Wang, Xungai, Chang, Lingli and McGregor, Bruce 2006, Hairiness of worsted wool and cashmere yarns and the impact of fiber curvature on hairiness, *Textile research journal*, vol. 76, no. 4, pp. 281-287.

The Hairiness of Worsted Wool and Cashmere Yarns and the Impact of Fibre Curvature on Hairiness

Xungai Wang[1] **and Lingli Chang**
School of Engineering and Technology, Deakin University,
Geelong Victoria 3217, Australia

Bruce McGregor
Department of Primary Industries,
Attwood Victoria 3049, Australia

Abstract

In this study, a range of carefully selected wool and cashmere yarns as well as their blends were used to examine the effects of fibre curvature and blend ratio on yarn hairiness. The results indicate that yarns spun from wool fibres with a higher curvature have lower yarn hairiness than yarns spun from similar wool of a lower curvature. For blend yarns made from wool and cashmere of similar diameter, yarn hairiness increases with the increase in the cashmere content in the yarn. This is likely due to the presence of increased proportion of the shorter cashmere fibres in the surface regions of the yarn, leading to increased yarn hairiness. A modified hairiness composition model is used to explain these results and the likely origin of leading and trailing hairs. This model highlights the importance of yarn surface composition on yarn hairiness.

[1] Corresponding author – email: xwang@deakin.edu.au

INTRODUCTION

Yarn hairiness affects not only the quality of products, but also the productivity in spinning and weaving. Excessive yarn hairiness is undesirable for many end uses as well as the spinning and post-spinning processes. To reduce yarn hairiness, it is necessary to understand the influence of key parameters on yarn hairiness. Thus, many research laboratories have studied the effects of fibre, yarn, and spinning parameters on the hairiness of various yarns. Most of these studies up to about 10 years ago have been summarised in three reviews on yarn hairiness [1 – 3]. Later studies have focused on yarn hairiness testing, reduction and prediction [4, 9, 11, 13-15, 23-30].

Gaps and discrepancies still exist in yarn hairiness study. For instance, the effect of fibre crimp or curvature on the hairiness of worsted yarns is yet to be clarified. The bulk of cashmere yarn production is woollen spun, and very little has been reported on the hairiness of worsted cashmere yarns. Question also remains on whether the hair-length distributions of various yarns follow an exponential function [1, 6, 16, 21, 22, 30] or two exponential mechanisms operating respectively [7]. About yarn hairiness composition, Barella [1] stated that the number of protruding ends was appreciably the same as the number of fibres in the cross-section of the yarn. He also proposed two hypotheses: (1) all fibres stuck out of one of their ends to the yarn surface, (2) half of fibres projected both ends to the yarn surface. However, the experimental results confirmed "the majority of the emergent fibres corresponded to fibre tails (some 56-64%), the number of heads constituting some 30-40%; the number of ends that could be identified as neither head nor tail was small (2-10%)" [1, 5]. These experimental results are contradictory to hypothesis (2) that half of fibres projected both ends to the yarn surface.

Against this background, the current study aims to: (a) clarify the effect of fibre curvature on the hairiness of worsted yarns; (b) analyse the hair-length distribution of the worsted wool, cashmere and their blend yarns, using the data obtained from the Zweigle G565 Hairiness Meter; and (c) examine the yarn hairiness composition theory.

THEORETICAL CONSIDERATIONS

Fibre Migration Behaviour in a Blend Yarn

Fibre migration occurs in the formation of conventional ring spun yarns. The path of a fibre in a yarn is a helical one, and the radius of which is alternately increasing and decreasing along its length [20]. Three possible mechanisms, tension mechanism, geometric mechanism, and combined mechanism of migration have been proposed [10,20]. For blend yarns, according to the tension mechanism of fibre migration, it is likely that the fibres having higher initial Young's modulus tend to occupy the inner zones of the structure. Those having the lower modulus tend to be in the outer zones [20]. Experiments have confirmed this hypothesis [10]. In cashmere/wool blends, it is likely the wool fibres, with longer length and possibly higher initial modulus than the cashmere component, would locate in inner zones of the yarn.

The Composition of the Yarn Hairiness

According to the theory of tension mechanism in fibre migration, Morton [20] regarded each fibre-trailing end projected from the yarn body as hairiness. On this basis, Barella [5] established a theory of hairiness. He stated that the number of protruding ends was the same as the number of fibres in the cross-section of the yarn. Furthermore, the experimental result confirmed that "the majority of the emergent fibres corresponded to fibre tails (some 56-64%), the number of heads constituting some 30-40%; the number of ends that could be identified as neither head nor tail was small (2-10%)" [1].

He has postulated a theory to explain the proportion of leading ends. Assuming the diameter of a yarn is D, the diameter of the fibres is d_o, the area of the first outer layer of a yarn is S_{outer1}, then the area of the first outer layer would be:

$$S_{outer1} = \frac{\pi[D^2 - (D - 2d_0)^2]}{4} \qquad ...(1)$$

For a worsted yarn, D can be taken as approximately equal to $10d_0$ [5], then:

$$S_{outer1} = \frac{0.36\pi D^2}{4} = 36\% S \qquad ...(2)$$

Where, S is the total area of the yarn cross-section. In other words, 36% of the fibres comprising a yarn fall within the surface layer. From this basis, Barella [5] obtained following inferences:

a) That all the fibre leading ends which comprise the surface zones of the fibre project from the yarn.
b) A large proportion of the fibre tails project when they find themselves liberated at the point where they leave the last pair of rollers, and this proportion should be regarded as at least 65%.

Barella [1, 5] did not give a theoretical explanation for the proportion of trailing ends. More recently, Wang *et al* [31] studied the formation of the yarn hairiness using a special CCD camera and thought that for a Z-twist yarn, edge fibres in the left-hand side of the spinning triangle form the majority of trailing hairs. The pre-twisting in the right-hand side of the twist triangle helps to keep the fibres there under good control. Hearle *et al* [10] suggested that fibres on one side will be in the center and fibres on the other side will be the outsides due to the wrapped form of the yarn. From the conclusions of Wang *et al* [31] and Hearle *et al* [10], it seems to suggest that the trailing ends would be originated from the outer layer fibres.

It should be noted that with Barella's calculating method, $D \approx 10d_0$, where d_0 is the fibre diameter. However, this calculation does not consider the case of yarns with different yarn thicknesses. To take yarn thickness into consideration, we suggest a modified hairiness composition model, in which the yarn cross-section is divided into five zones of equal radial spacing d (Figure 1).

With this division, the areas of the zone 5, zone (4+5), and zone (3+4+5) can be calculated as follows:

$$S_{zone5} = \frac{\pi[D^2 - (D-2d)^2]}{4} \qquad ...(3)$$

$$S_{zone(4+5)} = \frac{\pi[D^2 - (D-4d)^2]}{4} \qquad \text{...(4)}$$

$$S_{zone(3+4+5)} = \frac{\pi[D^2 - (D-6d)^2]}{4} \qquad \text{...(5)}$$

In formula (3)-(5), d is the spacing width of every zone. Thus D = 10d, and the area of zone 5, zone (4+5), and zone (3+4+5) as a percentage of the yarn cross-section area can be obtained as shown in Table 1.

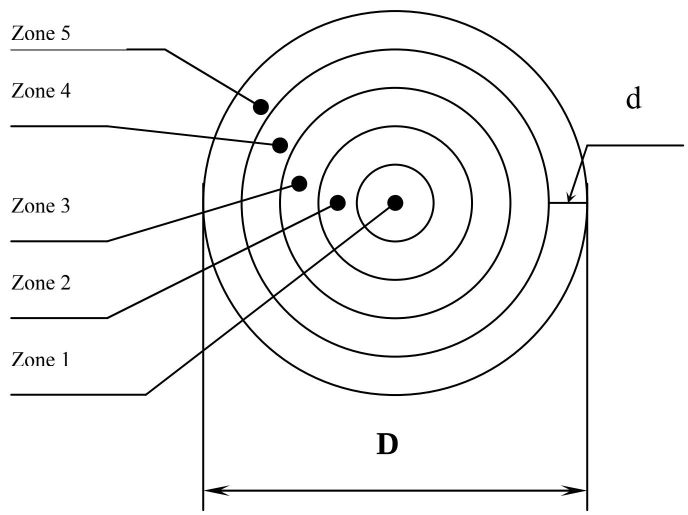

Figure 1. Dividing yarn cross-section into 5 zones of equal radial spacing

Table 1. Percentage area of outer zones in the yarn cross-section

Zone	S_{zone5}	$S_{zone\ (4+5)}$	$S_{zone(3+4+5)}$
% in total cross-section area	36%	64%	84%

It is surprising that the percentage of the area of the zone (4+5) in the yarn cross-section area is close to the percentage of fibre tailing ends (56-64%). From this and Barella's results, the mechanism of hairiness composition may be postulated as:

(1) the 'leading-end' hairs arise from the fibres occupying the outermost zone of the yarn (20% diameter thickness); and

(2) the 'trailing-end' hairs arise from the fibres occupying the outer two zones of the yarn (40% diameter thickness).

This highlights the critical importance of the surface regions of a yarn on yarn hairiness. If the fibre compositions in the surface regions of a yarn are changed, it is likely that the hairiness of the yarn will be significantly affected. This will be demonstrated empirically in the following section where the hairiness of cashmere/wool yarns is examined.

EXPERIMENTAL

Materials

We conducted this study with nine treatments each with 3 replicates. The design was:
Blend / (WT * BR), where
Blend was analysed as: **Control (CM),** specified as 100% cashmere; **Blends,** blends of cashmere with wool and the pure wool treatments.
WT was wool type which had two levels: **SW,** standard high crimp ultrafine wool tops; **LCW,** soft handling low crimp ultrafine wool tops.
BR was blend ratio and had four levels specified as: 75, 50, 25 and 0 referring to the percentage of cashmere in the blend.

In the graphical presentation of results, BR 100 refers to the Control (CM). Fibre was processed into tops and following combing, but before gilling, was allocated at random into three replicates and treatments.

Details of the origin of the wool and cashmere, the properties, processing, testing and top properties are provided elsewhere [17-19]. At purchase, the greasy wool and cashmere had a mean fibre diameter (MFD) of 16.9 μm. The LCW had significantly lower staple crimp frequency (3.8 vs 7.2 crimps/cm), fibre curvature (FC, 74 vs 114 deg./mm) and resistance to compression (Rc, 7.4 vs 10.4 kPa) than the SW. The respective values for cashmere were: fibre crimp frequency 3.2 crimps/cm, FC 49 deg./mm, Rc 5.3 kPa. The differences in greasy wool FC and Rc were translated to significant differences between LCW, SW and CM top FC and Rc attributes. The mean fibre length or Hauteur in the tops ranged from 47 mm (100% LCW) to 50.5 mm (100% SW) with the 100% cashmere being 41 mm. Yarns were 18 tex/ 822 tpm. In this study only 1 replicate of 100% CM was used.

We selected these yarns were so that the effects of fibre blend ratio and wool crimp on yarn hairiness can be examined. We chose samples at random among the yarns. Five bobbins were selected from every lot. For each test, the yarn length used was 100m, the test was repeated two or three times on the same bobbin, the total length is 1200m for every lot of yarn. These results were then averaged and expressed as hairs/100m.

Test Apparatus and Hairiness Parameters

We used the Zweigle G565 Hairiness Meter [32] to measure yarn hairiness, and conducted the tests in a standard atmosphere of 20±2 °C and 65±2% r.h. We conditioned the yarn samples for more than two weeks in the laboratory before the measurements.

We used the following five-parameters to assess the yarn hairiness:

a) Number of hairs in different hair-length groups expressed in **hairs/100m**. This value will be termed N_i (i = 1, 2, 3, 4, 6, 8, 10, 12, 15, 18, 21, and 25mm).
b) Number of hairs registered with a length exceeding 3 mm (or S_3, expressed in **hairs/100m**).
c) The total number of hairs registered (T_P, **hairs/100m**).
d) The number of hairs exceeding 3mm (S_3) as a percentage of the total number of hairs protruding more than 1mm (T_P), ie. $100S_3/T_P$ (**%**).
e) The total length of hairs ***K'*****(mm/cm)**.

RESULTS AND DISSCUSSION

Overall Results and Statistical Analyses

Figure 2 gives the experimental results of yarn hairiness. We analysed the results using Genstat 5.4.1 for Windows [8]. Results given in the text include the standard error of difference between means (sed). Plotted with the control treatment (pure cashmere) are error bars indicating the effective standard error (ese) for the comparison of any two means using the sed for the Blend.WT.BR interaction. The ese = sed/√2. In the results the main effects are given, along with the sed and probability (P). The subscript on the sed value indicates to which main effect comparison the value refers.

During analysis, the data were tested for linearity and curvature. Depending on the significance of these tests, the plotted graphs have been fitted with either:

a) two straight lines - indicating an effect of WT and an effect of BR. If these lines have different slopes then there was an interaction of BR with WT;
b) separate curves - indicating a quadratic effect of BR and an effect of WT. If these lines have different slopes then there was an interaction of BR with WT.

We undertook linear regression analysis to determine the relationship between total number of hairs (Tp) of the experimental yarn and the Hauteur and fibre curvature of the top.

The total number of hairs (Tp), the total number of long hairs (S_3), the proportion of long hairs ($100S_3$/Tp) and the constant K' of pure cashmere yarn (CM) were all significantly greater than those of the other treatments (Table 2, $P<0.001$). These values were all affected by wool type ($P<0.001$) with low crimp wool yarns (LCW) having greater values than standard high crimp wool yarns (SW). All these hairiness values increased as blend ratio (i.e. cashmere component in blend) increased ($P<0.001$, see Figure 2). These results, together with the results in the subsequent section, will be explained in the context of hairiness composition theory later.

Table 2. Main effects of blend and wool type on hairiness attributes of yarns composed of pure cashmere (CM), low crimp ultrafine wool (LCW) and standard high crimp ultrafine wool (SW). Measurements are per 100 m of 18 tex yarn

Attribute	**CM**	**LCW**	**SW**	**sed$_{CM-WT}$**	**P**	**sed$_{WT}$**	**P**
Tp	22318	14636	12187	502	< 0.001	317	< 0.001
S_3	4214	1780	1364	95	< 0.001	60	< 0.001
$100S_3$/Tp	19.54	12.00	10.61	0.39	< 0.001	0.25	< 0.001
K'	5.196	3.021	2.466	0.112	< 0.001	0.071	< 0.001

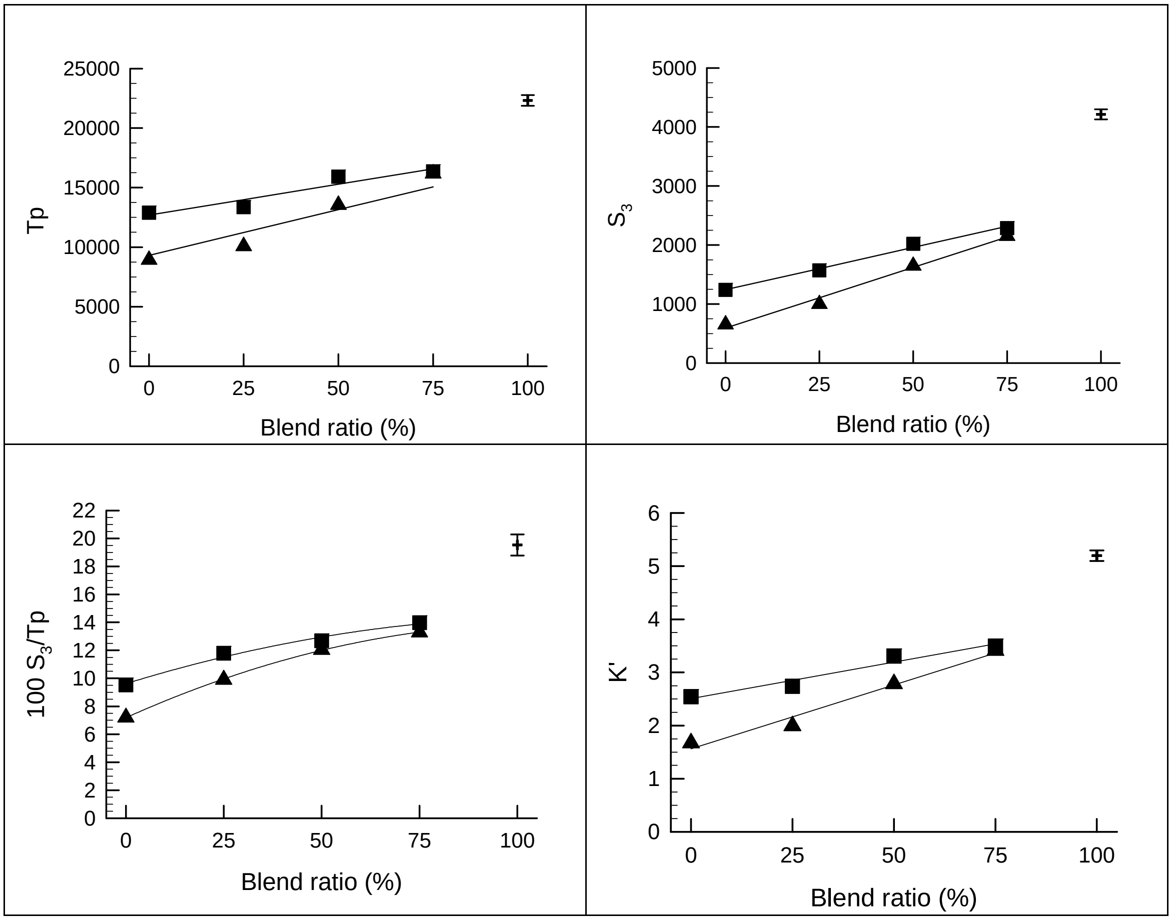

Figure 2. Hairiness properties of 18 tex yarn (per 100 m of yarn) where blend ratio refers to the percentage of cashmere in the blend (Symbols for wool type: ■ Low crimp wool; ▲ Standard wool; + pure Cashmere with effective standard error bars for comparison between any points on the graph. Note, BR0 are pure wool treatments and BR100 is the pure cashmere treatment)

Hair-length Distribution

Figure 3 shows the hair-length distributions of cashmere, cashmere/wool, and wool yarns, using the data of the Zweigle G565 Hairiness Meter. A single exponential regression analysis has been conducted for the hair number and length. Figure 3 gives the square of the regression coefficient (r^2) and the regression equations. The high regression coefficient suggests that the hair-length distributions of worsted cashmere, cashmere/wool, and wool yarns obey a single exponential decay curve.

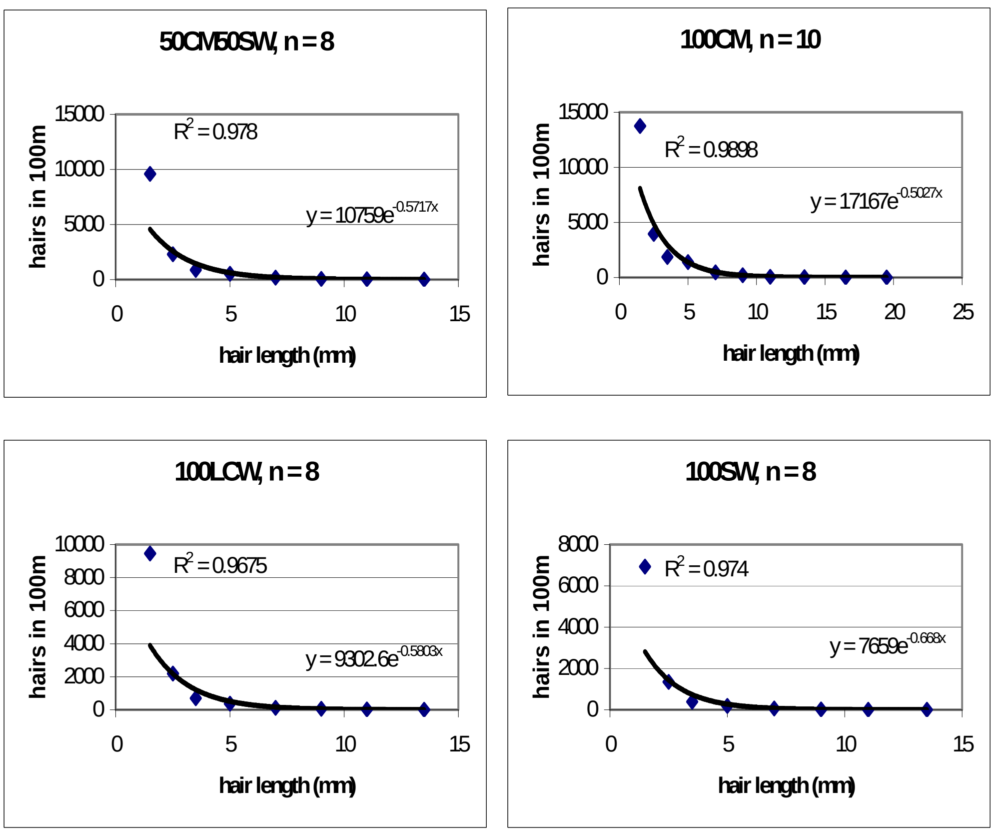

Figure 3. The hair-length distribution of conventional ring-spun worsted wool, cashmere and their blend yarns, using the data of Zweigle G565 Hairiness Meter

Effect of Wool Fibre Curvature on Yarn Hairiness

Since the fibre diameter of the LCW and SW wool types was not different, so the yarn hairiness is affected by the wool fibre curvature. The SW yarns exhibit less hairiness than the LCW yarns. The total hairiness number (Tp), the number of the hair length equal to or greater than 3mm (S3), the percentage of the longer hairs in total hairs (100S3/Tp), and the total hair length (K') all support this trend as indicated in Figure 2.

It is worth noting that the LCW top has a shorter Hauteur than the SW top (47 mm vs 50.5 mm). One could argue that the higher hairiness of the LCW yarns is due to the shorter fibre length than the SW yarns. However, when we plot the replicate data for fibre curvature vs Tp and S3, the effect of fibre curvature on hairiness is quite obvious (Figure 4). Figure 4 confirms that for fibres of similar diameter, an increased fibre curvature will lead to reduced yarn hairiness.

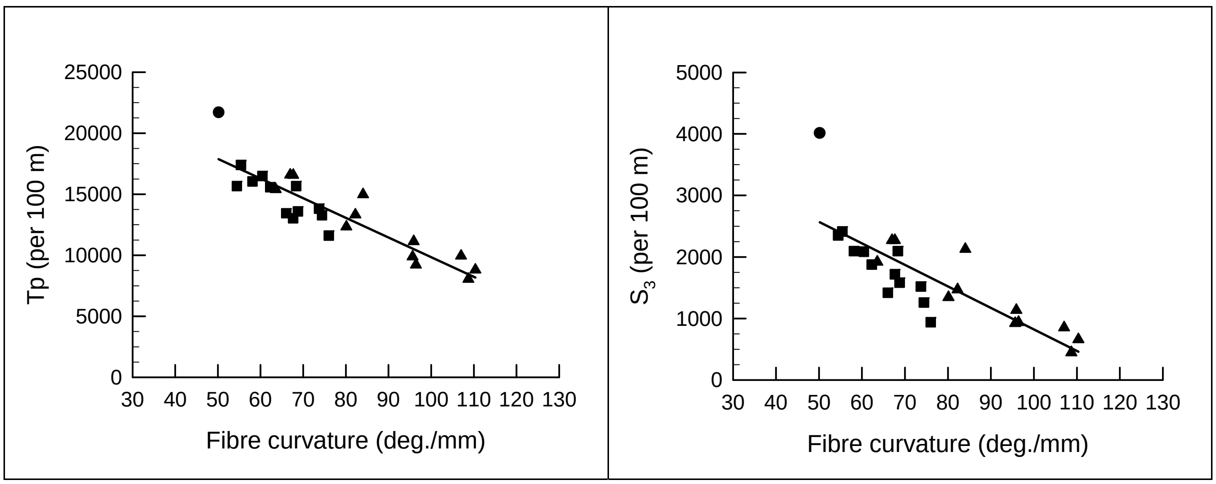

Figure 4. Fibre curvature versus yarn hairiness (Tp and S3). For details of linear lines of best fit, see Table 3. (Symbols for wool type: ■ Low crimp wool; ▲ Standard wool; ● pure Cashmere)

Relationship between yarn hairiness and other yarn properties

As expected, there was a high correlation between Tp and both Hauteur and the fibre curvature of the tops. The multiple regression analysis (Table 3) indicated that slightly better predictions of Tp could be obtained using both Hauteur and fibre curvature.

Table 3. Regression and correlation coefficients for the relationships between yarn hairiness (Tp) and top attributes

Response variate	Regression constant	Dependent variate	Regression coefficient (se)	r	RSD	P
Tp	25950	FC*	-161.1 (16.9)	0.89	1453	0.001
Tp	71275	Hauteur	-1248.4 (98.7)	0.93	1148	0.001
Tp	222708	Hauteur	-7972 (2684)	0.95	994	0.01
		Hauteur^2	76.5 (29.1)			0.05
		FC	-59.1 (28.0)			0.05
S_3	4317	FC	-34.95 (5.14)	0.81	443	0.001

* FC, fibre curvature of washed de-aged fibres measured using the OFDA 100

Discussion of Results in the Context of Hairiness Composition Theory

An accurate verification of the hairiness composition model described earlier is difficult, because the hairiness instrument does not differentiate between leading-end hairs and trailing-end hairs. Nonetheless, the hairiness composition model can help with the explanation of results obtained in the previous sections.

It is obvious from Figure 2 that the effect of wool crimp on Tp, S_3, K' and $100S_3/Tp$ decreases as the percentage of wool decreases. This is shown in two ways: (1) The slopes of the regression lines each wool type LCW and SW approach the value of pure cashmere as the Blend ratio of cashmere increases; and (2) The regression line for the higher crimp SW approaches the regression line of lower crimp LCW as Blend Ratio (BR) approaches 75. If the regression lines were extrapolated, they would intersect at a BR of 80-85. It should be noted that the difference between Wool Type (WT) in the four hairiness measurements was not significant at BR 75, ie 75CM/25LCW and 75CM/25SW (Figure 2).

With the wool/cashmere blend yarns used, the diameters of the cashmere and wool are almost identical, but the cashmere is shorter and possibly has a lower rigidity than the wool. It is known that during ring spinning, the shorter fibres tend to stay near the yarn surface while the longer ones tend to stay in the inner regions of the yarn [12]. So as the proportion of wool decreases in the wool/cashmere blend yarn, the yarn surface layers will be dominated by more and more cashmere fibres. Since the cashmere fibres are shorter, there are more fibre ends per unit length of yarn, leading to increased yarn hairiness. This explains why the yarn hairiness increases as the proportion of cashmere in the yarn increases (see Figure 2).

According to the hairiness composition model, the hairiness of the yarn is governed largely by the fibres in the outer regions of the yarn, it is therefore reasonable that the effect of wool crimp on the hairiness of the wool/cashmere blend yarn diminishes as the proportion of wool reduces. When the wool proportion is reduced, there will be fewer wool fibres in the outer layers of the wool/cashmere yarn, hence the effect of wool crimp on yarn hairiness will diminish.

With the high-crimp wool, there is good cohesion between the fibres, and the fibres are less likely to be dislodged during ring spinning to the yarn surface to form hair fibres. This explains the results in Figure 2 that the hairiness of yarns spun from the high-crimp wool standard wool (SW) is lower than the hairiness of yarns from the low-crimp wool (LCW).

CONCLUSION

In this study, a Zweigle Hairiness Meter was employed to test the hairiness of carefully selected worsted wool, cashmere and cashmere/wool blend yarns. The total hairiness number (Tp), the number of hairs longer than or equal to 3mm (S3), the percentage of the longer hairs in total hairs (100S3/Tp), and the total hair length per unit yarn length (K’) were used to compare the hairiness of these yarns. The following conclusions can be drawn from this study:

- The hair-length distributions of the conventional worsted wool, cashmere, and wool/cashmere yarns follow a single negative exponential law.
- For the blend yarns made from wool and cashmere of similar diameter, yarn hairiness increases with the increase in the cashmere content in the yarn. This is likely to be caused by the increased proportion of the shorter cashmere fibres in the surface regions of the yarn, leading to increased yarn hairiness. This can be explained qualitatively with the modified hairiness composition model also.

- Fibre curvature has a significant effect on yarn hairiness. Yarns spun from fibres with a higher curvature have lower hairiness than yarns spun from similar fibre of a lower curvature. This is likely due to the increased fibre/fibre cohesion provided by the higher curvature wool, which helps with the fibre security during spinning. The effect of wool curvature in the cashmere/wool blend yarn diminishes as the proportion of cashmere in the yarn increases. This is due to the reduced presence of wool in the outer regions of the yarn, which play a dominant role in yarn hairiness as stipulated by the hairiness composition model.

Literature Cited

1. Barella, A., Yarn Hairiness, *Textile Progress*, **13,** No. 1 (1983).
2. Barella, A., The Hairiness of Yarns, *Textile Progress*, **24**, No. 3 (1993).
3. Barella, A. and Manich, A. M., Yarn Hairiness Update, *Text. Progress*, **26,** No. 4 (1997)
4. Barella, A. and Manich, A. M., The Effect of Testing Speed on the Hairiness of Ring-spun and Sirospun Yarns, *J. Text. Inst*., **89**, 605-607 (1998).
5. Barella, A., Yarn Hairiness: the Influence of Twist, *J. Text. Inst*., **48**, 268-280 (1957).
6. Barella, A., and Vigo, J. P., The Variability of Hairiness in Conventional and Open-spun Yarns, *J. Text. Inst*., **64**, 440-442 (1973).
7. Barella, A., and Manich A. M., The Hair-length Distribution of Yarns, Measured by Means of the Zweigle G565 Hairiness Meter, *J. Text. Inst*., **84**(3), 326-335 (1993).
8. GenStat Committee, The Guide to GenStat, Part 2: Statistics. Lawes Agricultural Trust, Rothamsted, UK (2000).
9. Beltran R, Khan Z and Wang X., Predicting the Hairiness of Worsted Spun Wool yarns – *Textile Institute 84th World Conference,* March, 2005, USA.
10. Hearle, J. W. S., Grosberg, P., and Backer, S., Structure Mechanics of Fibres, Yarns, and Fabrics, Vol**. 1**, A Division of John & Sons, London (1969).
11. Hellwig, A., Ways of Reducing Hairiness, *Rieter*, No. **3**, 12-16 (2000).

12. Hickie, T. S., and Chaikin, M., Some Aspects of Worsted-yarn Structure, Part II: The Mechanical State of Single Fibres Leaving the Drafting Zone, *J. Text. Inst*., **64**, 426-432 (1973)
13. Iridag, Y., and Nergis, B.U., The Influence of Testing Length and Speed on Yarn Hairiness, *International Textile Bulletin*, March, 58-62 (1999).
14. Jiang, H., and Zhu, N., Research of Yarn Hairiness Test with Uster Tester 3, *Journal of China Textile University*, **23**(5), 90-95 (1997).
15. Khan, Z. and Wang, X. Research into the Production of Fine and Low Hairiness Yarns, *Textile Institute 83rd World Conference*, May, 2004, Shanghai-China.
16. Lappage, J., and Onions, W. J., An Instrument for the Study of Yarn Hairiness, *J. Text. Inst*., **55**(8), T381-T395 (1964).
17. McGregor, B.A., The quality of cashmere and its influence on textile materials produced from cashmere and blends with superfine wool. Ph.D. Thesis. The University of New South Wales, Sydney (2001).
18. McGregor, B.A. and Postle, R., Single yarn knitted fabrics produced from low and high curvature superfine Merino wool, *Wool Techn. and Sheep Breeding,* **50**, 691-697 (2002).
19. McGregor, B.A. and Postle, R., Processing and quality of cashmere tops for ultra-fine wool worsted blend fabrics. *International J. Clothing Sci. and Tech.*, **16**, 119-131 (2004).
20. Morton, W. E., The Arrangement of Fibres in Single Yarns, *Textile Res. J*., **26**(5), 325-331 (1956).
21. Pillay, K.P.R., A Study of the Hairiness of Cotton Yarns, Part I: Effect of Fibre and Yarn Factors, *Textile Res. J*., **34**(8), 663-674 (1964).
22. Viswanathan, G., Munshi, V. G., Ukidve, A. V., and Chandran, K., Comparative Evaluation of Yarn Hairiness by Different Method, *Textile Res. J*., **58**(8), 477-479 (1988).
23. Wang, X., Effect of Testing Speed on the Hairiness of Ringspun and Sirospun Yarns, *J. Text. Inst*. **88**, Part 1, No. 2, 99-106 (1997).
24. Wang, X., and Miao, M., Reducing Yarn Hairiness with Air-Jet Attachment During Winding, *Text. Res. J*., **67**(7), 481-485 (1997).

25. Wang, X., Miao, M., and How, Y., Studies of JetRing Spinning, Part 1: Reducing Yarn Hairiness with the JetRing, *Text. Res. J.*, **67**(4), 253-258 (1997).
26. Wang, X., Testing the Hairiness of a Rotor-spun Yarn on the Zweigle G565 Hairiness Meter at Different Speeds, *J. Text. Inst.*, **89**, 167-169 (1998).
27. Wang, X., Recent Research on Yarn Hairiness Testing and Reduction: Part 1 – Hairiness Testing, *Research Journal of Textile and Apparel*, **2**(1), 13-20 (1999).
28. Wang, X., Recent Research on Yarn Hairiness Testing and Reduction: Part 2 – Reduction of Yarn Hairiness, *Research Journal of Textile and Apparel*, **3**(1), 1-8 (1999).
29. Wang, X., and Chang, L., An Experimental Study of the Effect of Test Speed on Yarn Hairiness, *Textile Res. J.*, **69**(1), 25-29 (1999).
30. Wang, X., Huang, W., and Huang, X., Effect of Test Speed and Twist Level on the Hairiness of Worsted Yarns, *Textile Res. J.*, **69**(12), 889-892 (1999).
31. Wang, X., Huang W and Huang X, A Study on the Formation of Yarn Hairiness, *J. Text. Inst.*, **90** Part 1, No 4, 555-569 (1999).
32. Zweigle GmbH & Co. KG, G565 Instruction Manual + Hairiness Index (1989).