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Studies on the Basic Characteristics of South African Merino Wool.—I. Breaking Strength and Tensile Strength.

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THE basic characteristics of the raw material from which textiles are manufactured largely determine the characteristics of the finished cloth, and a knowledge of the basic characteristics of the raw material is valuable.

It has already been shown (Bosman, 1937) that the Union of South Africa produces an extremely fine fibred type of Merino wool which is used as raw material in the manufacture of fine fibred fabrics.

As regards the other characteristics, little experimental data have been available and information regarding South African wool could not be given to the users of the raw product. In addition, the wool producer has not been able to compare his product with other textile fibres, nor has he known how to effect improvements in his raw material.

Other textile organisations, such as those that control the manufacture of synthetic fibres, are in a stronger position in this respect, since by constant research they are able to say precisely what the intrinsic characteristics of their products are. In their case the continued improvement in the characteristics of synthetic fibres is due to intensive researches.

This position was realised by the South African Wool Council and research projects for studying the basic characteristics of South African Merino wool were financed by the Council out of Wool Levy funds.

The present contribution deals with tensile strength. Other characteristics are described elsewhere.

Apart from the actual experimental results presented in these publications, a great deal of work has had to be undertaken to evolve suitable methods for expressing the characteristics in arithmetic and comparable terms. This system is also essential in research work that deals with Merino wool from production aspects and it forms the basis for further work on researches into Merino genetics and nutrition.

Review of Literature.

Although several publications, dealing with the breaking strength and tensile strength of wool from different breeds of sheep are available, no work dealing directly with the breaking strength and tensile strength of South African Merino wool is known.

The first reliable estimate of the breaking load of wool appears to be recorded by McMutrie (1886) who gave average values for various breeds of sheep. Matthews (1904) designed an instrument for determining breaking strength and considered that an average of 10 fibres per sample gave a reliable estimate of the characteristic. Hill (1908, 1911, 1912) concluded that an average obtained from a 1,000 fibres per sample was not reliable and considered that the breaking strength is more nearly proportional to the diameter of the fibre than to the square of the diameter.

Miller and Tallman (1915) studied the tensile strength of wool fibres, testing 1,000 fibres per sample. Güldenpfennig (1915) studied the breaking strength of fibres from pure-bred and cross-bred sheep. Hardy (1918, 1920) concluded that the tensile strength of wool, both in the grease and as scoured, decreased with an increase in relative humidity from 40 per cent. to 80 per cent. and showed a tendency to increase thereafter to saturation. Hardy stressed the need for diameter measurements and considered that the smallest diameter should be used in calculating tensile strength. He found an increase in the tensile strength with a decrease in fibre diameter and asserted that the breaking strength of fine wool varied more closely with the first than with the second power of the diameter, while the breaking strength of coarse wool varied with a figure lying somewhere between the first and second powers of the diameter.

Kronacher (1924) found a high correlation between fineness and breaking strength and gave standards of breaking strength for the various fineness classes.

Kühler (1924) found a higher tensile strength for fine than for coarse wools in the case of Karakul sheep, his conclusions being verified by Dimitriades (1926) who used wool from Merino yearlings. Deppe (1926) found a high correlation between fineness and breaking strength. Further investigations were carried out by Tänzer (1926) and Anert (1929), the latter using the smallest fineness value for the calculation of tensile strength. Krais (1927), whilst reviewing the testing methods used at Dresden, gave instances of the value of tensile strength determinations.

Ogrizek (1926) and Constantinescu and Contescu (1928) found correlations between breaking strength and diameter in a study of the wool of Zigaja sheep.

Barker and Hedges (1927) found a decrease of approximately 0·57 per cent. in the breaking strength of yarns for each 1 per cent. rise in relative humidity. Reimers and Swart (1930) studied the relation between diameter, extensibility and carrying capacity of fibres from a number of closely related Merino rams. Saur (1931) advocated the standardisation of the duration of the time of tests on tensile strength.

The variation of tensile strength and extensibility and their correlation with fibre fineness were studied by Kärrner (1932). Doehner (1932) devised an apparatus for determining the tensile strength of a bundle of fibres, and later (1935) applied the instrument in a study of the monthly and yearly variations of tensile strength in the wool of sheep of the most important breeds occurring in Germany.

Cunliffe (1933) published photographs of fibres under stress which showed clearly the diminution of fibre diameter during stretching. Schmidhäuser (1936) compared the tensile strength, extensibility and fineness of various textile fibres including staple fibre.

An extensive series of experiments on the elastic properties of wool was commenced by Speakman (1924, 1926, 1927, 1928, 1929, 1930 and 1931) using English Cotswold wool. He was able to form a picture of the structure of the fibre and explain its properties. The work was supplemented by X-ray studies (Ewles and Speakman 1928 and 1930).

Experimental.

The Selection of Samples and Methods of Analysis.

The South African wool clip is produced under varying conditions of climate and pasturage and a representative selection of the clip must take into account the types of wool produced in the different wool-growing areas.

The question of how a representative selection of samples from the South African Merino clip could be obtained was carefully considered. Assuming that there are approximately 50,000 Union farmers who sell wool, the question of obtaining samples from each of these clips would make a study of this nature prohibitive. A reasonable representative selection of samples could be obtained, however, by choosing representative samples from distinctive wool growing areas. The range of samples used for the study therefore includes types grown on grass-veld, mixed-veld and karroo-veld and were obtained from wool growing areas of the four provinces of the Union.

The laboratory determinations of the series of samples were carried out on a representative selection of fibres taken from a larger lot of wool, whether this was a farmer's clip, a bale or a lesser quantity. Each case was treated on its own merits and a sample taken according to the size of the lot.

The instrument used for the test was that devised by Doehner (1932). It was found to be very suitable for these studies, since it determines the mean breaking strength of a bundle of fibres and for this reason was preferred to other existing instruments.

Usually the original sample was divided into zones, fifteen to thirty, or more, depending on the size of the sample, and single staples were drawn at random from each zone in succession, until a sub-sample of about 100 grams had been made up. From each of the staples forming a sub-sample, a small strand of fibres was separated off and cleansed in ether, the strands being laid side by side after washing. A single fibre was drawn at random from each strand and after being straightened just sufficiently to eliminate the crimping, was mounted on a frame devised by Doehner (1932) and its ends secured with adhesive wax. When a hundred fibres had been mounted, the ends of the bundle were fixed by sealing wax to a strip of paper perforated by a special instrument that is included in the Doehner appartus. The mean value obtained from three such bundles made up of fibres from the original sub-sample, was shown, by special tests, to be of sufficient accuracy for the purpose of the present study. It was shown that the variation among the three bundles of a sample (expressed by a standard deviation of $\pm\cdot 080$) was considerably smaller than the variation among the different samples (the standard deviation of the latter being $\pm\cdot 231$). There was thus a real difference in the tensile strengths of different samples.

All determinations were carried out in a room maintained at a constant relative humidity of 70 per cent. at a temperature of 70° Fahrenheit. (According to tests made on a number of samples, values obtained at 70 per cent. relative humidity may be adjusted to correspond to 65 per cent. relative humidity by adding $0\cdot 45$ ($\pm\cdot 21$) grams to the breaking strength, and $0\cdot 14(\pm 0\cdot 04)\times 10^6$ gms./cm.^{2} to the tensile strength). The paper strips containing the fibres were placed in a desiccator for 24 hours before being exposed to the conditions of the humidity chamber. The fibres therefore in all cases contained moisture corresponding with adsorption conditions.

The breaking strength was determined at points two millimeters apart on the bundle of fibres, this operation being aided by the perforations on the paper holding the bundles. The number of points of breaking was thus dependent on the length of the bundle of fibres and usually ranged from 3 to 5.

The rate of loading of the instrument was 2 kilogrammes per minute giving an average of 20 grammes per minute for individual fibres. The load at break was read off directly on the calibrated scale.

When the tests were made, the Onderstepoort Wool Research Laboratories had, for certain reasons, its Constant Humidity Chamber set at 70 per cent. Relative Humidity and 70° Fahrenheit. Since then the conditions have been changed to the internationally adopted standard of 65 per cent. Relative Humidity and 70° Fahrenheit.

After the fibres, forming one bundle, had been broken, all the fragments were collected and mounted on a slide in Euparal. From each slide two hundred fibre thickness measurements were made at random on a Zeiss Lanameter and the mean cross-sectional area calculated from the mean square of the two hundred measurements, it being assumed for comparative purposes that the fibres were circular in cross-section. From the data on the breaking strength, the number of fibres broken, and the cross-sectional area, the tensile strength was calculated.

As regards the power of the diameter with which the breaking strength varies, Hardy (1920) asserted that the breaking strength of fine wool varied more closely with the first than with the second power of the diameter, while the breaking strength of coarse wool varied with a figure lying somewhere between the first and the second powers of the diameter. This assertion was tested on 114 merino samples by calculating the regression coefficient of the logarithm of the breaking strength on the logarithm of the diameter. The result was 1·895 (± ·0183) which is near enough to 2 to justify the assumption adopted for the present work that the breaking strength varies as the square of the fibre diameter.

Results.

A. *Fibres within the same Staple.*

A portion of the work deals with the breaking strength and tensile strength of fibres within the same staple of Merino wool.

Twenty different Merino staples were selected and the coarse and fine fibres were separated from each other. Each lot of fibres separated was measured for fibre fineness and for straight fibre length. The high degree of correlation between the fibre fineness and the length of the fibres in the same staple shown by Duerden and Bosman (1931), viz. values from + ·91 to + ·99, was also evident in this series where the correlation was found to be + ·7944.

The results of the measurement of fibre fineness, breaking strength and tensile strength are summarised in Table 1.

The fibre fineness of the fine and coarse fibres of each staple is given in column 3. The mean breaking strengths per fibre are recorded in column 4 where the degree to which fine and coarse fibres in the same staple differ in breaking strength is demonstrated. The average breaking strength of the coarse fibres is 6·66 (± ·504) grammes and that of the fine fibres is 4·38 (± ·300) grammes. On an average the coarse fibres are 52 per cent. stronger per fibre than the fine fibres. When the same load is placed on the different fibres in the staple, the finer ones will break sooner and the coarser ones will stand a load of at least half as large again as do the finer fibres.

The practical application of these facts, whether during the processes of manufacture of wool fabrics, or during wear in wool garments, needs further investigation, although several authors have already contributed to the subject (Cowden, 1927; Williams, 1932, *et alia*). Williams in discussing the strength of textile fabrics, asserts that "the problems of strength were perhaps not so important in the past when fabrics were usually heavy and strong, but now that lighter and necessarily weaker fabrics are in demand

and synthetic textile fibres of inferior strength to the natural fibres are extensively used, the strength problem is certainly of great importance."

TABLE 1.

The Results of the Measurement of Fibre Fineness, Breaking Strength and Tensile Strength of Fibres within the same Staple of Merino Wool.

Sample.	Type of Fibre Selected.	Mean Fineness. (μ).	Mean Breaking Strength per Fibre (gms.).	Mean Tensile Strength (gms. per sq. cm. ± 10.
1	Fine................	17·97	3·40	1·32
	Coarse..............	29·02	6·84	0·99
2	Fine................	18·36	4·37	1·62
	Coarse..............	22·24	6·26	1·59
3	Fine................	15·25	2·80	1·44
	Coarse..............	20·96	4·84	1·10
4	Fine................	17·54	3·97	1·56
	Coarse..............	20·71	5·03	1·47
5	Fine................	21·75	6·06	1·68
	Coarse..............	26·09	8·60	1·05
6	Fine................	19·37	3·87	1·29
	Coarse..............	23·58	5·73	1·28
7	Fine................	15·80	2·95	1·48
	Coarse..............	23·45	6·74	1·53
8	Fine................	20·00	5·25	1·64
	Coarse..............	25·67	8·22	1·51
9	Fine................	16·35	2·76	1·28
	Coarse..............	19·87	5·09	1·61
10	Fine................	19·17	4·71	1·60
	Coarse..............	25·60	7·89	1·48
11	Fine................	16·02	3·33	1·60
	Coarse..............	19·08	4·53	1·54
12	Fine................	19·00	3·58	1·24
	Coarse..............	20·64	3·66	1·07
13	Fine................	17·23	3·69	1·55
	Coarse..............	20·57	4·27	1·25
14	Fine................	17·18	3·45	1·45
	Coarse..............	21·97	5·61	1·44
15	Fine................	24·81	5·90	1·20
	Coarse..............	34·14	12·08	1·27
16	Fine................	23·36	6·51	1·40
	Coarse..............	27·50	8·30	0·97
17	Fine................	19·37	7·54	2·49
	Coarse..............	27·62	11·45	1·84
18	Fine................	25·03	4·49	0·86
	Coarse..............	31·80	6·91	0·85
19	Fine................	18·88	3·41	1·19
	Coarse..............	21·33	4·68	1·27
20	Fine................	22·29	5·46	1·38
	Coarse..............	25·79	6·50	1·21

The point, whether large differences in fineness of the fibres in the same staple tend to give large differences in the breaking strength, was investigated. It was found that there was a coefficient of correlation of 0·853 between differences of these two characteristics, which finding is significant from a breeding aspect. It has been shown by Duerden and Bosman (1931) that "a wool very variable in length will also be very variable in thickness, or a wool uniform in length will also be uniform in thickness. In striving for the uniformity of one attribute, the breeder will tend to attain uniformity of the other". One must then also conclude that the breeder, in striving for uniformity of fibre fineness, will tend to attain uniformity in fibre length and also in the breaking strength of the fibres.

As regards the tensile strength, given in the last column of Table 1, the average (expressed as grammes per square cm. $\times 10^6$) was 1·32 ($\pm$·058) for the coarse fibres and 1·46 ($\pm$·070) for the fine fibres. The difference (0·14$\pm$0·054) is significant at the 5 per cent. probability level. The fine fibres within the same staple thus tend to have a higher tensile strength than the coarser ones.

The coefficients of correlation of the fibre characteristics within the same staple of Merino wool are summarised in Table 2.

TABLE 2.

Correlation Coefficients.

	Fibre Diameter.	Breaking Strength.	Tensile Strength.
Fibre Diameter.....	—	+ ·9508 (significant at 1 per cent.)	— ·4822 (significant at 5 per cent.)
Breaking Strength..	+ ·9508 (significant at 1 per cent.)	—	— ·4338 (significant at 5 per cent.)
Tensile Strength....	— ·4822 (significant at 5 per cent.)	— ·4338 (significant at 5 per cent.)	—

There is a highly significant correlation between fibre diameter and breaking strength (·9508) and a significant negative correlation between fibre diameter and tensile strength (– ·4822) and also between breaking strength and tensile strength (– ·4338). The correlation between fibre diameter and tensile strength shows that the fine fibres in the staple have a higher tensile strength than the coarse fibres and suggests structural differences between the fine and coarse fibres of the staple, a point that is now being further studied from such aspects as breeding and nutrition.

In his work on "Fleece Density and the Histology of the Merino Skin" Carter (1939) has shown the existence of "primary" and "secondary" wool-producing follicles and it is probable that the coarse and fine fibres referred to above are produced respectively from the "primary" and "secondary" follicle and constitute two distinct types in the same staple.

B. *Analysis of Different Samples.*

A representative selection of 134 samples of South African Merino wool was analysed for breaking strength and tensile strength. The results of the two characteristics, arranged as frequency tables, are summarised respectively in Tables 3 and 4.

TABLE 3.

The Average Breaking Strengths per Fibre of a selection of South African Merino Wool Samples.

Group Interval (expressed as grammes).	*Frequency.*
1 to 2	2
2 to 3	3
3 to 4	8
4 to 5	33
5 to 6	41
6 to 7	31
7 to 8	14
8 to 9	1
9 to 10	0
10 to 11	1

Mean: 5·50* grammes (at 70 per cent. Relative Humidity and 70° Fahrenheit).

Standard deviation: 1·357 grammes.

Coefficient of variability: 24·67 per cent.

The average breaking strength per fibre of the samples ranges from 1 gramme to 11 grammes with a mean of 5·50 grammes.

TABLE 4.

The Tensile Strength of a selection of South African Merino Wool Samples.

Group Interval (expressed as grammes per square cm. $\times 10^6$).	*Frequency.*
0·6 to 0·7	1
0·7 to 0·8	1
0·8 to 0·9	2
0·9 to 1·0	3
1·0 to 1·1	14
1·1 to 1·2	24
1·2 to 1·3	41
1·3 to 1·4	27
1·4 to 1·5	19
1·5 to 1·6	2

Mean: 1·243† $\times 10^6$ grammes per sq. cm.

Standard deviation: $\pm 0 \cdot 1552 \times 10^6$ grammes per sq. cm.

Coefficient of variability: 12·49 per cent.

* or 5·95 grammes at 65 % Relative Humidity and 70° F.

† or $1 \cdot 383 \times 10^6$ grammes per square centimetre at 65% Relative Humidity and 70° F.

The tensile strength of South African Merino wool samples varies from 0·6 to 1·6 ($\times$ 10^6) grammes per square cm. with an average of 1·243 ($\times$ 10^6) grammes per square cm. The latter figure can also be expressed as 8 tons per square inch or 12·4 kilogrammes per square millimetre.

The values for tensile strength, given in this paper, represent averages of large numbers of fibres (tested in bundles) and have a more direct bearing on general practice than those determinations that take into account only single fibres. It has been shown by Küsebauch (1937), who also discusses the advantage of bundle tests, that the average strength found by single fibre tests is 1·0799 times the value obtained by tests of bundles of 100 fibres.

Correlations.

A study of correlations in the range of South African samples shows that the coefficient of correlation between fibre fineness and breaking strength is 0·896($\pm$ ·0186) indicating a highly significant relationship between the two characteristics.

The value for this constant between fibre fineness and tensile strength is – ·1780($\pm$ ·0911) indicating an insignificant correlation.

It cannot, therefore, be said that in a random selection of Merino wool such as was used for the present study, the finer types have a higher or lower tensile strength than the coarser wools. This conclusion does not apply to fibres within the same staple (shown above) and it is likely that a random selection of wools from different sources would have undernourished as well as well-grown types, a factor which might reduce the value of a correlation coefficient. Further work on this aspect is now in progress.

The regression coefficient of the breaking strength on the fibre finess is 0·445 ($\pm$ ·0208) indicating that on an average every increase of 1μ in fibre fineness is associated with an increase of approximately 0·445 grammes in the breaking strength. This value is valid over a limited range only, since the relation between breaking strength and fibre diameter is not linear.

Summary and Conclusions.

A series of South African Merino wool samples, representing wools from different parts of the Union, was analysed for breaking strength and tensile strength.

The method of determination, using Doehner's instrument, consisted of bundle tests, this giving average values for larger samples and lots.

A portion of the analysis is devoted to the breaking strength and tensile strength of fibres within the same staple. It is shown that the average breaking strength of the coarse fibres within the staple is 6·66 ($\pm$ ·504) grammes. That of the fine fibres is 4·38 ($\pm$ ·300) grammes, so that the coarse fibres are 52 per cent. stronger per fibre than the fine fibres. The practical significance of this is discussed.

Breeding aspects are discussed and it is shown that the Merino breeder, in striving for uniformity of fibre fineness, will tend to attain uniformity in fibre length and also in the breaking strength of the fibres.

The average tensile strength of the coarse fibres within the staple is 1·32(±0·058) and that of the fine fibres is 1·46 (±·070), (expressed as grammes per square cm. $\times 10^6$). When fibres within the same staple are considered, there is a significant correlation of ·9508 (±·7938) between fibre diameter and breaking strength and a significant negative correlation of −·4822 (±·0456) between fibre diameter and tensile strength.

The average breaking strength (per fibre) of representative South African Merino wool samples ranges from 1 to 11 grammes with a mean of 5·50 grammes.

The tensile strength of South African Merino wool varies from 0·6 to 1·6 ($\times 10^6$) grammes per square centimetre with an average of 1·243 ($\times 10^6$) grammes per square centimetre of fibre. The latter figure can also be expressed as 8 tons per square inch or 12·4 kilogrammes per square millimeter of fibre.

When different samples are considered there is a significant correlation ($r = 0 \cdot 896 \pm 0 \cdot 0186$) between fibre fineness and breaking strength, but an insignificant correlation ($r = -0 \cdot 1780 \pm 0 \cdot 0911$) between fibre fineness and tensile strength.

The regression coefficient of the breaking load on fibre fineness is 0·445 (±·0208) indicating that, on an average, every increase of 1μ in fibre fineness is associated with an increase of 0·445 grammes in the breaking strength.

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