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MECHANICAL CONSTANTS OF SINGLE WOOL FIBRES

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Abstract. Mechanical constants of single fibres from wools of widely different dimensional attributes have been determined after stretching to 30%. No relationship was found between area of cross-section and the stress at 30% strain. The work done in stretching to 30% exhibited a significant correlation with the cross-sectional area and the linear regression of the former on the latter was also found significant at 5% level and accounted for some 27% of the variation.

Rheological properties of wool are of considerable importance in commercial transactions, processing and marketing of end products as is evident from the voluminous literature available on the subject.[1,2] It is probably true to say that no other single area of wool research has received so much attention.

During felting and bulk compression studies,[3,4] some of the relevant mechanical constants of various types of wool were determined and, in view of the above, it was considered worthwhile to report the results for addition to the existing knowledge in this area.

Materials and Methods

The wool samples employed in this study were the same as reported earlier.[3,4] With the exception of the Scottish Blackface, a 'Carpet' wool which was derived from a scoured commercial sample, the wools of 'Fine, 'Long' and 'Down' types were selected in the grease. They were given a preliminary scour in a nonionic detergent at 40°C followed by extraction with diethyl ether, ethanol and finally distilled water. Ten fibres were randomly withdrawn from each wool for the stress-strain experiments.

In previous studies, the mean fibre diameter was calculated from a number of optical measurements on a single profile neglecting the inherent ellipticity of the wool fibre. Recently James[5] and Collins[6] were able to determine major and minor axes and the angles at which these occured by single fibre rotation techniques under a projection microscope. Using this method James[6] claimed to observe variations in cross-sectional area of the order of 24% in a length interval of only 40 microns.

In the present study the fibre diameter was, therefore, measured in two perpendicular directions with the help of the single fibre rotator devised by Collins[6] for 10 fibres (free of medullation) per sample in view of the findings[7,8] that the measurements of diameter at any two perpendicular directions are as effective in calculating area of cross-section as the true major and minor axes. The ellipticity was not high in these samples and the small correction needed for area of cross-section was neglected, since it has been observed[9] that a correction of this order does not affect the final results significantly.

Two readings of diameter at right angle to each other were taken at intervals of 0.5 mm on a 2.5-cm length of each fibre. The fibres were attached to light metallic hooks with flexible collodion, so that the fibre length was 2.5 ± 0.10 cm, and soaked in distilled water at 21 ± 1°C for at least 24 hr. The fibres were then extended on an Instron tensile tester (Type TT-BM), at a constant rate of 20%/min in distilled water at 21 ± 1°C to 30% strain and unloaded immediately. The automatic integeration unit recorded the work done to stretch to 30% extension (W_s), and work done in recovering from that strain (W_r).

Results and Discussion

The detailed values of area of cross-section, contour ratio, Young's modulus, stress at 30% extension (S_{30}), W_s, W_r, and the percentage extensional resilience $(W_r/W_s) \times 100$ for Lincoln and Merino sample A are recorded in Table 1 and the mean results of the above characteristics for all the wool samples employed in this investigation are summarised in Table 2.

The mean values of S_{30} vary from 5.70 to 6.42 kg/mm² and are well within the ranges reported by Thorsen[10] (5.0–7.5 kg/mm², i.e. 3.7–5.8 g/tex) and Shah and Whiteley[9] (4.5–7.0 kg/mm²). Values of S_{30} of the order of 4.60–6.44 kg/mm² in case of Merino wools[11] and of 4.29–6.20 kg/mm² in case of Merino and Corriedale wools[12] have also been observed. The mean values of all the other parameters given in Table 2 are also compatible with those reported in the literature.[1,2]

Young's modulus calculated from the Hookean slope of the stress–strain curve varies from 1.12×10^{10} dynes/cm² (South Down) to 2.00×10^{10} dynes/cm² (English Leicester). The work expended in extension to 30% ranged from 1.89×10^6 ergs/mm² (Merino sample C) to 2.63×10^6 ergs/mm² (Lincoln) and the amount of work recovered during retraction was greatest (1.21×10^6 ergs/mm²) for Lincoln and least (0.82×10 ergs/mm²) for Merino sample C. The figures for the mean single fibre resilience did not show a great deal of variation, the highest value being 47.1% (Leicester) and the lowest 41.2% (Dorset Down).

TABLE 1. SINGLE FIBRE MECHANICAL CONSTANTS OF LINCOLN AND MERINO SAMPLE A.

Fibre No.	Area of cross-section A (μ^2)	Coefficient of variation of A (%)	Contour ratio	Young's modulus ($\times 10^{10}$ dynes/cm²)	Stress at 30% strain (kg/mm²)	Work done ($\times 10^6$ ergs/mm²) Extension to 30% (Ws)	Recovery from 30% strain (Wr)	Resilience (%) $Wr/Ws \times 100$
Lincoln								
1	1511·1	4·61	1·07	2·13	6·39	3·43	1·75	50·9
2	1682·4	5·27	1·08	1·60	6·25	2·62	1·19	45·4
3	1158·2	6·60	1·12	1·77	5·79	2·13	1·00	46·9
4	1663·7	3·10	1·07	1·46	5·34	2·31	1·06	45·9
5	1154·6	8·25	1·12	1·76	5·61	2·21	0·99	44·8
6	1558·2	8·00	1·13	2·04	5·83	2·51	1·12	44·6
7	1548·5	7·34	1·13	1·73	6·46	2·75	1·17	42·8
8	1089·0	6·89	1·10	2·10	6·43	2·67	1·24	46·4
9	1637·1	4·51	1·07	1·53	6·24	2·72	1·24	45·5
10	1366·6	6·64	1·07	1·80	6·56	2·99	1·33	44·5
Mean	1438·9	6·12	1·10	1·79	6·09	2·63	1·21	45·8
Merino sample A								
1	243·2	11·93	1·09	1·30	5·61	2·25	0·95	42·2
2	256·4	11·47	1·10	1·38	5·38	2·06	0·88	42·7
3	163·3	15·34	1·08	2·00	6·15	2·05	0·88	42·9
4	256·0	9·55	1·06	2·09	5·92	2·33	0·96	41·2
5	231·0	13·58	1·13	1·33	5·58	2·01	0·75	37·3
6	598·9	9·44	1·14	1·26	5·28	2·28	1·13	49·5
7	340·6	10·14	1·10	1·32	6·22	2·31	1·02	44·2
8	229·4	11·04	1·10	1·58	5·79	2·16	0·91	42·1
9	222·2	12·09	1·10	1·21	5·18	1·94	0·81	41·7
10	409·3	11·44	1·10	1·27	5·86	2·45	1·01	41·2
Mean	295·0	11·60	1·10	1·47	5·70	2·18	0·93	42·5

TABLE 2. MEAN MECHANICAL CONSTANTS OF DIFFERENT WOOLS.

	Name of sample	Area of cross-section A (μ^2)	Coefficient of variation of A (%)	Contour ratio	Young's modulus ($\times 10^{10}$ dynes/cm²)	Stress at 30% strain (kg/mm²)	Standard error of mean $S_{30}(\pm)$	Work done ($\times 10^6$ ergs/mm²) Extension to 30%	Recovery from 30% strain	Resilience (%)
1	Tasmanian Merino	283·3	14·2	1·12	1·24	5·93	·160	2·11	0·91	43·2
2	Merino sample A	295·0	11·6	1·10	1·47	5·70	·113	2·18	0·93	42·5
3	Merino sample B	345·0	21·9	1·08	1·85	6·42	·110	2·59	1·13	43·2
4	Merino sample C	507·4	24·1	1·11	1·59	6·06	·219	1·89	0·82	43·1
5	Romney Marsh	833·2	18·4	1·14	1·56	6·26	·118	2·46	1·02	41·5
6	Cheviot	873·8	16·1	1·16	1·26	6·00	·060	2·38	1·02	42·7
7	English Leicester	1234·0	6·0	1·08	2·00	6·01	·137	2·39	1·13	47·1
8	Border Leicester	1250·7	10·2	1·15	1·57	5·81	·110	2·26	1·02	44·7
9	Lincoln	1438·9	6·1	1·10	1·79	6·09	·133	2·63	1·21	45·8
10	Shropshire	588·3	15·1	1·17	1·33	6·26	·067	2·28	0·97	42·6
11	Suffolk Down	597·0	15·1	1·16	1·26	6·14	·070	2·19	0·90	41·3
12	South Down	598·7	13·6	1·15	1·12	6·14	·087	2·13	0·98	45·8
13	Hampshire	696·8	22·4	1·18	1·18	6·08	·131	2·10	0·89	42·0
14	Dorset Down	813·9	13·3	1·16	1·50	5·98	·063	2·36	0·97	41·2
15	Dorset Horn	821·3	13·4	1·19	1·42	6·31	·127	2·51	1·09	43·2
16	Ryeland	1102·8	15·4	1·20	1·14	6·01	·103	2·59	1·17	45·0
17	Scottish Blackface	708·7	11·5	1·15	1·60	5·74	·104	2·20	0·94	42·7

Conclusions drawn concerning variations in the mechanical constants of different wool types vary. Bergen and Wakelin,[13] Evans and Montgomery[14] and Rigby[15] observed no great difference but O'Connel and Lundgren[16] found that, although the wools used by them had been grown under the same conditions of environment and constant nutrition, various wool types exhibited significantly different mechanical parameters. Similar views were expressed by Thorsen[10] and Dusenbury and Walkelin[17] as well. Ripa and Speakman[18] encountered large variations in plasticity (rate of extension under a constant load) among the fibres of a single staple of wool. These variations were explained by the observation[19] that primary follicles produced fibres of lower plasticity than those of secondary follicles and the order of plasticity was generally the inverse of the order of development of the follicles. Differences in plasticity have also been attributed[20] to the relative proportion of amorphous and crystalline material in the fibre.

Whiteley and Speakman[21] have shown that in addition to variations in dimensional characteristics differences of substance could play a part in the selection of wool for a specific end use. Bhogale and Whiteley[22] compared mechanical constants of Indian 'Carpet' wools grown under comparatively poor

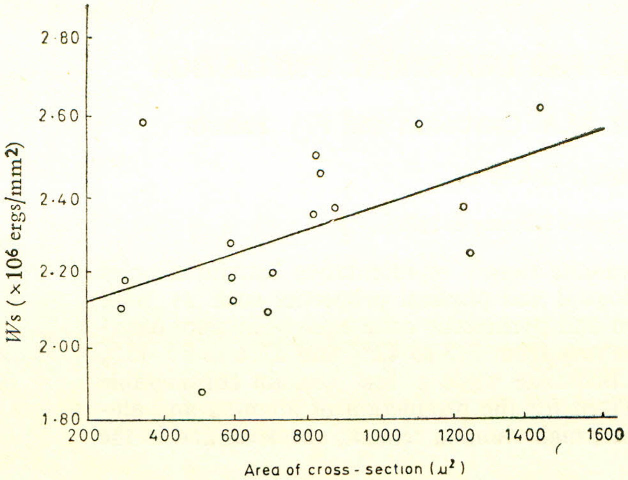

Fig. 1. Linear regression of *Ws* on area of cross-section.

nutritional levels and drastic atmospheric conditions with those previously observed for Australian wools of high and low plasticity; and with those of African 'hardfelt' wools of low plasticity and observed that the Indian 'Carpet' wools were of the low plasticity type and possessed comparatively high mean values of stress at 30% extension.

Kenny and Chaikin[23] have demonstrated theoretically that variations of considerable magnitude can result from non-uniformity of cross-sectional area. It has been reported that mechanical properties are dependent upon both fibre diameter and its coefficient of variation.[9,10,25] The coefficient of variation of diameter was observed to directly modify the form of the stress–strain curve[24] whereas diameter effects were considered to result from differences in the composition of coarse and fine fibres.[9]

In the present study neither the cross-sectional area nor its coefficient of variation contributed significantly to the variations in S_{30} and Young's modulus. It has been shown [9,24] that the wools possessing higher coefficient of variation of fibre diameter exhibit the greatest deviation from the normal form of the stress-strain curve resulting in comparatively lower breaking strains. Since the fibres were not stretched to break, this conclusion could not be verified in the present study.

On the other hand, the variations in the work done in extension to 30% were observed to correlate significantly (5% level) with area of cross-section (r=0.52, r required = 0.48). The linear regression coefficient of W_s on cross-sectional area (Fig. 1) was also significant (5% level) and accounted for some 27% of the variations in the amount of energy expended in extension of fibres to 30%. This tendency is also evident within breeds and in case of Merino in particular (Table 1). It still remains to determine, however, whether the higher values of W_s associated with higher cross-sectional area arise due to difference in the composition of coarse and fine fibres,[9] e.g. because of a larger proportion of paracortex in thicker fibres or any other reasons involving types and order of development of wool follicles.[19]

The mechanical parameter W_s involves integration of the area under the whole curve contrary to the point values of stress at 2% strain, Young's modulus, stress at 30% extension and stress at break, the generally adopted parameters which could be relatively more subject to error. It is, therefore, suggested that W_s values could be taken as the most reliable and representative characteristic in the study of variations in rheological behaviour within and between wool types. Further investigations concerning the suitability of this parameter as a tool for quality control and in the selection of wools for different end uses is recommended.

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References

1. R. Meredith, *The Mechanical Properties of Textile Fibres* (North Holland Publishing Co., Amsterdam, 1959).
2. W.E. Morton and J.W.S. Hearle, *Physical Properties of Textile Fibres* (Butterworths, London, 1962).
3. M.A. Chaudri and K.J. Whiteley, Textile Res., J., **38,** 897 (1968).
4. M.A. Chaudri and K.J. Whiteley, Textile Res., J., **40,** 297 (1970).
5. J.F.P. James, Nature, **198,** 1112 (1963).
6. J.D. Collins, J. Sci. Instr., **40,** 198 (1963).
7. J.D. Collins, Ph.D. thesis, University of New South Wales, 1964.
8. J.D. Collins and M. Chaikin, 3rd Int. Wool Textile Res. Conf. Paris, Sec. I, 277 (1965).
9. S.M.A. Shah and K.J. Whiteley, J. Textile Inst., **57,** T286 (1966).
10. W.J. Thorsen, Textile Res. J., **28,** 185 (1958).
11. E. Balasubramaniam and K.J. Whiteley, Nature, **1–5,** 74 (1962).
12. E. Balasubramaniam and K.J. Whiteley, Textile Res. J., **33,** 436 (1963).
13. W. von Bergen and J.H. Wakelin, Textile Res. J., **22,** 123 (1952).
14. T.F. Evans and D.J. Montgomery, Textile Res. J., **23,** 689 (1953).
15. B.J. Rigby, Textile Res. J., **32,** 1034 (1962).
16. R.A. O'Connel and H.P. Lundgren, Textile Res. J., **24,** 677 (1954).
17. J.H. Dusenbury and J.H. Wakelin, Textile Res. J., **28,** 989 (1958).
18. O. Ripa and J.B. Speakman, Textile Res. J., **21,** 215 (1951).
19. R.W. Burley and J.B. Speakman, Textile Res. J., **23,** 701 (1953).
20. P.L. le Roux and J.B. Speakman, Textile Res. J., **27,** 1 (1957).
21. K.J. Whiteley and J.B. Speakman, Textile Res. J., **30,** 46 (1960).
22. G.D. Bhogale and K.J. Whiteley, Textile Res. J., **33,** 161 (1963).
23. P. Kenny and M. Chaikin, J. Textile Inst., **50,** T18 (1959).
24. J.D. Collins and M. Chaikin, Textile Res. J., **35,** 777 (1965).
25. T.F. Evans, Textile Res. J., **24,** 637 (1954).