewed charged system dry-cleaning and the durability of water-repellent finishing while Van der Merwe and Strydom[460] discussed various aspects related to solvent dyeing.

Van der Walt[762] discussed the rôle of energy measurements in increased dyehouse profitability and described equipment for measuring the consumption of steam, electricity and water during a dyeing process. A typical example of monitoring a winch-dyeing operation involving wool fabric and reactive dyes was given. Van Rensburg and Van der Walt[749] discussed the energy savings possible through proper maintenance of steam lines.

Veldsman[646] considered the technological aspects of electromagnetic fre-cy heating of textiles and also discussed[738] energy conservation in the ng and finishing industries. Barkhuysen[915] reviewed the radio frequency ng of textiles. Van der Walt and Van Rensburg[887 982] reviewed low add-on n application techniques in dyeing and finishing.

Maasdorp[871] reviewed the chrome mordant dyeing of wool with special erence to the afterchrome process.

McMahon and Van der Walt[937] reviewed recent developments in warp ing.

Hunter[768] gave a detailed review on the effect of wool fibre properties on xtile processing performance and yarn and fabric properties. Strydom[557 850] iscussed the influence of fibre properties on wool processing while Turpie[529] eviewed the rôle of crimp in the assessment of wool quality and Cilliers and Veldsman[323] discussed some of the top requirements for spinning. Kruger[343] discussed the requirements and relative merits of the Continental (French or rectilinear combing) and the Bradford (Noble combing) systems of manufacture while Cilliers[341] briefly discussed the features of the semi-worsted system with specific reference to local conditions.

Hunter[626] summarised the progress which had been made in the prediction of worsted yarn properties from the fibre properties and presented various mathematical relationships which had been derived for this purpose. He also described new developments in staple yarn spinning and the properties of knitted and woven fabrics produced from them and produced a detailed review[641 723] on the production and properties of staple fibre yarns produced by recently developed techniques. Strydom[823] briefly dealt with some recent developments in spinning technology and their relevance to the wool spinning section.

Van der Merwe[891] reviewed the developments and principles pertaining to the woollen system of manufacture while Brydon and Van der Merwe[960] reviewed the principles of wrap spinning and developments in this field.

Erdursun and Hunter[811] reviewed the processing of wool and wool blends on the short staple (cotton) system.

Hunter[417] conducted a literature survey of the linear densities of various types of yarns (natural and synthetic) commonly used on the various types of weft-knitting machines and presented graphs (and equations) relating yarn linear density to machine gauge for the different types of yarns and knitting machines.

Wolfaardt[183] briefly covered the latest developments in yarn clearers.

Slinger[361] discussed the evaluation of yarn and fabric quality. Hunter also discussed[503] the control of yarn and fabric quality and reviewed[740] the dimensional constants of knitted fabrics and their uses, covering various fibres and knitted fabric structures.

Strydom[639 647] reviewed the factors affecting the dimensional stability of knitted and woven fabrics containing natural fibres, with particular reference to

SAWTRI's work in this field. He later[737] gave specific attention to dimen stability of wool worsted woven fabrics in making up as well. He also d. sed some of the parameters which influence the physical properties of double jersey fabric[561].

Hunter[519 695 696] published some technical data and information on vai aspects of textiles while Hunter and Cawood[750] reviewed the field of sewabi. sewing needles, threads and seams. Cawood[846] published a review on fus while Galuszynski[969] reviewed factors which affect seam pucker in fabri

Veldsman discussed comfort aspects of textiles[739], dimensional stability dry-cleaning[514], performance testing[513], noise control in textile and clothi. mills[520] and textiles in the year 2000[661].

Bird[900] reviewed the prediction of textile wear performance with specifi reference to abrasion.

Aldrich[211 212] and Veldsman[260] reviewed the use of radio-isotopes in the textile industry, including the studies carried out at SAWTRI. Kruger[221] reviewed the application of strain gauges in the textile industry, with specific reference to SAWTRI's work on the measurement of withdrawal and dabbing forces as well as yarn friction.

Galuszynski and Robinson[867] undertook a survey in which 56 leading clothing manufacturers participated and produced a general picture of the production and problems of this sector.

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