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by

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THE CORRELATION BETWEEN STAPLE STRENGTH AND SINGLE FIBRE STRENGTH FOR SOUND AND TENDER WOOLS

by L. HUNTER, WILLIENA LEEUWNER, S. SMUTS AND M.A. STRYDOM

ABSTRACT

A good correlation (r = 0,96) was found between staple tenacity and single fibre tenacity for sound and tender wools. Wools subjectively classified as tender generally had staple tenacity values below about 2cN/tex, while those of sound wools generally were higher than 3 cN/tex. Based on the minimum fibre cross-section (assuming that this point coincides with the position of rupture), the single fibre tenacity of tender wools were, on average, 12 cN/tex while the corresponding value for sound wools were around 18 cN/tex. This suggests that tenderness can be associated with both a reduction in mean fibre diameter as well as a reduction in intrinsic fibre strength. Scanning electron photomicrographs of fibres with a pronounced tenderness ("break") are given.

INTRODUCTION

A great deal of published information exists on the causes of wool becoming tender[1-9] and the problems associated with tender wool during the textile manufacturing processes[10-28]. In the present context tender wool is defined as having a "break" or localised weakness (see Fig 1), thus excluding wools which are weak along the entire (or greater part) of the staple or fibre, for example as a result of micro-organism attack[2] (e.g. belly wool)[29,32,33,35,36] or a copper deficient diet [30,31,34].

It is generally accepted that a tenderness or break in the wool is due mainly to a decrease in fibre diameter. Reductions in diameter, in turn, mainly are associated with nutritional deficiencies[1,2,5,37-59], lambing[1,46,48,49,53,60,61], ill-health[38,49,52] and parasites[19]. Horton and Wickham[58] emphasized that staple strength and soundness are related to the minimum diameter along each fibre, Orwin *et al*[63] finding that about 85% of the tender and 70% of the sound wool fibres tested broke at the thinnest place.

There are conflicting opinions on the question of whether the tenacity (i.e. strength corrected for cross-section *at the point of rupture*) is similar for sound and tender wools. Certain workers[49,62,63] found differences between the tenacity of tender and sound wools whereas according to other workers[34,52,56,64,65] there is little, if any, difference between the mechanical properties of tender and

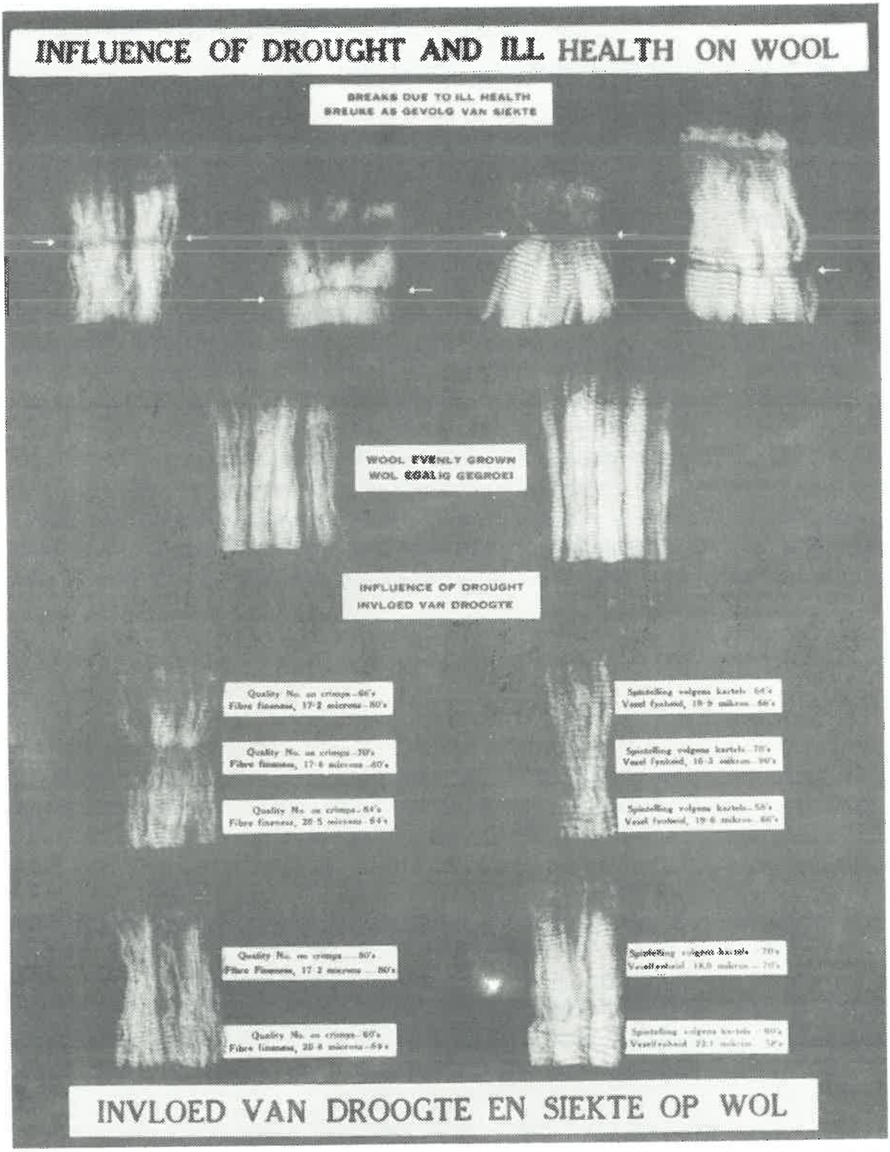

FIG 1: (By courtesy of the Fleece Testing Centre, Department of Agriculture Grootfontein, Republic of Sourth Africa.)

sound wools (cross-section corrected). Orwin *et al*[63] found that tender wools had a greater proportion of ortho-cortex than sound wools of similar diameter and that, in the larger diameter ranges, they were also weaker than sound wools of similar diameter. Nutritional effects have been observed on fibre plasticity[66], sulphur content[67], on wool compressibility and certain other characteristics[62,68,69].

In the light of the importance of staple strength or soundness in textile processing, it is hardly surprising that considerable attention has been paid to its measurement[20,70-86] and work is in progress to evaluate the feasibility of introducing staple strength testing into the objective measurement programme for raw wool[20,25,75,81-83].

In spite of the large volume of published data on tender wools very little is known about the correlation between staple strength and single fibre strength. It was therefore decided to measure and relate the tenacity of tender and sound wools, both in staple and in single fibre form, and also to relate the single fibre tenacity to the minimum fibre cross-section in that fibre, in an attempt to throw some additional light on the question whether tender fibres are weaker than sound fibres of the same cross-section.

EXPERIMENTAL

Staple Strength Tests

A range of staples was selected from both sound and tender merino and merino-type wools (see Tables I and II). Between five and ten staples per sample were tested on the CSIRO manual staple strength tester[85], while one staple per sample was tested on the newly developed SAWTRI staple length/strength tester[86]. In each case the test length was adjusted to suit the staple length. Prior to the staple strength test, a wisp of fibres was removed from the prepared staple to enable single fibre tests to be carried out.

Single Fibre Tests

From the wisp of fibres, between five and ten fibres were carefully removed, their fineness measured on a vibroscope, and the single fibre tensile properties measured on an Instron tensile strength tester, the test length being adjusted to approximate the length of the stretched fibres clamped between the jaws of the staple strength tester. A pre-tension of 0,5 cN/tex and a rate of extension of 100% per minute were used for the single fibre tensile tests.

From the original wisp of fibres, a further ten fibres were removed and mounted in oil for diameter measurement by means of a projection microscope. The fibres were so mounted that the segment of the fibre scanned generally corresponded in position to the segments of the other fibres from the same staple which had been subjected to the staple and single fibre tensile tests.

TABLE I
RESULTS FOR WOOLS TESTED ON CSIRO MANUAL STAPLE STRENGTH TESTER (CV VALUES GIVEN IN PARENTHESIS)

Sample	Staple Tests			Single Fibre Tests: Based upon Projection Microscope Readings							Based upon Vibroscope Readings:		
	Staple Length (mm)	Staple Test Length	Staple Strength (cN/tex)	Average Fibre Diameter (μm)	Minimum Fibre Diameter (μm)	Average Linear Density (dtex)	Minimum Linear Density (dtex)	Tenacity (cN/tex) T_A	Tenacity (cN/tex) T_M	Toughness	Average Linear Density (dtex)	Tenacity (cN/tex) T_{AV}	Extension (%)
Sound Wools													
BR 10	104(5)	74 (7)	4,8(23)	26,0(19)	20,2(21)	7,0(19)	4,2(21)	10,5	17,4	173	5,8(19)	12,1(6)	33,0(9)
BR 16	97(7)	67(10)	5,1(19)	24,8(14)	20,4(18)	6,3(14)	4,3(18)	11,9	17,4	160	6,7(20)	11,1(11)	26,8(21)
BR 20	96(11)	66(16)	4,3(14)	20,1(29)	17,0(28)	4,2(29)	3,0(28)	12,9	18,0	157	6,1(22)	9,9(22)	24,3(39)
BR 21	101(9)	71(13)	4,3(14)	23,8(20)	16,2(22)	5,8(20)	2,7(22)	9,7	20,7	149	5,4(18)	10,7(8)	30,8(11)
BR 22	116(8)	86(11)	3,9(9)	30,6(22)	22,4(26)	9,6(22)	5,2(26)	7,4	13,7	84	9,6(14)	9,8(12)	22,6(26)
BR 49	109(4)	79(5)	3,1(34)	33,6(16)	24,0(10)	11,6(16)	5,9(10)	9,6	18,8	109	13,7(10)	10,0(14)	22,8(35)
Mean	104(7)	74(10)	4,2(16)	26,5(18)	20,0(15)	7,4(36)	4,2(29)	10,3(19)	17,7(13)	139(26)	7,9(41)	10,6(8)	26,7(16)
Tender Wools													
BR 58	94(7)	—	2,0(15)	23,2(25)	17,2(26)	5,5(25)	3,0(26)	7,3	13,3	73	4,3(20)	8,1(15)	19,9(22)
BR 63	95(7)	—	1,5(41)	30,0(19)	21,2(27)	9,3(19)	4,6(27)	6,7	13,5	56	8,3(25)	6,9(17)	16,7(47)
33/1008	98(7)	—	1,0(74)	21,7(21)	15,8(25)	5,0(45)	2,7(54)	5,4(34)	9,9(18)	35	4,8(49)	5,8(36)	12,8(66)
32/3008	91(11)	—	0,9(51)	23,3(8)	16,0(12)	5,6(16)	2,7(23)	6,5(23)	13,9(25)	40	5,4(16)	6,6(29)	12,3(57)
33/3005	106(9)	—	0,6(88)	18,3(10)	13,1(7)	3,5(21)	1,8(13)	5,2(34)	10,1(34)	11	4,1(19)	4,2(35)	4,3(50)
32/2006	92(14)	—	2,0(53)	22,3(11)	17,1(13)	5,2(24)	3,0(28)	9,1(18)	15,6(12)	84	5,0(20)	9,2(20)	18,4(32)
32/2013	102(4)	—	0,7(46)	22,6(12)	16,5(14)	5,3(23)	2,8(27)	5,5(60)	10,4(61)	15	5,1(15)	5,0(46)	5,5(65)
32/2001	103(10)	—	1,7(58)	23,7(12)	18,1(14)	5,8(23)	3,4(29)	7,6(31)	12,6(23)	64	5,3(20)	8,0(24)	16,8(54)
Mean	98(6)	—	1,3(45)	23,1(14)	16,9(14)	5,7(29)	3,0(26)	6,7(20)	12,4(17)	47(56)	5,3(25)	6,7(25)	13,3(44)

T_A — Tenacity based upon average fibre linear density (projection microscope)
T_M — Tenacity based upon minimum fibre linear density (projection microscope)
T_{AV} — Tenacity based upon average vibroscope linear density
Toughness = 0,5 x Tenacity (T_A) x Extension

TABLE II
RESULTS FOR WOOLS TESTED ON SAWTRI STAPLE STRENGTH TESTER (CV VALUES GIVEN IN PARENTHESIS)

Sample	Staple Tests					Single Fibre Tests								
						Based upon Projection Microscope Readings						Based upon Vibroscope Readings		
	Staple Length (mm)	Staple Strength (cN/tex)	Work to Rupture (J/ktex)	Elongation (%)	Max. Stress at: %	Average Fibre Diameter (μm)	Minimum Fibre Diameter (μm)	Average Linear Density (dtex)	Minimum Linear Density (dtex)	Tenacity (cN/tex) T_A	Tenacity (cN/tex) T_M	Average Linear Density (dtex)	Tenacity (cN/tex) T_{AV}	Extension (%)
ST 001	88	0,8	0,3	63	25,2	25,8(22)	16,2(26)	6,9(22)	2,7(26)	3,3	8,6	5,8(38)	4,6(50)	5,3(32)
ST 002	69	3,8	2,8	142	53,0	27,8(13)	19,4(14)	8,0(13)	3,9(14)	7,7	15,7	7,0(20)	8,9(14)	23,6(41)
ST 003	82	5,5	3,1	137	59,4	21,0(16)	14,6(13)	4,5(16)	2,2(13)	8,4	17,2	4,2(26)	9,6(44)	28,1(54)
ST 004	81	2,2	1,0	74	30,7	25,2(17)	15,2(17)	6,5(17)	2,4(17)	7,2	19,6	7,6(20)	5,9(28)	10,3(48)
ST 005	78	2,0	0,9	74	30,3	24,8(13)	14,8(15)	6,3(13)	2,3(15)	4,8	13,2	5,4(18)	5,5(17)	8,8(38)
ST 006	70	5,0	2,4	84	38,8	23,2(16)	16,6(11)	5,5(16)	2,8(11)	14,2	28,0	7,0(16)	11,1(22)	31,8(36)
ST 007	92	1,4	0,4	45	23,0	22,6(13)	12,8(11)	5,3(13)	1,7(11)	6,1	19,0	6,2(11)	5,2(12)	6,2(12)
ST 008	48	4,3	4,7	252	73,9	20,0(18)	16,2(16)	4,1(18)	2,7(16)	12,6	19,1	5,0(11)	10,3(17)	33,9(11)
ST 009	89	1,0	0,4	61	20,7	25,6(19)	12,4(18)	6,7(19)	1,6(18)	3,3	14,0	5,9(22)	3,9(13)	5,2(23)
ST 010	53	5,8	2,1	107	28,4	21,0(20)	13,8(21)	4,5(20)	2,0(21)	5,5	12,4	3,0(10)	8,4(35)	24,9(38)

T_A — Tenacity based upon average fibre linear density (projection microscope)
T_M — Tenacity based upon minimum fibre linear density (projection microscope)
T_{AV} — Tenacity based upon average vibroscope linear density.

Each fibre was read at ten different places along its length, the average of these values representing the average fibre diameter values given in Tables I and II. In addition, the thinnest place in the fibre segment was located and its diameter measured. The ten values so obtained in each case were then averaged to give the "minimum" diameter values in Tables I and II. From these values the respective "average" and "minimum" fibre linear densities were calculated. From these and the single fibre strength values, the single fibre tenacities (T_A and T_M) were calculated based upon the "average" and "minimum" fibre cross-sections, respectively (see Tables I and II). The T_M values are, therefore, based upon the assumption that, the point of rupture coincides with the minimum fibre cross-section between the jaws. The vibroscope fibre linear density values were used to calculate a second fibre tenacity value, namely T_{AV}. All results for tenacity were expressed in cN/tex rather than N/ktex.

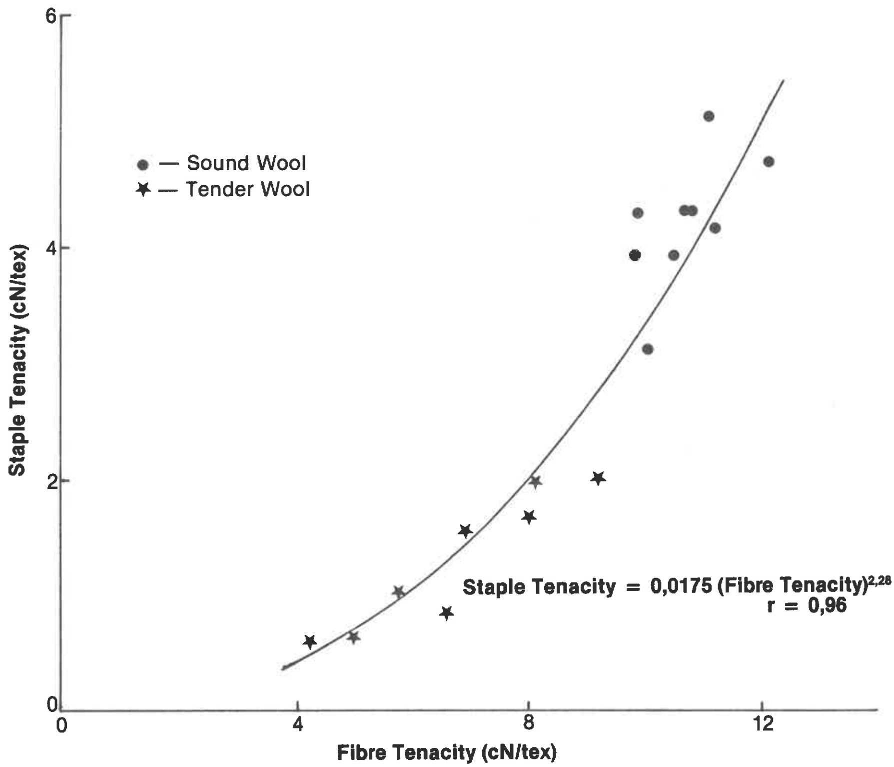

FIG 2:
Average Staple Tenacity measured on CSIRO instrument vs. Average Single Fibre Tenacity (T_{AV}).

RESULTS AND DISCUSSION

In Fig 2 staple tenacity has been plotted against single fibre tenacity (T_{AV}) for the sample averages obtained on the CSIRO staple strength tester. T_{AV} was used rather than T_A since the vibroscope fineness was considered to be a more accurate measure of the average fibre fineness than that derived from the projection microscope diameter.

The good correlation (r = 0,96) between the staple tenacity and single fibre tenacity values is clearly illustrated by Fig 2. From this figure it can be seen that the tender wools generally had staple tenacity values below 2,0 cN/tex, which is in broad agreement with previously published values[23,65,74,75,81,87]. The wools belonging to the sound group generally had staple tenacities greater than 3 cN/tex.

In Fig 3 staple tenacity (cN/tex) has been plotted against the single fibre tenacity (T_{AV}) for the individual staples.

As expected, the values for the individual staples plotted in Fig 3 show a much larger scatter, although the general correlation between the two variables and the lower values of the tender wools, which is clearly illustrated in Fig 2, are still evident.

Fig 3 shows a good correlation between the single fibre tenacity values and the staple tenacity values obtained on the SAWTRI instrument, the values tending to lie above those obtained on the CSIRO tester. The latter is not surprising since the tenacity values obtained on the SAWTRI instrument are based upon the minimum staple cross-section[86] which is not the case with the CSIRO values.

If a tender wool is defined as one having a staple tenacity below 2,5 cN/tex (based upon the "normal" staple cross-section), Table I shows that the average single fibre tenacity, based upon the minimum fibre cross-section (projection microscope), for the sound wools was 17,7 cN/tex (CV = 13%) and for the tender wools, 12,4 cN/tex (CV = 16%).

These two values differ significantly and this strongly suggests that, at least in very tender wools (i.e. those with a definite "break"), the fibre tenacity is lower than that expected from their reduced cross-section. According to the results of this study, therefore, the intrinsic strength of tender wools appears to be significantly lower than that of sound wools, suggesting a change in fibre substance, in addition to the more obvious change in fibre cross-section. This lends support to the findings of certain other workers[49,62,63,66-69]. Possibly different causes of tenderness have a different effect on the intrinsic fibre strength, which would explain the contradictory findings reported in the literature.

In Figs 4 and 5 scanning electron photomicrographs are shown of wool fibres with a pronounced tenderness ("break").

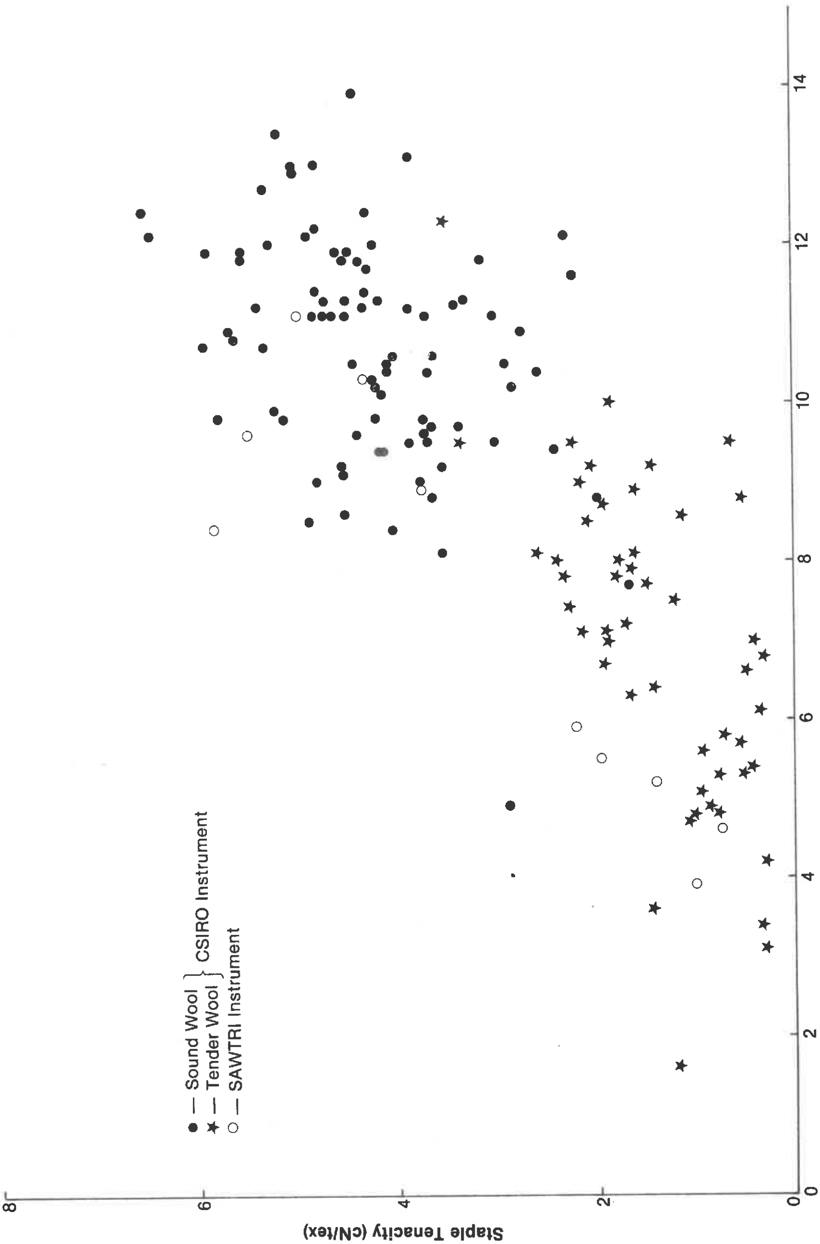

FIG 3

Staple Tenacity vs. Fibre Tenacity (T_{AV}) for Individual Staples.

A study of this nature draws attention to the need for consistency in units when dealing with a topic such as tenacity. The trend today is for staple tenacity to be expressed in N/ktex and for fibre and yarn tenacity to be expressed in cN/tex. If, however, tenacity is expressed in cN/tex throughout, comparisons are simplified.

SUMMARY AND CONCLUSIONS

The correlation between staple strength (or more correctly, staple tenacity) and single fibre tenacity has been investigated. The staple strength of a range of sound and tender (defined as those with a definite "break" or localised weakness) merino and merino-type wools was measured on a CSIRO manual staple strength tester and in a few cases on a newly developed SAWTRI staple strength/length tester. A wisp of fibres was removed from the staples before the staple strength test and from each wisp about ten fibres were removed for single fibre fineness tests, using a vibroscope, as well as for tensile tests using an Instron. A further ten fibres were drawn for average and minimum (thinnest) diameter measurement, using a projection microscope. Single fibre tenacity was then calculated using either the average fibre linear density or the minimum fibre linear density.

It was found that there was a good correlation between the staple tenacity and fibre tenacity. Subjectively classified tender wools generally had a staple tenacity below about 2 cN/tex while that of subjectively classified sound wools was generally above 3 cN/tex.

With respect to the results of the single fibre tensile tests, tender wools appeared to be still significantly weaker than sound wools, even after allowing for the reduced cross-section of the tender places (or "break"). Based upon the *minimum* fibre cross-section, tender wools had a single fibre tenacity of about 12,4 cN/tex while the corresponding value for sound wools was about 17,7 cN/tex. Based upon the *average* fibre cross-sectional values the corresponding single fibre tenacities were 6,7 cN/tex, 10,6 cN/tex, respectively. This study, therefore, indicates that at least for the range of wools studied here, tenderness (or a break) in the wool is associated both with a reduction in fibre diameter and a reduction in the intrinsic fibre tenacity. With respect to the latter aspect, contradictory findings have been reported in the literature. It is possible that the different causes of tenderness (e.g. nutritional deficiency, disease and lambing) may have different effects on the intrinsic fibre tenacity. It is recommended that staple strength be expressed in cN/tex rather than in N/ktex, since this would provide a common unit of tenacity for fibres, staples and yarns.

Scanning electron photomicrographs are shown of fibres having a pronounced tenderness ("break").

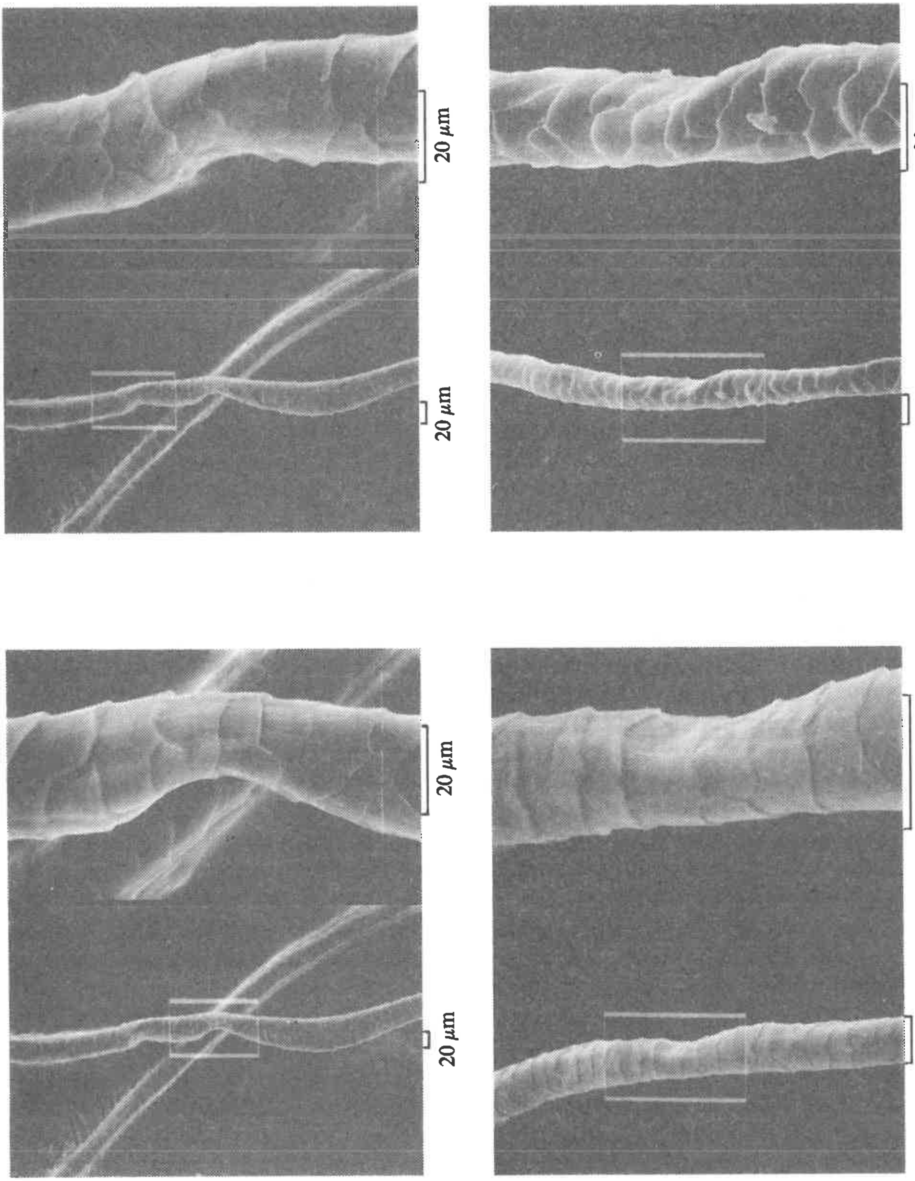

Fig 4 — Scanning electron photomicrographs of wool fibres which exhibit a marked tenderness ("break")

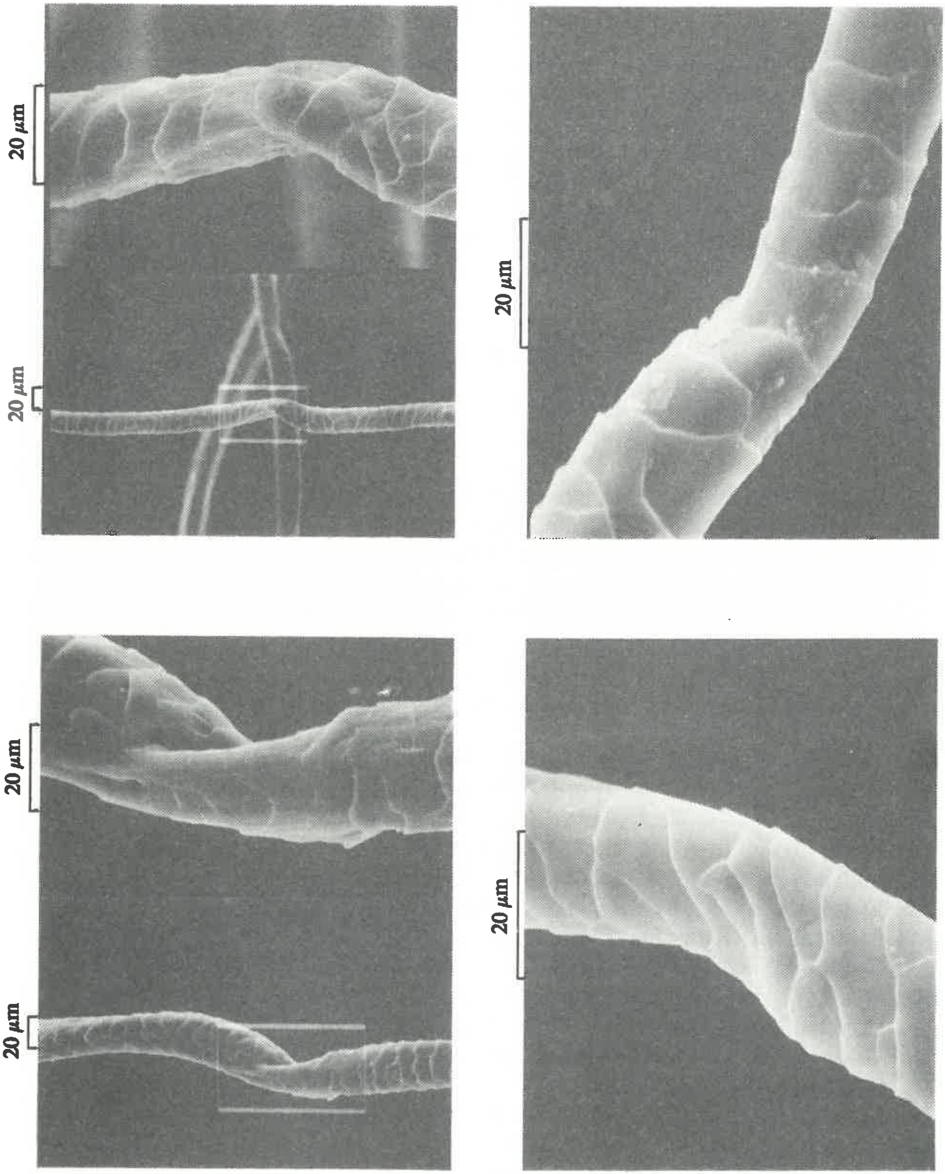

Fig 5 — Scanning electron photomicrographs of wool fibres which exhibit a marked tenderness ("break").

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