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Some Typical Single Fibre Tensile Properties for Wools Produced in South Africa

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ABSTRACT

Single fibre tenacity, extension at break and initial modulus were measured on a large number of wool samples covering a wide range of diameter and crimp. The results have been used to arrive at "typical" or "average" values for the tensile properties of wools grown in South Africa. It was found that crimp 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. Graphs are given to illustrate the observed trends and these can be used for reference purposes. Some values obtained on mohair have been included for purposes of comparison.

INTRODUCTION

It is widely recognised that the tensile characteristics of a textile fibre play an important rôle in determining its processing efficiency and its subsequent end-use performance or durability. It is not surprising, therefore, that the tensile properties of fibres feature prominently in quality control and in research and development work. For such purposes, however, it is often important to have available "average" or "typical" values which may serve as a basis of reference for assessing a particular fibre sample which is being evaluated.

Average values have been established for the bundle tensile properties of wool tops[1] and for the bundle and single fibre tensile characteristics of mohair[2]. In view of the fact, however, that sometimes it is necessary to determine the single fibre tensile characteristics of samples of wool, in spite of the time consuming nature of the procedure, it was decided to measure such characteristics for a wide range of South African wools and to establish average values which can be used in practice as a basis of reference. In so doing, however, it is also important to establish the effect of fibre properties, such as crimp and diameter, on the tensile properties so that, where necessary, allowance can be made for any variations in fibre properties which are reflected in their tensile properties. The effect of variations in staple crimp, fibre diameter and bulk/diameter ratio on the fibre tensile properties was therefore investigated also, supplementing recent work[3] in this field.

EXPERIMENTAL

The single fibre tensile properties of 56 wool tops, covering a wide range of diameter and crimp, were measured. The wools comprised mainly merino and related breeds (Table I lists the breeds used and also serves as a key to certain of the graphs). The mean fibre diameter ranged from 18,1 to 33,1 μm and the crimp from 1,9 to 6,5 crimps per cm . The results for a few very low crimped wools (lustre wools such as Lincoln and Buenos Aires) having about 0,5 crimps per cm and of a number of mohair lots varying widely in diameter (20,3 to 44,3 μm) were also included for purposes of comparison.

The single fibre tensile properties were measured on a constant rate of extension tensile testing machine (Instron model 1122) according to a standard method[4] at 65% RH/20°C. The test length was 20 mm, the rate of extension 20 mm/min and 15 to 20 fibres per sample were tested. A pretension of 0,5 cN/tex and "plug-type" fibre grips were used. The load-extension curve of each fibre was recorded using a very high chart speed. For each fibre the breaking load, extension at break and "pre-yield" modulus (i.e. the slope of the load-extension curve in the "Hookean" region) were read from the curves in the *usual* manner. Very rough estimates of the uncrimping stress were also obtained from these curves.

Prior to the tensile test the linear density of the fibre was measured on a vibroscope (Zweigle Vibroscop S151/2, test method ASTM D1577-78) on that part of the fibre which was to be subjected to the tensile test. The vibroscope used was of the fixed frequency, fixed tension and variable length kind. Although fibre crimp could be expected to affect the linear density values obtained on the vibroscope, it was shown[5] recently that, when linearly density was measured on *fibres taken from tops* (in which state the fibres could be expected to be fairly straight), the effect of the crimp still present in the fibre generally was to increase the measured linear density by about 2% compared with that obtained on fibres which had been "straightened". This difference was reasonably constant and, for all practical purposes, independent of the fibre diameter and the crimp originally present in the wool. It should be noted that the maximum vibroscope tension at which a linear density reading could be obtained was used always.

It was found that the linear densities obtained by means of the vibroscope generally were lower by about 10% than those calculated from projection microscope values for fibre diameter. It is not possible to offer an explanation for this but the implications are that a correction must be applied to the values arrived at here, when the projection microscope is used to determine fibre linear density.

The staple crimp was determined on unscoured staples in the usual manner using a crimp glass and the resistance to compression was measured, using the SAWTRI method[6], on steam relaxed tops.

RESULTS AND DISCUSSION

A summary of the average values for the various tensile properties of the wool and mohair samples is given in Table II. This table gives a general picture of the differences between wool and mohair and also of the variation between samples.

Multiple linear regression analyses were carried out on the logarithmic transform of the results. Each of the fibre tensile properties were used in turn as the dependent variable while the mean top fibre diameter (microscopically determined) and crimp were the independent variables. Different measures of the crimp were available and each of these was used in turn with the fibre diameter as the other independent variable. This was done to determine which measure of crimp correlated best with the fibre tensile properties. Because certain tensile properties were related to both crimp and bulk/diameter ratio it was considered of interest to examine the relationship between these two measures of crimp. The agreement between them is shown in Fig. 1. The mean fibre linear density (i.e. the vibroscope values) was also used in place of fibre diameter in certain additional analyses. Table III is a summary of the statistically significant regression equations and the discussion which follows will be with reference to this table.

Fibre Breaking Strength

As expected, the fibre breaking strength was essentially a function of approximately the square of the fibre diameter (i.e. proportional to linear density) and nearly all the variation in fibre strength was accounted for by diameter (or linear density). Compared with either fibre diameter or linear density, crimp had little effect on the fibre strength, the latter decreasing with an increase in crimp. In Fig. 2, fibre breaking strength has been plotted against the fibre linear density (vibroscope), with the corresponding approximate fibre diameter values given as well. Results for mohair have been plotted for purposes of comparison. Regression lines have been superimposed on the points and in practice these may be used to represent "average" or "typical" values for both wool and mohair. Some of the scatter in the results for wool is due to variation in crimp.

Factors associated with crimp may be responsible for the differences between wool and mohair. The difference in strength between the mohair and wool could, for example, be due to the unequal stress distribution across the ortho- and para-cortices of a bilateral wool fibre. Another possibility is that cross-sectional variation along the fibre increases with an increase in crimp which would result in a decrease in fibre strength at a constant mean fibre diameter (or linear density).

Tenacity

From Table III it is clear that fibre tenacity (or specific breaking stress) is more sensitive to changes in crimp than to changes in diameter, confirming recent findings [3,7]. Correlating tenacity with diameter therefore is pointless unless crimp is taken into consideration also since crimp and diameter frequently are correlated. Clearly, however, the relationship between crimp and tenacity observed here may be indirectly due to a relationship between crimp and another fibre characteristic (e.g. cross-sectional variation, structure, composition, etc.) which affects fibre tenacity.

The tenacity results have been plotted against diameter (Fig. 3), linear density (Fig. 4), staple crimp (Fig. 5) and bulk/diameter ratio (Fig. 6). These graphs illustrate the various trends and can also be used as a basis of reference in practice. For purposes of comparison, the results obtained on mohair and some lustre wools have also been plotted.

The apparent effect of diameter and linear density on wool fibre tenacity (Figs. 3 and 4) is actually an effect of crimp, the latter being correlated with diameter.

The tenacity of the wool tended to increase as the crimp decreased whereas mohair, which has virtually no crimp, had an almost constant tenacity value over the whole diameter range. The lustre wools, which were generally very coarse, tended to have tenacity values approaching that of mohair. The resistance to compression (or bulk/diameter ratio) accounted for appreciably more of the variation in tenacity than any of the other parameters.

Extension at Break

Fibre extension at break has been plotted against fibre diameter in Fig. 7. This figure and the statistical analyses show that the extension at break was not dependent upon either fibre diameter or crimp. The wool fibres, however, generally had a lower extension at break than the mohair fibres possibly because mohair fibres are more uniform in cross-section along the length of the fibre than wool fibres.

Initial Modulus

As found by other workers [8–17] the initial modulus of the crimped wools tended to increase as the staple crimp (or bulk/diameter ratio) decreased (Figs. 8 and 9). There was no relationship between the initial modulus of the wool and fibre diameter (see Table III and Fig. 10). The resistance to compression (or bulk/diameter ratio) accounted for more of the variation in initial modulus than any of the other measures of crimp. This indicates that the resistance to compression (or bulk/diameter ratio) was a good measure of the overall crimpiness. Mohair fibres and lustre wools had initial moduli appreciably greater than that of the crimped wools, mohair having the highest initial modulus (Fig. 8). Not surprisingly, because of the lack of crimp, the initial modulus of mohair was fairly constant over the entire diameter range covered (Fig. 10).

SUMMARY AND CONCLUSIONS

The aim of this study was to compile "average" or "reference" values for the single fibre tensile properties of wools produced in South Africa and to determine the effect of fibre characteristics such as crimp and diameter on these values. To this end, tensile properties were measured on a selection of South African wools covering a wide range of diameter and crimp. Some results for mohair and lustre wools were included for purposes of comparison. The results summarised in Table IV may be taken as "typical" of wool and can serve as a basis of reference whenever the tensile properties of wool is determined in practice.

It was found that crimp rather than diameter affected the single fibre tenacity of wool and this could explain the contradictory trends previously reported between fibre tenacity and diameter. The apparent effect of crimp on tenacity is probably due to other fibre characteristics (e.g. cross-sectional variation, structure, composition, etc.) changing with crimp and affecting fibre tenacity. The extension at break of the wool was independent of either crimp or diameter, whereas the initial modulus (pre-yield slope) decreased as crimp increased.

Within the range covered here, the breed of sheep from which the wool came had little effect on the trends observed.

Mohair generally had a higher tenacity, initial modulus and extension at break than wool of the same diameter, and the mohair tensile characteristics were fairly constant over the whole range of diameters, probably because of the absence of crimp and variations in crimp and any associated fibre characteristics. Lustre wools (e.g. Lincoln and Buenos Aires) had tenacities and initial moduli close to those of mohair.

It was found that the bulk/diameter ratio (resistance to compression divided by diameter) explained more of the variation in tenacity and initial modulus than did staple crimp.

Graphs and tables have been prepared of the average fibre tensile characteristics and these may be used as a basis of reference in practice provided the effect of crimp is taken into consideration.

ACKNOWLEDGEMENTS

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REFERENCES

1. Hunter, L. and Smuts, S., *SAWTRI Techn. Rep.* No. 409 (May, 1978).
2. Hunter, L. and Smuts, S., *SAWTRI Bull.,* **15**, No. 2, 18 (June, 1981).
3. Smuts, S. and Hunter, L., *SAWTRI Bull.,* **15**, No. 1, 22 (March, 1981).
4. The tensile properties of individual textile fibres, BS. 3411 : 1971.
5. Hunter, L. and Smuts, S., Unpublished results.
6. Slinger, R.I. and Smuts, S., *SAWTRI Techn. Rep.* No. 89 (Jan., 1967).
7. Smuts, S., Hunter, L. and van Rensburg, H.L.J., *SAWTRI Techn. Rep.* in preparation.
8. O'Connel, R.A. and Lundgren, H.P., *Text. Res. J.,* **24**, 677 (1954).
9. Dusenbury, J.H. and Wakelin, J.H., *Text. Res. J.,* **28**, 989 (1958).
10. O'Connel, R.A. and Yeiser, A.S., *Text. Res. J.,* **24**, 629 (1954).
11. Evans, T.F., *Text. Res. J.,* **24**, 637 (1954).
12. Evans, T.F. and Montgomery, D.J., *Text. Res. J.,* **23**, 689 (1953).
13. Collins, J.D. and Chaikin, M., *Text. Res. J.,* **39**, 121 (1969).
14. Collins, J.D. and Chaikin, M., *J. Text. Inst.,* **62**, 289 (1971).
15. Dillon, J.H., *Ind. Eng. Chem.,* **44**, 2115 (1952).
16. Barach, J.L. and Rainard, L.W., *Text. Res. J.,* **20**, 308 (1950).
17. Bendit, E.G., *Proc. 6th Int. Wool Text. Res. Conf.* (Pretoria) **II**, 43 (1980).

TABLE I

CODE INDICATING THE DIFFERENT BREEDS PLOTTED ON THE VARIOUS GRAPHS

M	= Merino
G	= Mutton merino
D	= Döhne merino
L	= Letelle
Gl	= Gladdelyf
Bs	= Basuto
B	= "Merino" Black
T	= Fine Transkei
Mh	= Merino Hoggets
Ml	= Merino lambs
Mx	= Merino cross
C	= Corriedale
O	= Low crimp wools (lustre wools such as Lincoln and Buenos Aires)

TABLE II

AVERAGE VALUES FOR SOME TENSILE PROPERTIES* OF WOOL AND MOHAIR

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

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

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

***- Low crimp wools excluded

TABLE III

SUMMARY OF STATISTICAL ANALYSES ON THE SINGLE FIBRE TENSILE PROPERTIES

Dependent Variable	Contribution of each Independent Variable (%)							Significant Regression Equation	n	r	% Fit
	X_1	X_2	X_3	X_4	X_5	X_6	X_7				
Breaking Strength (cN)	82	*	*	*	*	*	*	$9{,}792 \times 10^{-3} X_1^{2{,}160}$	56	0,91	82
	67	20	*	*	*	*	*	$0{,}160\ X_1^{1{,}522}\ X_2^{-0{,}285}$	56	0,93	87
	*	*	97	*	*	*	*	$0{,}993\ X_3^{1{,}132}$	56	0,98	97
	*	1	97	*	*	*	*	$1{,}258\ X_2^{-0{,}067}\ X_3^{1{,}054}$	56	0,98	97
	*	*	98	ns	*	*	*	$1{,}036\ X_3^{1{,}114}$	55	0,99	98
	77	*	*	*	6	*	*	$5{,}694 \times 10^{-2} X_1^{1{,}790}\ X_5^{-0{,}264}$	52	0,92	84
	*	*	96	*	2	*	*	$4{,}417\ X_3^{1{,}067}\ X_5^{-0{,}481}$	52	0,99	98
	*	*	*	*	*	70	*	$6{,}170\ X_6^{-1{,}067}$	52	0,84	70
	*	*	*	*	*	*	75	$65{,}37\ X_7^{-1{,}083}$	52	0,87	75
Tenacity (cN/tex)	ns	38	ns	*	*	*	*	$14{,}50\ X_2^{-0{,}098}$	56	0,62	38
	*	*	34	ns	*	*	*	$10{,}22\ X_3^{0{,}122}$	55	0,58	34
	13	*	*	*	40	*	*	$15{,}53\ X_1^{0{,}153}\ X_5^{-0{,}238}$	52	0,73	53
	*	*	17	*	38	*	*	$20{,}18\ X_3^{0{,}090}\ X_5^{-0{,}221}$	52	0,74	55
	*	*	*	*	*	52	*	$12{,}05\ X_6^{-0{,}198}$	52	0,72	52
	*	*	*	*	*	*	55	$18{,}69\ X_7^{-0{,}201}$	52	0,74	55
Initial Modulus (cN/tex)	ns	21	ns	*	*	*	*	$335\ X_2^{-0{,}102}$	56	0,46	21
	*	*	ns	30	*	*	*	$245\ X_4^{-0{,}298}$	55	0,55	30
	ns	*	ns	*	44	*	*	$9{,}710 \times 10^2\ X_5^{-0{,}421}$	52	0,66	44
	*	*	*	*	*	38	*	$2{,}732 \times 10^2\ X_6^{-0{,}254}$	52	0,62	38
	*	*	*	*	*	*	41	$4{,}782 \times 10^2\ X_7^{-0{,}257}$	52	0,64	41

n = number of results on which regression was based
r = correlation coefficient
ns = non significant
* = variable not included in regression analysis
X_1 = mean fibre diameter of parent tops (μm)
X_2 = mean staple crimp (cm^{-1})
X_3 = mean linear density of fibres tested (dtex)
X_4 = mean uncrimping stress of fibres tested — fibres were taken from unrelaxed tops (cN/tex)
X_5 = resistance to compression of steamed tops (compressed height in mm)
X_6 = bulk/diameter ratio (mm/μm)
X_7 = bulk/linear density ratio (mm/dtex)

TABLE IV

TYPICAL TENSILE PROPERTIES OF WOOL AT VARIOUS CRIMP LEVELS

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

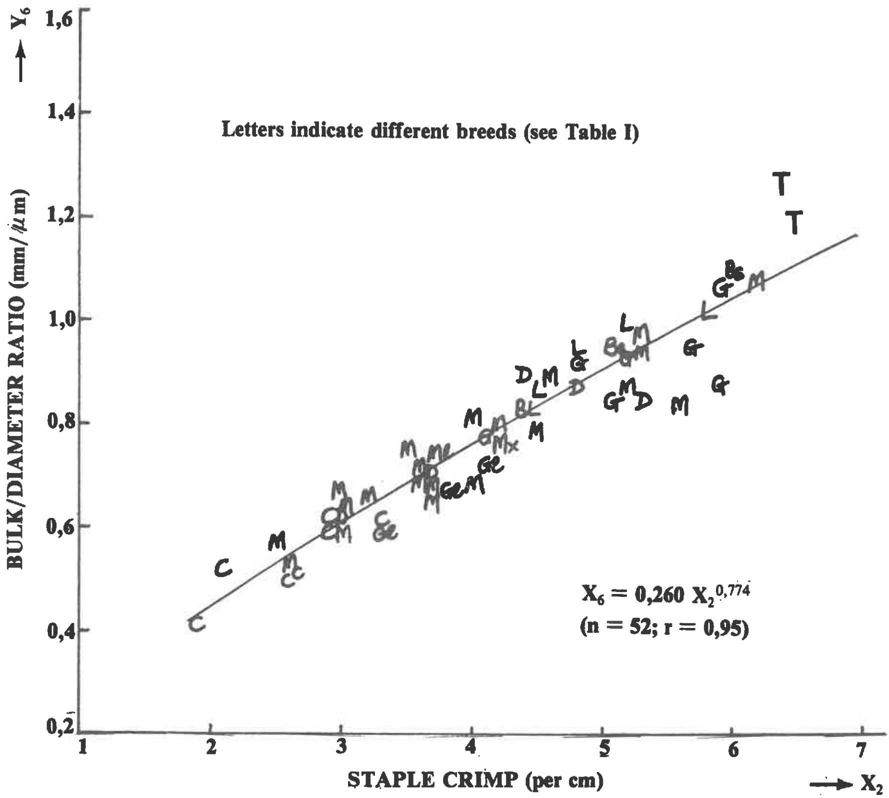

Fig 1 – The relationship between bulk/diameter ratio and staple crimp.

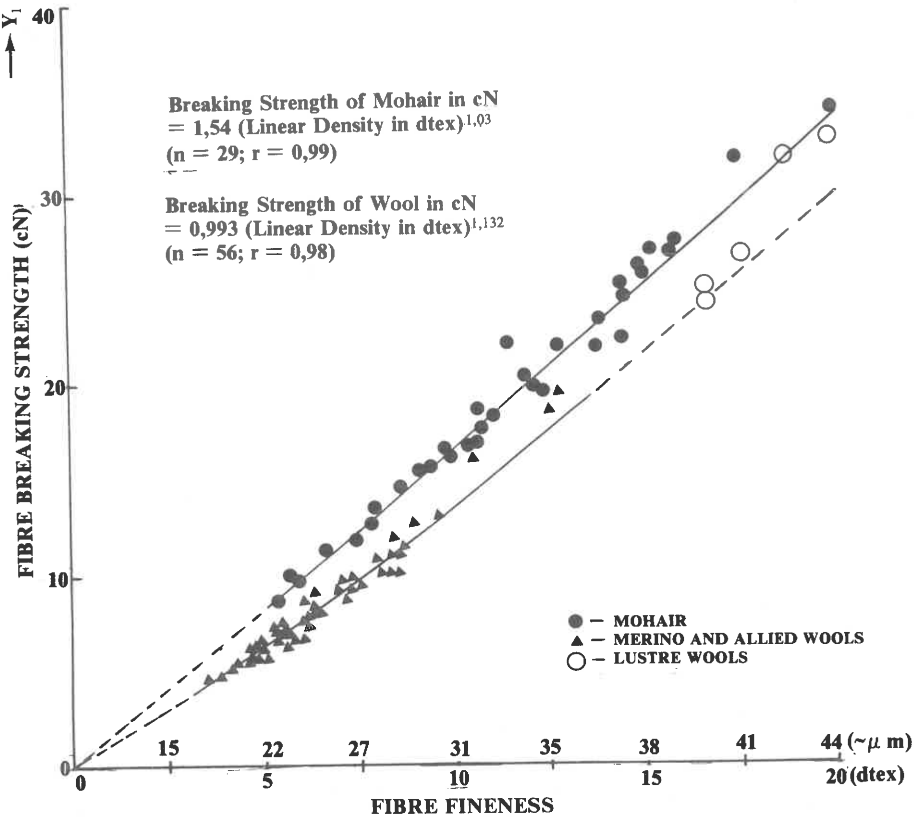

Fig 2 – Fibre breaking strength vs fibre fineness for wool and mohair fibres

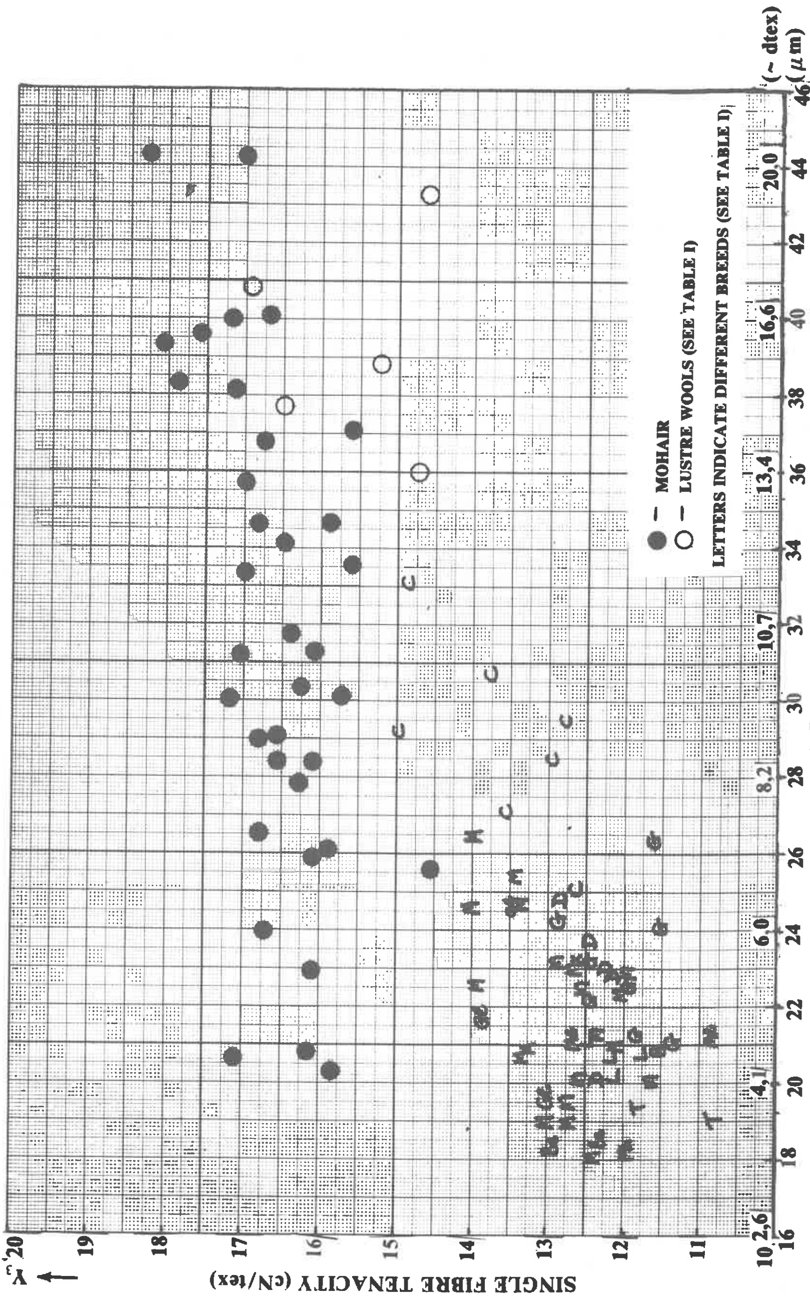

Fig 3 – Single fibre tenacity vs fibre fineness for wool and mohair.

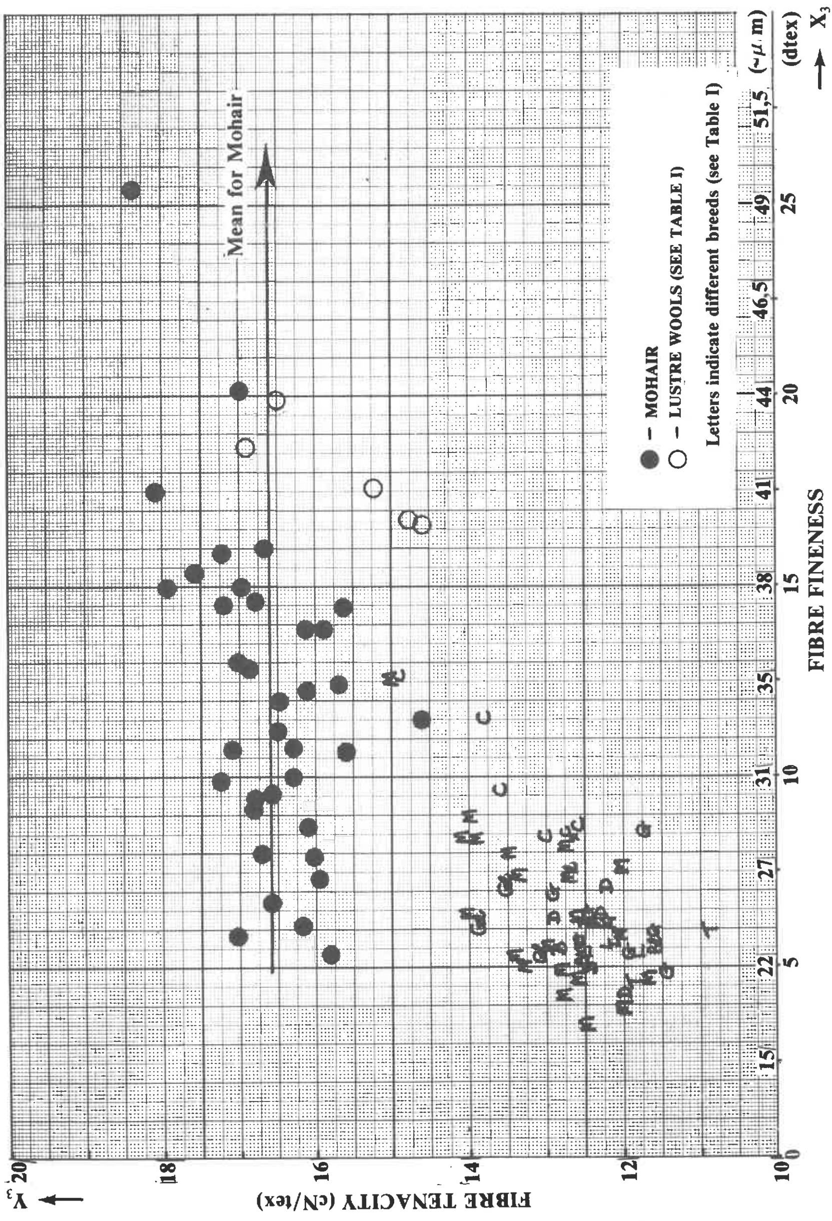

Fig 4 – Single fibre tenacity vs fibre fineness for wool and mohair.

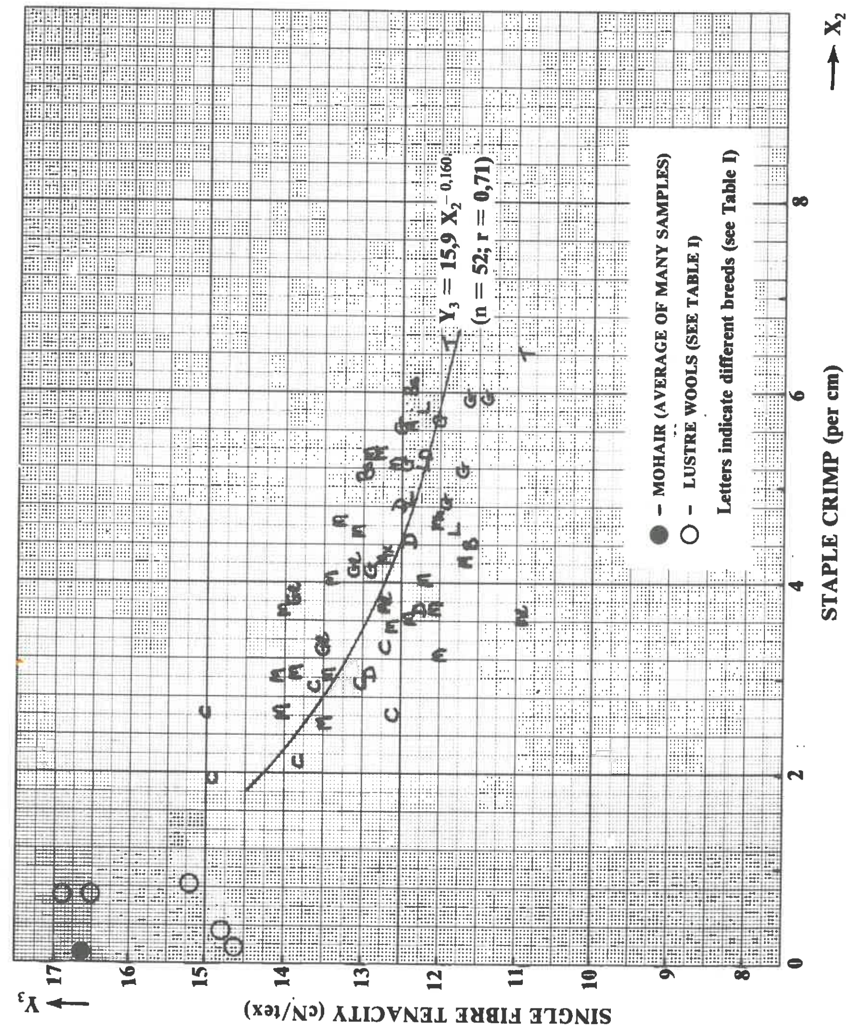

Fig 5 – Single fibre tenacity vs staple crimp

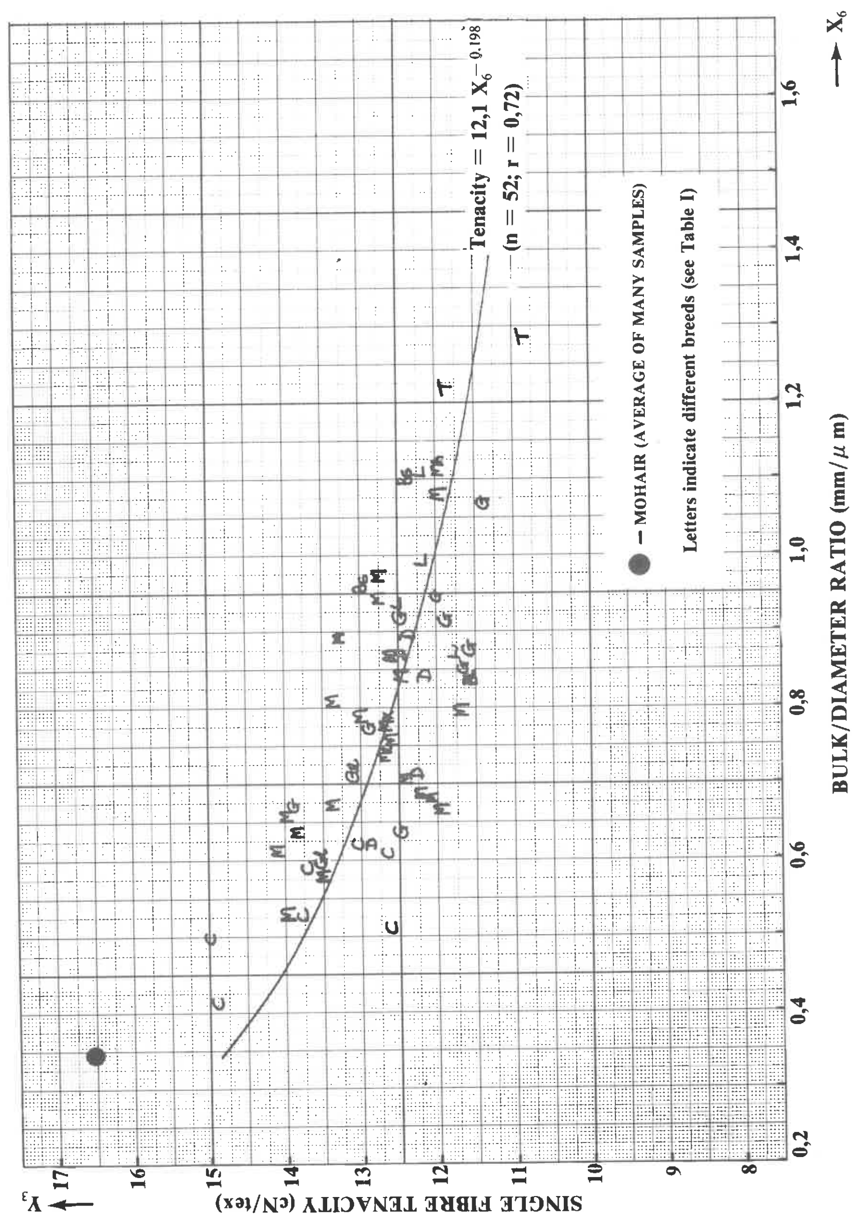

Fig. 6 – Single fibre tenacity vs bulk/diameter ratio

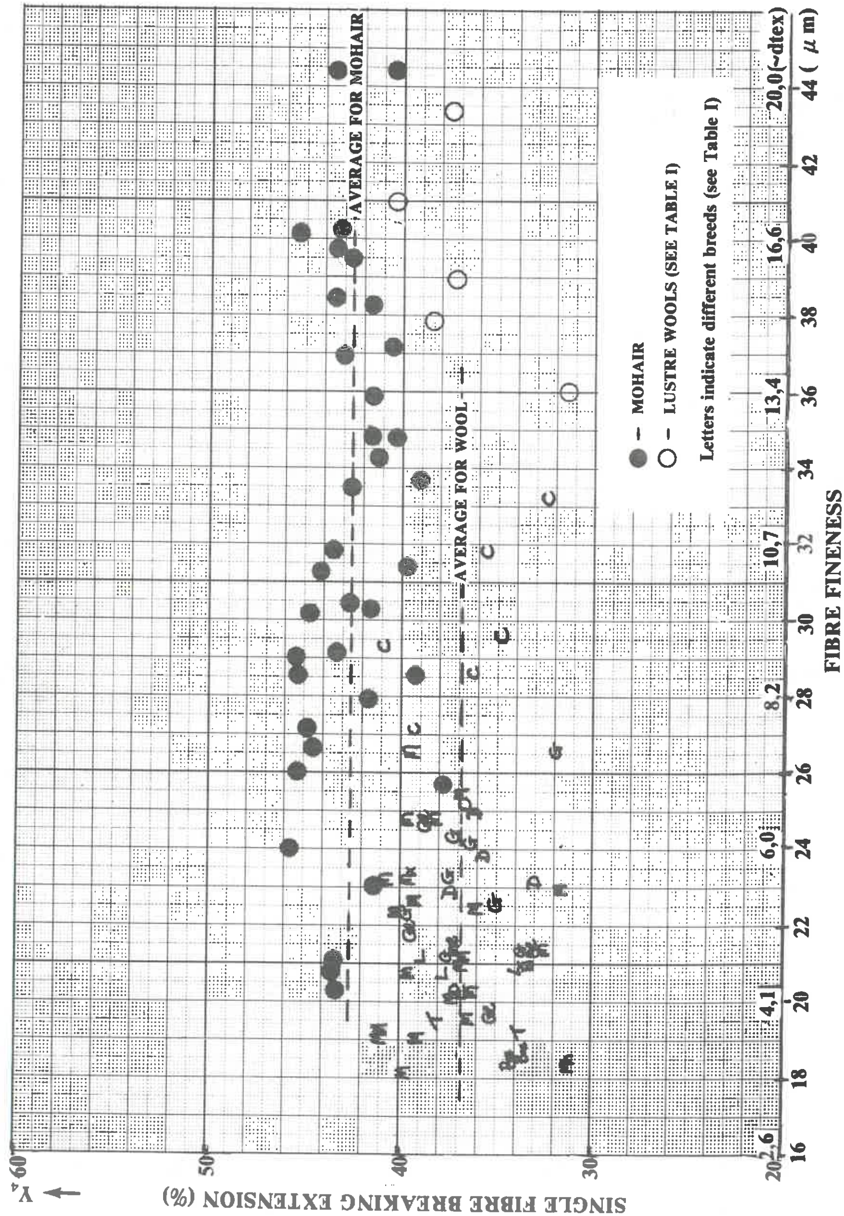

Figure 7 – Single fibre breaking extension vs fibre fineness for wool and mohair.

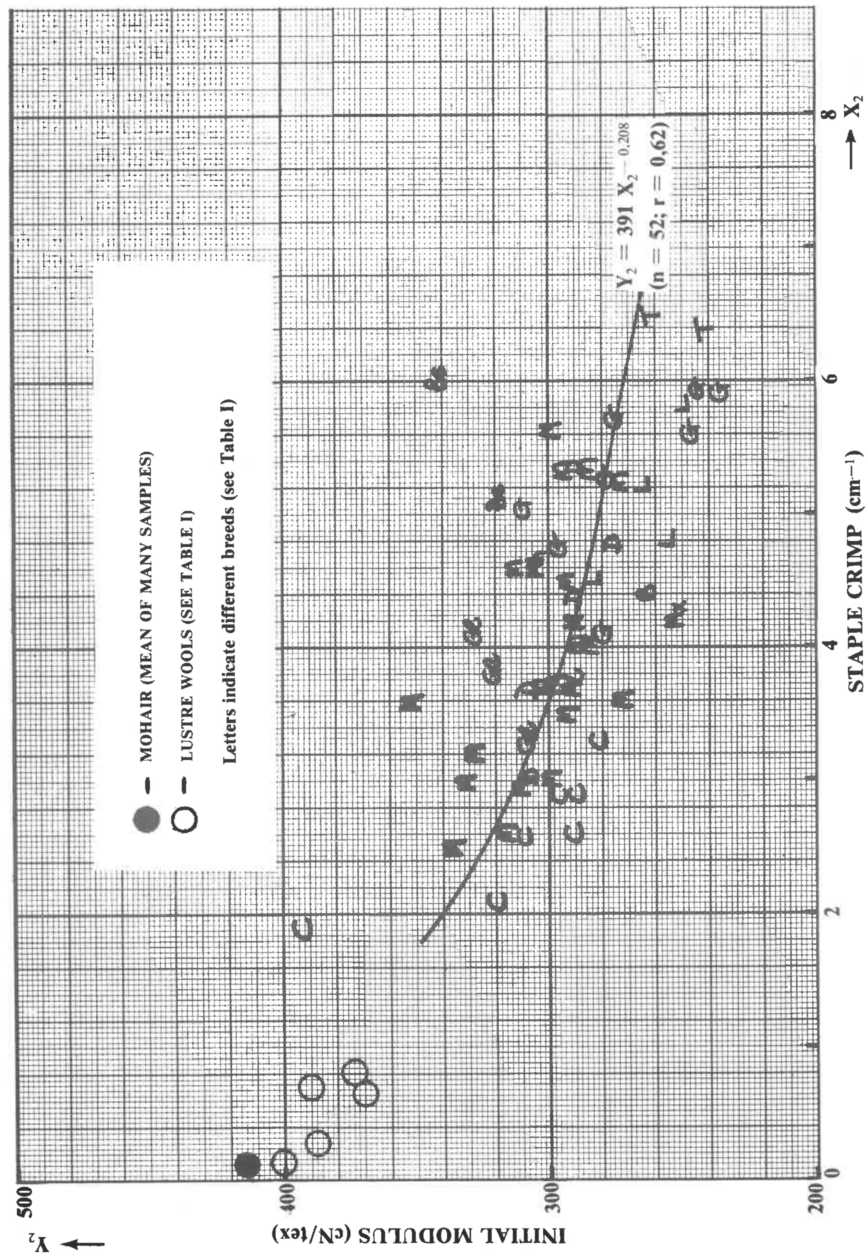

Fig 8 – Initial modulus vs staple crimp.

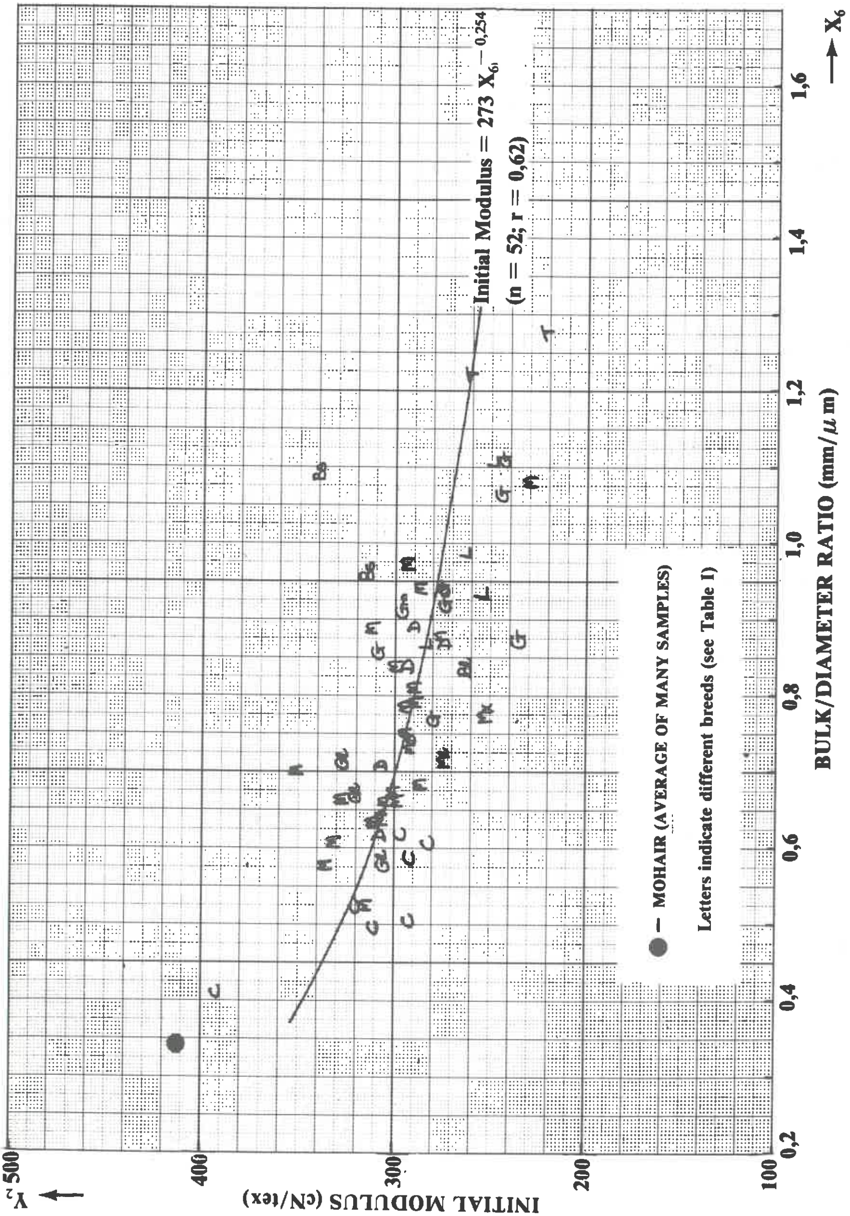

Fig. 9 – Single fibre initial modulus vs bulk/diameter ratio

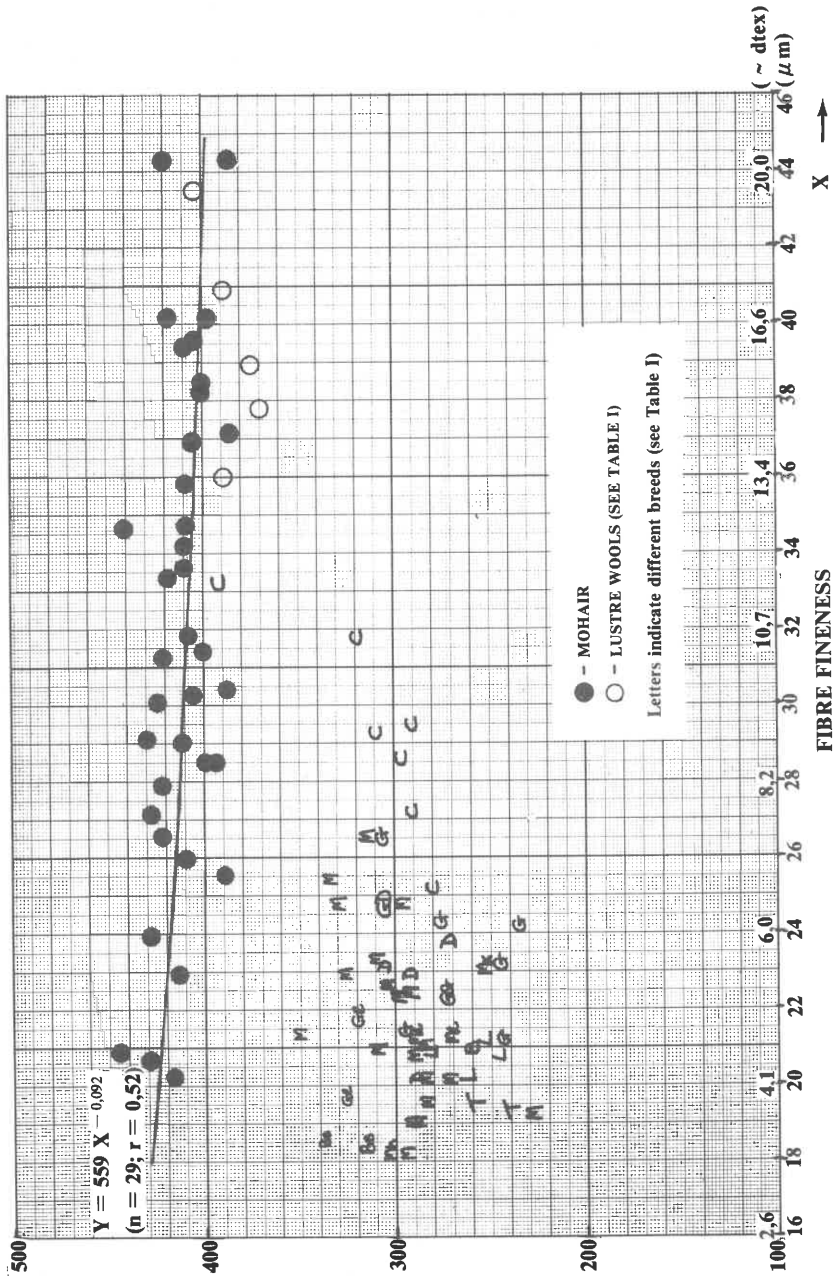

Fig 10 – Initial modulus vs fibre fineness for wool and mohair.

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