The effect of coarse edge on wool spinning performance and yarn properties

Anton F. Botha[a*] **and Lawrance Hunter**[b]

The interrelationship of natural fibre, yarn and fabric properties is both important and complex, and has attracted considerable research. An area which has received little attention is that concerning the effect of fibre diameter distribution, notably of relatively coarse fibres, on processing behaviour and yarn and fabric properties, except for their well-known effect on handle and prickle (scratchiness). Prickle is an unpleasant sensation sometimes experienced with garments worn next to the skin. The effect of fibre diameter distribution, of coarse fibres (or coarse edge, CE) in particular, on spinning performance and yarn properties, was investigated for 400 different wools. Multiple regression analyses were carried out to quantify the relationships between all the main fibre properties, including CE, on the one hand, and the spinning performance and yarn properties on the other hand. We found that CE had no significant effect on spinning performance and yarn properties, except for yarn neps and yarn hairiness. These findings are important for sheep breeding practices as well as for selecting the most appropriate wools when yarn of a specified quality is to be processed, because attention needs be paid only to fibre diameter, not to coarse edge.

Introduction

There is a growing requirement for softer and more comfortable garments, with consumers becoming increasingly demanding in respect of these and other quality aspects. Many fabric properties contribute to comfort, including insulation, softness, moisture absorption, handle (softness to touch of the fabric), drape (the way a fabric hangs or falls over an object or person) and especially prickle and itch (scratchiness).

The importance and quantitative effect of mean fibre diameter on wool processing performance and yarn and fabric properties have been widely researched and documented.[1,2] So, too, has the effect of wool fibre diameter on fabric handle and prickliness. This research has led to the conclusion that it is primarily the coarse component of the fibre diameter distribution [notably fibres coarser than 30 μm, termed the coarse edge (CE)], which is responsible for prickle-related discomfort. It is recommended that the proportion of such fibres should be below 5% to avoid discomfort.[3,7,8] By contrast, relatively little work has been done on the effect of fibre diameter distribution, notably CE, on processing performance and yarn and fabric properties; this is addressed in this paper. A complicating factor in any such investigation relates to the high correlation between CE and mean fibre diameter (D), making it difficult to isolate their respective effects.

In the 1970s and 1980s, the South African Wool and Textile Institute (SAWTRI) of the CSIR carried out pioneering research aimed at quantifying the effect of wool fibre properties on worsted processing performance, and yarn and fabric properties.[1,2] Nevertheless, at that time no CE values were available and their effect could not therefore be investigated. We have consequently measured the CE of the various lots processed then and undertook statistical analysis to determine its effect on spinning performance and yarn properties, information which could be valuable to both sheep breeder and wool spinner.

[a]CSIR Materials Science and Manufacturing, P.O. Box 1124, Port Elizabeth 6000, South Africa.

[b]Department of Textile Science, Nelson Mandela Metropolitan University, P.O. Box 77000, Port Elizabeth 6000, South Africa.

*Author for correspondence. E-mail: afbotha@csir.co.za

Experimental

The fibre diameter distribution, including the CE, was measured on some 400 raw wool lots, covering South African merino and related sheep breeds and ranging widely in fibre diameter and staple length, previously processed on full-scale worsted machinery into 734 ring yarns.[2,6] Details of the raw wool and tops are given in Table 1 and of the yarns in Table 2. Fibre diameter distribution was measured on all the top samples using an image analyser system and 8000 fibre snippets per sample.[4] Standard test methods and instruments were used for measuring the yarns, whereas the spinnability of the lots was measured by the mean spindle speed (MSS) at break test,[5] which provides a rapid and accurate means of assessing the spinning potential of wool.

When deciding which purported 'independent' variables to include simultaneously in a multiple regression analysis, the Pearson's correlation coefficient needs to be considered. As a rule, it is not advisable to include a pair of variables simultaneously in a regression analysis when the coefficient exceeds about 0.8. Table 3 shows the Pearson's values for the various pairs of independent variables for the complete data set of approximately 400 sample results. Only for CE versus D, mean fibre length (hauteur) versus the length of the 5% longest fibres (tail) and coefficient of variation of diameter (CV_D) versus coarse edge ratio (CE_R) did the correlation coefficient exceed 0.8, hence these pairs of parameters were excluded from the statistical analyses performed.

Essentially two sets of multiple regression analyses (involving various combinations of independent variables (see Table 4 in supplementary material online) were carried out. In the first place, yarn linear density (tex) (models A to C) and the fibre diameter distribution parameters (D, CV_D and CE) were used. In the second, the number of fibres in the yarn cross-section (NoF) (models D and E) and CE were used in place of D and CV_D, because NoF is a function of D and CV_D. These regression models were used to establish and isolate the effects of the various fibre physical properties, particularly CE, on spinning performance and yarn properties. To establish whether CE significantly improved the correlation, it was included and then excluded, as an independent variable; the option of excluding CV_D, but retaining CE, was also investigated. The models (see Table 4) were repeated by substituting CE with CE_R.

Table 1. Summary of the fibre properties[†] of the wool tops processed.

Properties	Mean	Minimum	Maximum	s.d.
Diameter (D) (μm)	22.4	18.0	32.8	2.6
CV of diameter (CV_D) (%)	23.6	19.3	27.7	1.7
Coarse edge (CE) (% fibres > 30 μm)	8.9	1.6	62.8	10.3
Coarse edge ratio (CE_R)	1.0	0.5	1.5	0.16
Hauteur (H) (mm)	60.0	33.0	115.0	12.6
CV of hauteur (CV_H) (%)	46.7	20.6	66.3	7.3
% Fibres <25 mm (Sh25)	10.0	0.0	27.0	5.8
Tail length (tail)(L 5%) (mm)	100.1	64.8	170.6	17.6
Duerden crimp ratio (De)*	0.9	0.7	1.7	0.13
Staple crimp (Cr)(crimp/cm)*	3.9	1.9	6.5	0.85
Resistance to compression (Rc) (mm)	16.5	12.9	24.7	2.2

*Measured on the raw wool.
[†]Number of samples *c.* 400 in each case.

Table 2. Range of yarn properties.†

Properties	Mean	Minimum	Maximum	s.d.
Yarn linear density (tex)	34.9	16.8	53.3	12.1
Number of fibres in yarn cross section (NoF)	65.6	21.0	143.0	26.9
Twist factor (turns/cm × $tex^{0.5}$) (Tf)	31.5	26.9	45.3	5.9
MSS (rev/min)	10 727	5500	13 597	1813
Irregularity (CV%)*	18.0	12.3	28.1	2.9
Thin places per 1000 m**	141	0	1547	198
Thick places per 1000 m**	79	0	681	96
Neps per 1000 m	29	0	452	37
Breaking strength (cN)	234.2	79.0	414.0	97.7
Extension at break (%)	15.6	5.9	34.0	5.5
Hairiness (hair)(hairs/m)	40.6	14.0	93.0	12.8
Tenacity (cN/tex)	6.6	3.6	8.7	0.8
Classimat faults 1 (total yarn faults)	788	33	35 802	1976
Classimat faults 2 (objectionable yarn faults)	51	2	1276	75

†Number of samples *c.* 734 in each case with the exception of MSS, for which number of samples was *c.* 702.
*Unevenness (irregularity) of the yarn given as a percentage.
**The number of thin and thick places in the yarn.

As mentioned above, the high correlation ($R^2 = 0.97$) between CE and mean fibre diameter (Fig. 1) makes it difficult to separate the effects of these two parameters. To overcome this, a new parameter, namely the *coarse edge ratio* (CE_R), which is defined as the ratio of the actual CE to the average CE for the same *D* calculated from the CE versus *D* regression line shown in Fig. 1. CE_R is independent of *D* ($R^2 = 0.00024$) and was included together with *D* in the regression analysis, and its effect established independently of either CE or *D*. In essence, using CE_R indicates whether a higher or lower CE relative to the 'norm' for a certain *D* has any effect on spinning performance or yarn properties, the concept essentially being analogous to the Duerden ratio used for wool staple crimp.

Results and discussion

Spinnability. Various analyses demonstrated that multiquadratic regressions gave the best correlations for spinnability (MSS), with the predicted results normally distributed. High percentage fits could be achieved for the regressions, with R^2 ranging from 0.85 to 0.87. Nevertheless, many terms were required to obtain such high percentages and we chose to exclude all fibre properties which contributed less than 1% to the total fit. When this was done, 8 terms emerged as significant (see Table 5 as supplementary material online), the percentage fit ranging from 79.1% to 83.1%, with the trends generally similar as those obtained with more terms. Overall, five prediction equations for MSS, referred to as A–E, essentially displayed the same trend,

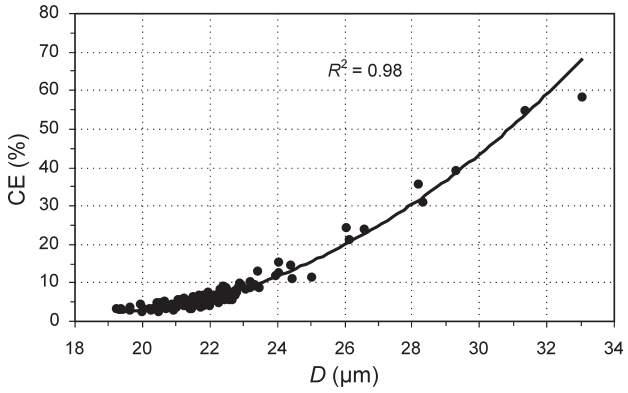

Fig. 1. Relationship between CE and *D* for tops.[4]

with a higher yarn linear density or more fibres in the yarn cross section, coupled with a lower mean fibre diameter and higher hauteur, leading to improved spinnability, confirming earlier work.[2] In some cases, certain other fibre properties were also significant, although their overall contribution was mostly small. For example, as found previously,[2] an increase in crimp (Cr) tended to be associated with a decrease in spinnability and so too a decrease in CV_H.

Including CE at best improved the percentage fit only marginally. CE_R gave similar, if not the same, results as CE (Table 5). Introducing CE in place of *D* did not change the correlation coefficient significantly, and we concluded that once *D* is taken into consideration, neither CE nor CE_R improved the correlation coefficients significantly; thus CE and CE_R had little, if any, effect on spinnability.

Similar statistical models to those applied above for MSS were used to establish the effect of CE on yarn properties. We found that the log–log regression analyses gave the best correlations for these properties and the predicted results were normally distributed. The results and contribution of the various independent variables to the total percentage fit are summarized in Table 6 (see supplementary material online). Only the most important yarn properties will be discussed here.

Yarn evenness and tensile properties. Similar trends were observed for all the yarn evenness-related properties. As shown in Table 6, CE had no statistically significant effect on these properties; the number of fibres in the yarn cross section and yarn linear density contributed most to the overall fit, as was found previously in explaining the variations in yarn evenness and tensile properties.[6]

For frequencies of thin and thick places (Table 6), the trends were similar to those for irregularity, although the total percent-

Table 3. Pearson's correlation coefficients (*r*) for pairs of the main independent variables* ($n = 400$).

	Cr	De	H	CV_H	Tail	Sh25	Rc	*D*	CV_D	CE	CE_R	Tex	MSS	NoF
Cr	1.00													
De	0.33	1.00												
H	–0.30	0.06	1.00											
CV_H	–0.09	0.03	0.09	1.00										
Tail	–0.30	0.05	0.88	0.47	1.00									
Sh25	0.16	–0.12	–0.68	0.39	–0.42	1.00								
Rc	0.45	0.58	–0.13	0.19	–0.003	0.12	1.00							
D	–0.52	0.50	0.33	0.14	0.30	–0.22	0.08	1.00						
CV_D	–0.37	–0.39	–0.04	0.01	0.003	0.10	–0.24	–0.03	1.00					
CE	–0.58	0.33	0.27	0.12	0.25	–0.16	–0.01	0.92	0.15	1.00				
CE_R	–0.32	–0.34	0.03	–0.07	0.02	–0.02	–0.23	–0.16	0.81	–0.01	1.00			
Tex	–0.32	0.28	0.12	0.01	0.09	–0.12	–0.04	0.58	0.03	0.59	–0.05	1.00		
MSS	–0.07	–0.03	0.41	0.15	0.41	–0.23	–0.03	–0.01	0.003	0.002	0.05	0.56	1.00	
NoF	0.14	–0.05	–0.16	–0.09	–0.16	0.07	0.04	–0.18	0.03	–0.14	–0.02	0.67	0.69	1.00

For the above, it is required that $r > 0.26$ for significance at the 95% level, $r > 0.34$ for significance at the 99% level, and $r > 0.43$ for significance at the 99.9% level.
*Terms are defined in Tables 1 and 2.

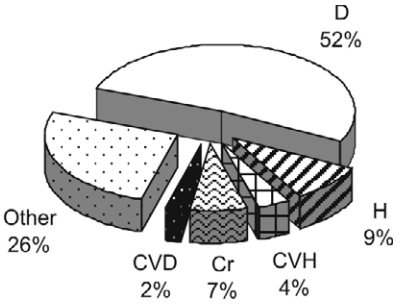

Fig. 2. Percentage contribution of the various fibre properties towards explaining the observed variations in yarn tensile and evenness characteristics (average over 50 and 25 tex yarns).[6]

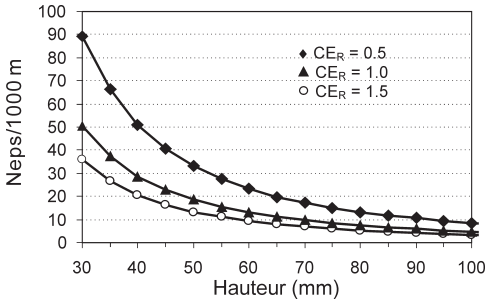

Fig. 3. Effect of hauteur and CE_R on nep frequency (model C_Cr equations derived from model C, using Cr as an independent variable instead of Rc (see Table 4 online).[4]

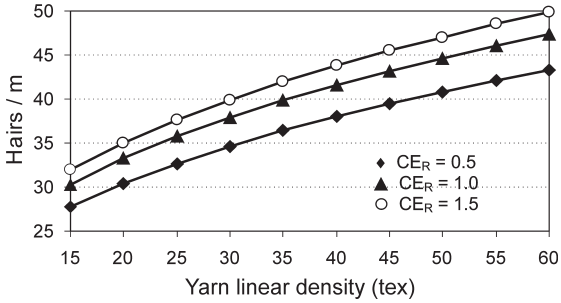

Fig. 4. Effect of tex and CE_R on yarn hairiness (model A_Rc, equations derived from model A, using Rc as an independent variable instead of Cr (see Table 4 online).[4]

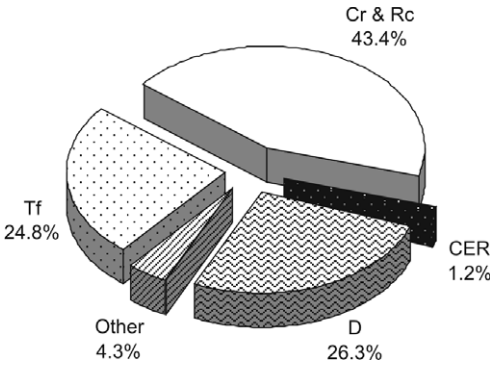

Fig. 5. Average contribution of wool top fibre properties towards explaining yarn hairiness.[4]

age fit was lower; CE and CE_R again had no significant effect on the frequencies.

For the yarn tensile properties, CE and CE_R also did not have a statistically significant effect; tex, NoF, Cr and D were the most significant. The results obtained here therefore confirm previous findings,[1,2,6] as summarized in Fig. 2, which shows the average contribution of the various fibre properties towards explaining yarn evenness and tensile characteristics.

Yarn neps. A decrease in CE or CE_R (Fig. 3) significantly increased the frequency of neps, the magnitude of the effect depending upon the number of fibres in the yarn cross section, resistance to compression, fibre length and diameter. The regression analyses showed that, at most, only 45% of the variation in nep counts could be explained empirically, 4% of which was contributed by CE.

Yarn hairiness. An increase in CE or CE_R (Fig. 4) significantly increased the hairiness, the effect being dependent upon twist factor (Tf). According to the regression results (Table 6), between 72% and 82% of the variation in hairiness could be explained. Figure 5 summarizes the average contribution of the fibre properties towards explaining hairiness. The figure also confirms previous findings[6] that Rc, Cr and Tf contributed most to the overall fit.

Conclusions

Five different statistical models were devised to determine the effect of wool fibre diameter distribution, coarse edge, and coarse edge ratio in particular, on spinning performance and yarn properties. Within the ranges covered here, neither CE nor CE_R had a statistically significant or consistent effect on spinning performance and yarn evenness and tensile properties, with the exception of yarn neps and hairiness. An increase in CE or CE_R was associated with a decrease in the nep frequency; a 1% absolute change in CE resulted in a change of 1 nep per 1000 m of yarn. An increase in CE or CE_R was associated with a rise in yarn hairiness; a 1% absolute change in CE, for example, resulted in a change of 1.6 hairs/m. The results presented here are of importance to wool sheep breeders and to worsted spinning mills, since they show that, with the exception of yarn neps and hairiness, changes in CE or CE_R alone are of little consequence for spinning performance or yarn quality. They therefore need not, in practice, concern themselves with possible variation in CE or CE_R, once mean fibre diameter has been taken into consideration, except for their effect on scratchiness.

The empirical equations derived in this study could form the basis for the prediction of spinnability and yarn properties for South African wool and for expert systems. These equations also enable a spinner to evaluate and cost the various options concerning the tops available for purchase, because they show the effect of changes in any one fibre property relative to those in any other.

We are indebted to the various staff members of the Fibre and Textiles Centre of the Materials Science and Manufacturing Operating Unit of the CSIR for technical assistance and statistical analyses. Permission by Cape Wools SA to publish these results is also appreciated.

Received 7 November 2005. Accepted 24 April 2007.

1. Hunter L. (1980). The effects of wool fibre properties on processing performance and yarn and fabric properties. *Proc. 6th Int. Wool Text. Res. Conf.,* Pretoria, **1**, 134.
2. Hunter L. (1987). A summary of SAWTRI's research on wool and wool blends—1952–1987. SAWTRI Special Publication, Wol 78, CSIR, Port Elizabeth.
3. Garnsworthy R.K., Gully R.L., Kandiah R.P., Kenins P., Mayfield R.J. and Westerman R.A. (1988). Understanding the causes of prickle and itch from skin contact of fabrics. *Aust. Text*. **8**(4), 26–29.
4. Botha A.F. (2005). *The fibre diameter distribution, particularly the coarse edge, of South African wool, and its effect on textile performance*. Ph.D. thesis, Nelson Mandela Metropolitan University, Port Elizabeth.
5. Turpie D.W.F. (1975). A rapid measure of spinning potential –'mean spindle speed at break'. *SAWTRI Techn. Rep.* No. 240, Port Elizabeth.
6. Hunter L., Turpie D.W.F and Gee E. (1982). The effect off wool properties on worsted processing performance and on yarn and fabric properties. *SAWTRI Techn. Rep.* No. 502, Port Elizabeth.
7. Kenins P. (1992). The cause of prickle and the effect of some fabric construction parameters on prickle sensation. *Wool Tech. Sheep Breed*. **40**(1), 19–24.
8. Garnsworthy R.K., Mayfield R.J., Gully R.L., Westerman R.A. and Kenins P. (1985). Mechanics in contaneous sensations of prickle and itch evoked by fabrics. *Proc. 7th Int. Wool Text. Res. Conf.,* Tokyo, **3**, 190–199.

Supplementary material to:

Botha A.F. and Hunter L. (2007). The effect of coarse edge on wool spinning performance and yarn properties. *S. Afr. J. Sci.* **103**, 174–176.

Table 4. Description of regression models A to E.[4]

A:	Tex	Crimp	De*	D	CV_D	CE/CE_R**	H	CV_H	Sh25	Tail*	
B:	Tex	Crimp	De*	D	CV_D		H	CV_H	Sh25	Tail*	(CE excluded)
C:	Tex	Crimp	De*	D		CE/CE_R**	H	CV_H	Sh25	Tail*	(CV_D excluded)
D:	NoF	Crimp	De*			CE/CE_R**	H	CV_H	Sh25	Tail*	(NoF includes D and CV_D)
E:	NoF	Crimp	De*				H	CV_H	Sh25	Tail*	(CE excluded)

*De and Tail were replaced by Tf in the regression analyses involving yarn properties.
**CE was replaced by CE_R in the regression analyses involving MSS and yarn properties.
Sh25, percentage of fibres shorter than 25 mm (ref. 4).
Tail, the length exceeding the longest 5% of the fibres in the top (hauteur diagram) referred to as the Almeter Tail Length (Tail).[4]

Table 5. Summary of the multiquadratic regression equations for MSS (n = 702).[4]

	Model	Regression equation	R^2 (%)
Tex	A	$10740 + 0.46(Tail)(Tex) - 1.99(CE)(Tail) - 1070(D) + 1243(Tex) - 23.27(Tex)^2 + 9.50(Tex)(CE) + 4.76(D)(H) + 0.64(CV_H)^2$	
		40.1† **28.4**† **2.4** **2.6** **2.3** **3.2** **2.1** **1.8**	83.0
	B	$7355 - 0.94(Tail)(Tex) - 52.07(D)^2 + 15.44(Tex) - 29.16(Tex)^2 + 124.4(H) + 0.80(CV_H)^2 + 75.77(Tex)(D)$	
		40.1 **28.1** **4.2** **2.8** **2.0** **2.3** **3.1**	82.6
	C	$10740 + 0.46(Tail)(Tex) - 1.99(CE)(Tail) - 1070(D) + 1243(Tex) - 23.27(Tex)^2 + 9.50(Tex)(CE) + 4.76(D)(H) + 0.64(CV_H)^2$	
		40.1 **28.4** **2.4** **2.6** **2.3** **3.2** **2.1** **1.8**	83.0
NoF	D	$2626 + 2.03(NoF)(H) + 2.17(CV_H)(NoF) - 0.09(CE)(Tail) - 10.85(CV_H)(Cr) + 11.75(H)(Cr) + 2.88(Sh)^2 + 17.2(Sh)(Cr) - 0.14(H)^2$	
		72.2 **5.6** **0.32** **0.24** **0.22** **0.17** **0.18** **0.13**	79.1
		$-26890 - 1.40(NoF)(H) + 1.0(CV_H)(NoF) + 4.10(CE_R)(NoF) - 0.80(NoF)(Sh) - 8.70(NoF)^2 + 932(NoF) + 430.3(H) - 2.10(H)^2 + 4.70(Sh)^2 - 20.4(Sh)(Cr)$	
		72.2 **5.6** **0.57** **0.14** **0.13** **3.2** **1.1** **0.59** **0.76** **0.63**	85.0
	E	$-8429 + 1.02(NoF)(H) + 2.61(CV_H)(NoF) - 67.72(De)(CV_H) + 60.56(De)(H) + 601.9(NoF) - 7.32(NoF)^2$	
		72.2 **5.6** **0.27** **0.18** **0.09** **3.6**	82.0

Tex, yarn linear density.
NoF, number of fibres in the yarn cross section.
In models A to C, tex only is used and in models D to E, only NoF is used, because NoF is a function of tex, D and CV_D (see text).
†These numbers indicate the percentage contribution the term (among the independent parameters) makes to the overall regression.

Table 6. Average percentage contribution of the various fibre properties to the overall percentage fit (R^2) for the yarn properties.[4]

Dependent variables	Model	Total R^2 (%)	Contribution of independent variables (%) (n = 734)											Most significant regression equations
			CE	CE_R	NoF	Tex	Tf	D	H	Cr	Rc	CV_D	CV_H	Sh25	
Irregularity (%)	D	85.1	*	0.17**	79.2**	*	0.58	*	3.6**	*	1.3	*	0.11**	NS	$10^{1.96}\ NoF^{0.37}\ H^{0.16}\ Rc^{0.15}\ Tf^{0.074}\ CE_R^{0.033}\ CV_H^{0.033}$
	E	84.9	*	*	79.2**	*	0.58	*	3.6**	*	1.3	*	0.12**	NS	$10^{1.93}\ NoF^{0.37}\ H^{0.15}\ Rc^{0.16}\ Tf^{0.073}\ CV_H^{0.034}$
	D	84.2	0.46	*	79.2**	*	0.58	*	3.6**	0.29	*	*	NS	NS	$10^{2.0}\ NoF^{0.36}\ H^{0.16}\ Tf^{0.076} CE^{0.024}\ Cr^{0.053}$
Thin places per 1000 m	D	81.1	0.51	0.25	75.1**	*	0.59	*	4.0**	*	0.81	*	NS	0.12**	$10^{10.35}\ Rc^{1.66}\ H^{2.49}\ CE^{0.21}\ Sh25^{0.11}\ Tf^{0.92}\ NoF^{4.38}$
	E	80.6	*	*	75.1**	*	0.59	*	4.0**	*	0.81	*	NS	0.12**	$10^{10.51}\ Rc^{1.55}\ H^{2.28}\ Sh25^{0.11}\ Tf^{0.92}\ NoF^{4.51}$
Thick places per 1000 m	D	75.2	1.2	0.16	63.6**	*	NS	*	9.2**	*	1.2	*	NS	NS	$10^{8.76}\ Rc^{1.21}\ H^{2.25}\ CE^{0.24}\ NoF^{2.72}$
	E	73.8	*	*	63.6**	*	NS	*	9.2**	*	0.96	*	NS	NS	$10^{8.94}\ Rc^{1.21}\ H^{2.25}\ NoF^{2.72}$
Breaking strength (cN)	A	96.7	0.02	*	*	93.6	0.05	1.8**	0.98	NS	*	NS	NS	0.22**	$10^{1.07}\ D^{0.83}\ CE^{0.03}\ H^{0.26}\ Tf^{0.061}\ Tex^{1.21}\ Sh25^{0.033}$
	D	91.3	*	0.34**	73.3	*	0.29	*	12.0	5.4**	*	*	NS	NS	$10^{0.49}\ NoF^{1.11}\ CE_R^{0.14}\ H^{0.54}\ Cr^{0.58}\ Tf^{0.15}$
	E	90.9	*	*	73.3	*	0.29	*	12.0	5.4**	*	*	NS	NS	$10^{0.61}\ NoF^{1.11}\ H^{0.60}\ Cr^{0.53}\ Tf^{0.15}$
Extension (%)	D	70.5	0.34**	0.94	49.4	*	3.3	*	9.6	*	7.0****	*	0.89**	NS	$10^{0.37}\ NoF^{0.68} Rc^{0.74}\ CE^{0.032} H^{0.56} CV_H^{0.20} Tf^{0.40}$
	E	70.2	*	*	49.4	*	3.3	*	9.6	*	7.0	*	0.89**	NS	$10^{0.37}\ NoF^{0.70}\ Rc^{0.72}\ H^{0.53}\ CV_H^{0.213}\ Tf^{0.40}$
Neps per 1000 m	C	42.3	*	0.25**	*	30.0**	NS	0.41	9.3**	*	0.37**	*	0.27	1.7	$10^{5.70}\ H^{1.57} Sh25^{0.15} Tex^{1.81} D^{0.51} CE_R^{0.32} CV_H^{0.68} Rc^{0.78}$
	D	45.5	3.7**	*	20.1**	*	NS	*	19.5**	*	0.54**	*	1.5	1.4	$10^{7.67}\ Rc^{0.74}\ H^{1.93}\ CE^{0.37} Sh25^{0.12} CV_H^{0.74} NoF^{1.80}$
	E	41.4	*	*	20.1**	*	NS	*	19.5**	*	0.16**	*	0.20	1.4	$10^{7.90}\ Rc^{0.627}\ H^{2.301}\ Sh25^{0.155}\ CV_H^{0.483}\ NoF^{1.59}$
Hairiness (hairs/m)	D	80.8	5.9	*	10.5	*	26.5**	*	0.13**	34.3**	*	*	0.4**	3.0	$10^{3.22}\ Cr^{0.83} CE^{0.15}\ Sh25^{0.069}\ Tf^{1.03}\ NoF^{0.30}\ CV_H^{0.11} H^{0.083}$
	D	72.2	30.4	*	8.9	*	23.9**	*	NS	*	7.0**	*	NS	2.0	$10^{3.34}\ Rc^{0.82}\ CE^{0.27}\ Sh25^{0.06}\ Tf^{0.97}\ NoF^{0.237}$
	D	74.8	*	0.73	10.5	*	26.5**	*	0.42**	34.3	*	*	NS	2.3	$10^{3.57}\ Cr^{1.18}\ CE_R^{0.17}\ Sh25^{0.047}\ Tf^{1.05}\ NoF^{0.27}\ H^{0.14}$
	D	72.2	*	2.5	8.0	*	24.0	26.3	NS	*	9.4	*	NS	2.0	$10^{1.00}\ Rc^{0.83}\ Tf^{0.97}\ NoF^{0.24}\ D^{1.91}\ CE_R^{0.24}\ Sh25^{0.057}$
	A	77.2	30.4	*	*	9.8	23.9	NS	*	*	10.8	2.4	NS	1.9	$10^{3.20}\ Rc^{0.85}\ CV_D^{0.18}\ CE^{0.20}\ Tf^{1.02}\ Sh25^{0.056}\ Tex^{0.32}$
	A	77.3	*	0.23	*	13.0	24.0**	26.3	*	*	9.4**	2.4	NS	1.9	$10^{1.15}\ D^{1.46}\ Rc^{0.85}\ CV_D^{0.36}\ CE_R^{0.13}\ Tf^{1.02}\ Sh25^{0.056}\ Tex^{0.32}$

NS, Not significant; *, omitted in regression; **, an increase in the fibre property causes a decrease in the yarn property in question.
Irregularity – unevenness of the yarn.[4]
Thin places – number of places thinner than half the average yarn linear density and at least 8 mm long per 1000 m of yarn.[4]
Thick places – number of places thicker than +50% of the average yarn linear density per 1000 m of yarn.[4]
Breaking strength represents the force required to break the yarn.[4]
Extension represents the percentage elongation of the yarn when it breaks.[4]