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Statistical Analyses and Properties of Viloft/Polyester and Viloft/Cotton Blended Ring-Spun Yarns

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Abstract
Viloft is a novel regenerated cellulosic fibre with a special cross section which creates air gaps in the yarn and improves the thermal properties of the fabric. This fibre is mainly used with the blends of polyester and cotton available on the market. In this study, it was aimed to analyse the mechanical and physical properties of viloft/polyester and viloft/cotton blended ring-spun yarns. For this purpose, five different blend ratios of viloft/polyester and viloft/cotton yarns (100%-0%, 67%-33%, 50%-50%, 33%-67% and 0%-100%) were spun as 19.7 tex on a ring spinning system. The breaking force, elongation (%), unevenness and hairiness results of these blended yarns were analysed using a simplex lattice mixture model. In addition, Tukey's test was also applied in order compare the means of the properties of the blended yarns. Statistical analysis showed that the blend ratio is significant for all the properties of viloft/polyester and viloft/cotton blended yarns. However, Tukey's test indicated that a few of the blends of viloft/polyester or viloft/cotton yarns do not differ from each other. Polyester blended viloft yarns showed higher breaking force, elongation and hairiness, but lower CVm % values compared to cotton blended ones.

Key words: *ring spinning, viloft, polyester, cotton, tensile properties, unevenness, hairiness, simplex lattice model, Tukey's test.*

Introduction

The performance and physical properties of yarns may be improved by blending different kinds of fibres. Fabric properties such as tenacity, moisture absorption, thermal insulation, etc. are also affected by the properties of the blended yarns. Various studies investigating the theory of blending and blended yarn properties produced on different spinning systems, such as ring, open-end, air-jet and vortex are available. In general, the blends of cotton, polyester, nylon, flax, and regenerated cellulosic fibres (viscose, modal, tencel, promodal, bamboo) were investigated in those studies.

Mogahzy [1] introduced the analytical aspects of multicomponent fibre blending which are mainly based on four basic modes: structural blending, attributive blending, appearance blending and interactive blending. In the second part of this study, Mogahzy et al. [2] conducted an experimental analysis of structural and attributive blending by using cotton and polyester fibres for the blend components. Lin et al. [3] investigated blend irregularity in two-component blended yarns and developed a theoretical model confirmed via experimental data. Blend irregularity decreases using finer fibres and the blend irregularity of one component decreases with increasing its proportion in the blend. Aghasian et al. [4] investigated the properties of blended rotor-spun cotton/polyester blended yarns using a hybrid model. Basu [5] studied the interaction of properties of individual cotton fibres in a blend. He derived equations for predicting the cotton blended yarn properties.

Basal and Oxenham [6] used seven different blends of polyester and cotton, spun in vortex and air-jet yarns. The strength of the vortex-spun yarns was comparatively high, whereas the elongation values were low. The unevenness, imperfections and hairiness values of the vortex yarns were also low. Erdumlu and Ozipek [7] compared 100% bamboo fibre properties spun at six different yarn counts with 100% viscose rayon and 100% cotton yarns using the ring spinning system. Kilic and Okur [8] investigated the properties of cotton-tencel and cotton-promodal blended yarns spun on ring, compact and vortex spinning systems. According to the results, unevenness, imperfections, diameter and roughness values decrease; however, the breaking force, elongation, density and shape values increase by increasing the regenerated cellulose fibre proportions in the blend. Prakash et al. [9] investigated bamboo/cotton blended ring-spun yarn properties by spinning these yarns in three yarn counts in different blend ratios. They found that the quality of the yarns decreases by increasing the bamboo content in the yarns. Erdumlu et al. [10] investigated cotton, viscose and cotton-modal blended yarns spun on vortex, ring and open-end spinning systems. Optimal processing parameters for an open-end rotor spinning frame for producing bamboo charcoal and cotton (70%) and polyester (30%) fibre blended yarns (Ne 30/1) were analysed in the study of Kuo et al. [11]. Canoglu and Tanir [12] studied the hairiness of polyester/cotton ring spun yarns. The hairiness values of polyester/viscose blends in five blend ratios spun by the ring spinning system was also studied by Canoglu and Yukseloglu [13], who found that viscose rich yarns show worse hairiness. Pan and Postle [14] investigated the strength of twisted blend yarns, in which the hybrid effect was discussed. Namiranian et al. [15] investigated the physical and mechanical properties of fine polyester/viscose-elastic composite rotor-spun yarns. In composite yarns, the breaking tenacity and elongation increased with an increase in the spandex draw ratio and decreased with an increase in the twist factor. Haghighat et al. [16] studied the hairiness of polyester-viscose blended yarns using artificial neural networks. Cyniak et al. [17] investigated the quality parameters of cotton/polyester blended yarns (20 tex and 30 tex) spun on a rotor spinning frame. Baykal et al. [18] developed a statistical model to determine the strength and elongation properties of cotton/polyester blended open-end rotor-spun yarns. Li and Yan [19] also investigated the strength of regenerated bamboo yarn. Cierpucha et al. [20] studied blended rotor-spun yarns with a high proportion of flax. Demiryürek and Uysaltürk [21] investigated the thermal comfort properties of viloft blended fabrics.

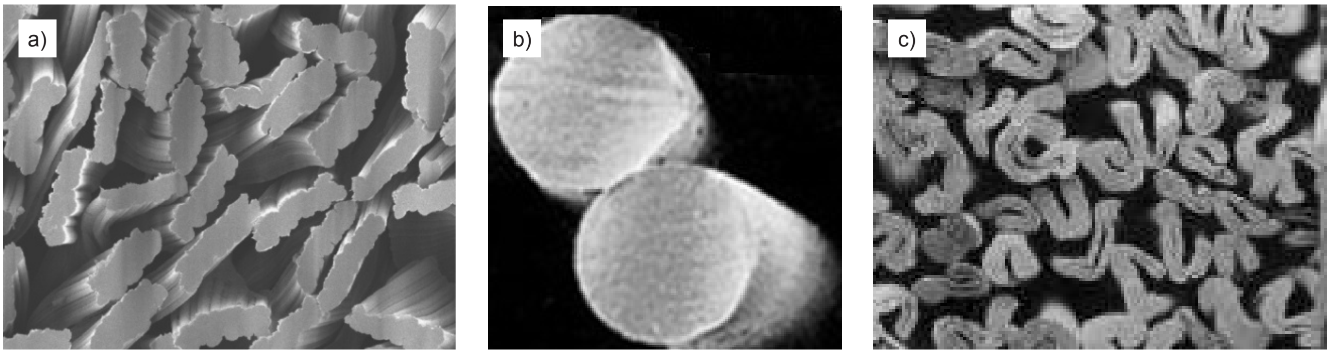

Figure 1. *Cross section views of fibres used in the study; a) Viloft [19], b) polyester, c) cotton.*

Produced by Kelheim Fibres and marketed by Lenzing, Viloft® is a novel regenerated cellulosic fibre known for its thermal insulation properties thanks to its flat fibre cross section (***Figure 1.a***), which provides air chambers in the yarn and fabric. Viloft fibre has a flat cross section and crenulated surface. It is used for functional textiles such as underwear, sportswear, socks, shirts etc [22]. The production of viloft fibre is similar to that of viscose fibre; only the profile of the spinneret used is different. This fibre is also called "thermal viscose" by the producer.

There are various studies regarding blended yarns. However, the properties of blended yarns containing viloft are yet to be investigated thoroughly in the literature. In addition, viloft fibre is commonly used as blends of polyester and cotton in the market. In this study viloft/polyester and viloft/cotton blended yarn properties were examined. For this purpose five different blend ratios of viloft/polyester and viloft/cotton yarns were spun as 19.7 tex on a ring spinning system. Important yarn characteristics such as the breaking force, elongation (%), unevenness and hairiness of these blended yarns were analysed with a simplex lattice mixture model developed and Tukey's test.

Material

Viloft, polyester and cotton were selected as the yarn components in this study. The cross section view of viloft is flat and crenulated, whereas for polyester it is round and that of cotton is bean-like, as seen in ***Figure 1***. The properties of viloft and polyester fibres used in this study are shown in ***Table 1***. Moreover some of the HVI results of the Aegean cotton used in this study are also shown in this table.

Method

Viloft/polyester and viloft/cotton fibres were blended at five different ratios (100%-0%, 67%-33%, 50%-50%, 33%-67% and 0%-100%). Slivers were produced using a Trützschler BOA 046 opener, a DX 903 blowroom and carding machines. Two passage drawing was applied using a Rieter SB-D40 drawframe and Ne 0.15 (3933 tex) slivers were obtained. A Zinser 660 roving frame was used for producing rovings of Ne 1.02 (578 tex). Blended yarns were spun as 19.7 tex on an Edera spinning machine using a twist coefficient of $\alpha_m = 112$.

Mechanical tests (breaking force and elongation) were performed on an Uster Tensojet at a speed of 400 m/min. The unevenness (CVm) and hairiness parameters of the blended yarns were measured by an Uster Tester 5 S800. The tests were performed at 400 m/min speed for 1000 m yarns. Mainly two replications were carried out for the tests and each replication consisted of seven separate measurements of different cops. The mean of the overall replications of mechanical and physical properties of the viloft/polyester and viloft/cotton blended yarns are shown in ***Tables 2*** and ***3***, respectively. Here the CV values of elongation, the breaking force and hairiness are also displayed. Since tenacity is the division of the breaking force to yarn count in tex, CV% values of the breaking force and tenacity are identical. Hence the CV%

Table 1. *Properties of viloft, polyester and cotton fibres.*

Property	Viloft	Polyester	Cotton (HVI)
Linear density, dtex	1.9	1.6	4.47 mic. (~1.76 dtex)
Staple length, mm	38	38	30.1
Tenacity, cN/tex	21.42	53.14	30.3
Elongation, %	19.62	21.18	8.0

Table 2. *Mechanical and physical properties of the viloft/polyester blended yarns.*

Blend proportions		Mechanical properties					Physical properties		
Viloft, %	Polyester, %	Elongation, %	CV, %	Breaking force, cN	Tenacity, cN/tex	CV, %	Unevenness CVm, %	Hairiness [21]	CV, %
100	0	10.8	16.9	279.8	14.2	11.4	15.2	8.2	5.1
67	33	11.6	8.7	431.5	21.9	10.2	14.4	7.9	2.3
50	50	11.7	6.4	529.9	26.9	9.7	13.7	7.1	3.6
33	67	11.8	5.7	594.3	30.2	8.6	13.5	6.6	5.5
0	100	10.5	7.0	664.3	33.8	9.2	12.2	6.6	3.2

Table 3. *Mechanical and physical properties of the viloft/cotton blended yarns.*

Blend proportions		Mechanical properties					Physical properties		
Viloft, %	Cotton, %	Elongation, %	CV, %	Breaking force, cN	Tenacity, cN/tex	CV, %	Unevenness CVm, %	Hairiness [21]	CV, %
100	0	10.8	16.9	279.8	14.2	11.4	15.2	8.2	5.1
67	33	5.4	15.5	243.0	12.7	9.4	14.9	7.1	3.5
50	50	4.9	10.2	250.1	12.4	10.1	15.2	6.9	3.1
33	67	4.3	10.1	268.9	13.7	8.8	16	6.2	3.1
0	100	4.1	8.8	345.0	17.5	10.3	14.2	5.2	3.2

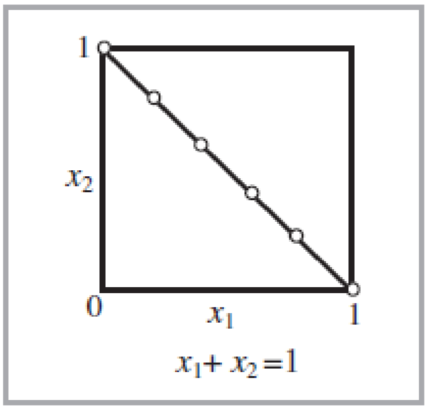

Figure 2. Constrained factor space and design points.

Table 4. Statistical findings for viloft/polyester blended yarn properties.

Yarn property	p-value	Regression equation	R^2
Elongation, %	<0.0001	= 10.78×V + 10.48×P + 5.14×V×P - 1.41×V×P×(V - P)	0.976
Breaking force, cN	<0.0001	= 283.49×V + 663.3×P + 242.32×V×P - 214.54×V×P×(V - P)	0.997
CVm %	<0.0001	= 15.0574×V + 12.208×P - 1.7515×V×P	0.948
Hairiness	<0.0001	= 8.252×V + 6.553×P - 6.21×V×P	0.844

Table 5. Statistical findings for viloft/cotton blended yarn properties.

Yarn property	p-value	Regression equation	R^2
Elongation, %	<0.0001	= 10.76×V + 4.06×C - 11.55×V×C - 9.88V×C×(V - C)	0.994
Breaking force, cN	<0.0001	= 282.9×V + 348.6×C - 252.68×V×C	0.992
CVm %	<0.0001	= 15.073×V + 13.92×C + 3.75×V×C - 9.173×V×C×(V - C)	0.840
Hairiness	<0.0001	= 8.19×V + 5.34×C - 0.255×V×C	0.890

value corresponds to both the breaking force and tenacity in those Tables.

Design Expert 6.02 software was used for analysing the results. A simplex lattice mixture design model was developed by determining the viloft/polyester and viloft/cotton percentages in the yarn structure as mixture components by taking the replication results of the tests into consideration. Simplex designs are used to study the effects of mixture components on the response variable [23]. Taking "*p*" as the component number, here it is $p = 2$, and "x" as the proportion of the component, $0 \le x_i \le 1$; $i = 1, 2$ and $x_1 + x_2 = 1$. A $\{p,m\}$simplex lattice design for *p* components has m + 1 spaced values from 0 to 1, where the number of design points can be calculated as

$$N = \frac{(p+m-1)!}{m!\,(p-1)!} \quad (1)$$

A mixture model for {2,4} can be represented as in ***Figure 2***.

Analysis of variance (ANOVA) was conducted for each fabric property and significance tests were applied at α=0.05 level. In order to compare the means of properties of the blended yarns, a Tukey's test was also conducted at α = 0.05 level. Tukey's test is a single-step multiple comparison procedure generally used with ANOVA to find which means are significantly different from one another [23].

Results and discussions

The p-values, regression equations and R^2 values of the models developed to determine the mechanical and physical properties of viloft/polyester and viloft/cotton blended yarns are given in ***Tables 4*** and ***5*** as statistical findings, respectively. Here p-values of the models less than 0.05 are considered to be significant. As seen in the tables, p-values of the yarn properties are less than 0.05 for the response variables of viloft/polyester and viloft/cotton blended yarns. In other words, the models developed for related yarn properties are significant. Here yarn properties were also given as a regression equation in terms of the blend compounds (Viloft:V, Polyester:P and Cotton:C). In general there are high R-squared values for the results, which indicates that the model developed explains the related yarn property. For instance, the R^2 of viloft/polyester blended yarn elongation is 0.975, which represents the model developed and explains 97.5% of the elongation.

The models developed are significant for all the response variables. However, there is a need for comparison of the properties or response variables of the blend proportions of viloft/polyester or viloft/cotton yarns. In order to carry out Tukey's test, the blended yarns were coded and are indicated in ***Table 6***. Here sample code 1 indicates that the viloft proportion is 0%, and the corresponding polyester or cotton proportion is 100% in the blend. Summarised Tukey's test results are also given in ***Table 7***. Here p-values less than 0.05 are considered to be significant. The terms marked with an asterisk (*) are considered not to be significant due to having p-values higher than 0.05, in which the means of the treatments do not differ statistically. For instance, when investigating the elongation results of viloft/polyester blended yarns, the p-value of the 2 vs. 3 yarn code is obtained as 0.4868, which means the elongation results of the yarns containing 33%/67% and 50%/50% viloft/polyester proportions do not differ statistically at α = 0.05 level.

The properties of viloft/polyester and viloft/cotton yarns are examined and given below, successively.

Elongation

The elongation results of viloft/polyester and viloft/cotton blended yarns are given in ***Figure 3***. Here, changing the blend ratio of actual viloft, polyester and cotton fibres in the blend from 0% to 100% can be seen. It is evident in the ***Figure 3*** that polyester blended viloft yarns have higher elongation values compared to cotton blended ones, which may be related to the elongation values of viloft (19.62%), polyester (21.18%) and cotton (8.0) fibres, shown in ***Table 1***; namely that the elongation of polyester and viloft fibres are close to each other and higher than that of cotton.

As the viloft fibre proportion increases in the yarn structure, elongation increases and the maximum is reached for 100% viloft in viloft/cotton blends. For viloft/polyester blends, the elongation is low for pure polyester (100%) and viloft (100%) yarns; however, the blended yarns (33/67, 50/50 and 67/33) are close to each other and higher than those of pure ones. This is mainly due to air gaps between viloft and polyester fibre in the yarn structure, which increases the elon-

Table 6. Blended yarn codes.

Yarn code	Viloft proportion	Polyester proportion	Cotton proportion
1	0	100	100
2	33	67	67
3	50	50	50
4	67	33	33
5	100	0	0

gation value of the blended yarn. However, pure yarns have a compact structure compared to blended ones.

Breaking force

Since one type of yarn count is investigated in this study, only the breaking force in cN is analysed. Tenacity in cN/tex is simply the division of the breaking force in cN to yarn count in tex. However, tenacity results are also shown in ***Tables 2*** and ***3***. The breaking force can be described as the applied force at the break of the yarn. Breaking force results of viloft/polyester and viloft/cotton blended yarns are given in ***Figure 4***. It is clear in the figure that polyester blended viloft yarns have higher elongation values compared to cotton blended ones, which may be related to the tenacity values of viloft (21.42 cN/tex), polyester (53.14 cN/tex) and cotton (30.3 cN/tex) fibres shown in ***Table 1***; namely that polyester has the highest tenacity whereas viloft has the lowest. Cotton fibres have a medium degree of tenacity compared to polyester and viloft.

By increasing the viloft fibre proportion in the yarn structure, the breaking force decreases and minimum elongation is reached for 100% viloft for viloft/polyester blends, which may simply be related to the fibre tenacity values mentioned above. However, for viloft/cotton blends, the maximum breaking force is obtained for pure cotton. Increasing the viloft fibre proportion in the blend decreases the breaking force, with the minimum value obtained for 67%/33% viloft/cotton blend, which may be related to the tenacity values of viloft and cotton fibres shown in ***Table 1***. However, further increasing the viloft fibre proportion increases the breaking force. Since viloft has a flat cross section, that of the yarn will be in a compact form when using pure viloft.

Microscopic analysis indicated that there will be gaps between viloft/polyester and viloft/cotton fibres since polyester and cotton fibres are located between the viloft fibres and air gaps occur. In ***Figure 5*** cross section views of 67%/33% viloft/cotton, viloft/polyester blends and 100%/0 pure viloft blended yarn are shown. Cotton and polyester fibres create gaps between the viloft fibres, as seen in ***Figures 5.a*** and ***5.b.*** However, a compact structure of the yarn cross section can be seen when using pure viloft (100%), as shown in ***Figure 5.c***. For this reason, viloft fibre is used as blends of polyester and cotton in the market for a thermal insulation point of view. The blends of viloft create air chambers in the yarn and thermal insulation is maintained. The slight increase in the breaking force for

Table 7. *Tukey's test results (p-values).*

Comparison	Viloft/polyester blend				Viloft/cotton blend			
	Elongation	Breaking force	CVm%	Hairiness	Elongation	Breaking force	CVm%	Hairiness
1 vs 2	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0061	< 0.0001	< 0.0001	0.0004
1 vs 3	< 0.0001	< 0.0001	< 0.0001	0.0153	< 0.0001	< 0.0001	< 0.0001	< 0.0001
1 vs 4	< 0.0001	< 0.0001	< 0.0001	**0.1283***	< 0.0001	< 0.0001	< 0.0001	< 0.0001
1 vs 5	0.0073	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
2 vs 3	**0.4868***	< 0.0001	0.0184	0.0007	< 0.0001	< 0.0001	< 0.0001	< 0.0001
2 vs 4	**0.2748***	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
2 vs 5	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0036	< 0.0001	< 0.0001
3 vs 4	**0.0899***	< 0.0001	< 0.0001	**0.3214***	0.0023	0.0368	**0.1201***	**0.6343***
3 vs 5	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	**0.3408***	< 0.0001
4 vs 5	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	**0.5323***	< 0.0001

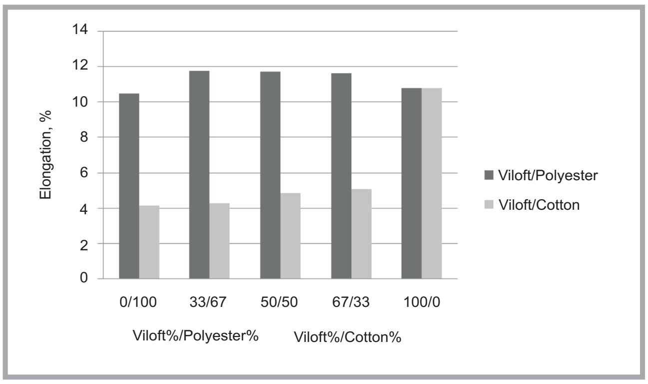

Figure 3. *Elongation (%) variation of viloft-polyester and viloft-cotton blended yarns.*

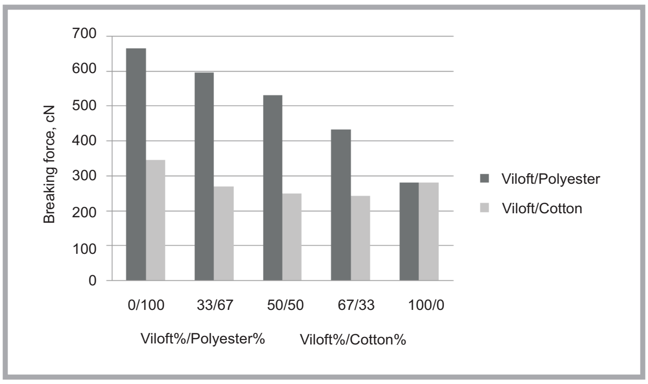

Figure 4. *Breaking force variation of viloft-polyester and viloft-cotton blended yarns.*

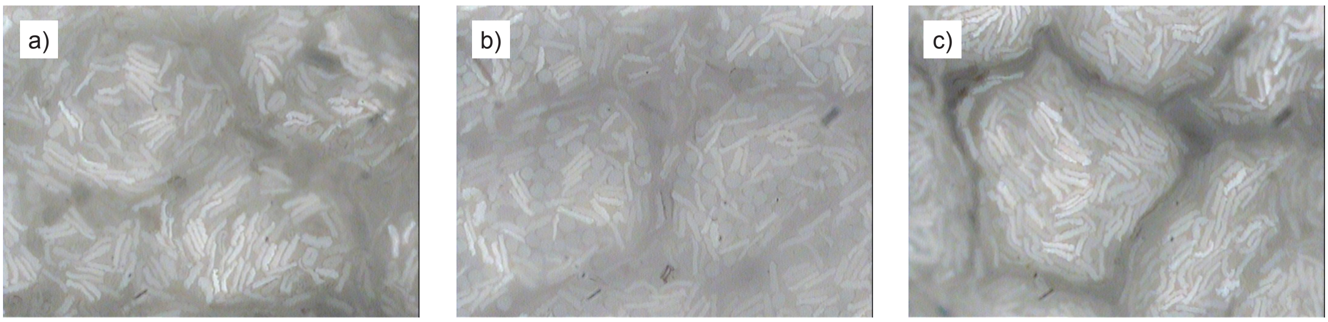

Figure 5. *Magnified cross sections of selected blended yarns; a) 67%/33% viloft/cotton, b) 67%/33% viloft/polyester, c) pure viloft (100%).*

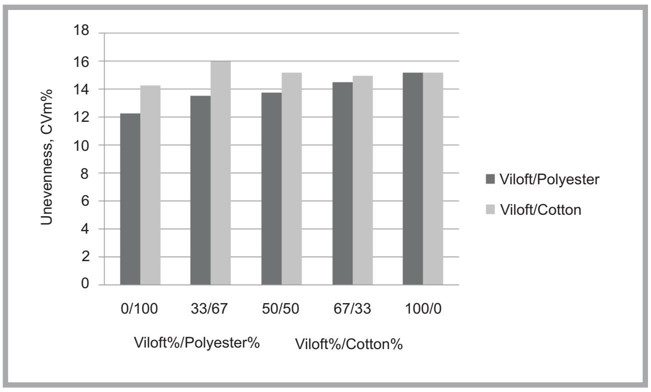

Figure 6. Unevenness - CV_m (%) variation of viloft-polyester and viloft-cotton blended yarns.

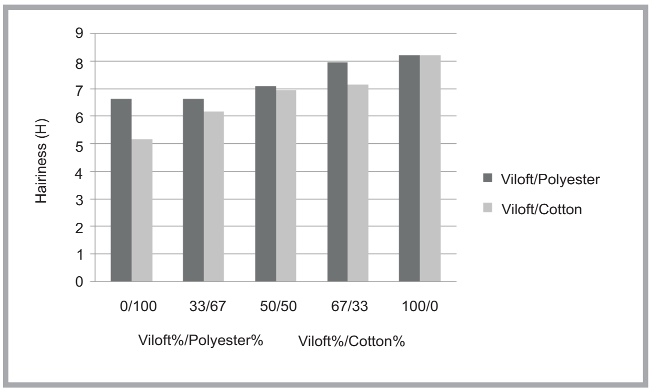

Figure 7. Hairiness variation of viloft-polyester and viloft-cotton blended yarns.

viloft/cotton when using pure viloft can be related to the increase in fibre-to-fibre friction in the yarn structure due to the crenulated surface of viloft fibres and the compact form of fibres in the yarn structure.

Unevenness - CVm (%)

The mass or weight variation per unit length of yarn is defined as unevenness or irregularity. The coefficient of variation of the mass (CVm%) is the calculation method to determine the variation of mass for yarns [24]. CVm % results of viloft/polyester and viloft/cotton blended yarns are given in ***Figure 6***. It is inferred from the figure that polyester blended viloft yarns have lower CVm % values compared to cotton blended ones. Unevenness increases when using cotton in the blend. Unevenness in blended yarns depends mainly on the physical properties of fibres (fibre cross section deviation, length and length uniformity etc.), the number of fibres as well as on the fibre location or positioning in the yarn cross section and blend ratio. The length of polyester, viloft and cotton fibres was 38 mm, 38 mm and 30.1 mm, meaning that the viloft and polyester fibres were longer than cotton ones. In addition, due to having a flat cross section and crenulated surface, viloft fibre can resist the packing of yarn. Hence variation can occur in the cross section of the yarn by changing the blend ratio.

Hairiness

Hairiness can be identified as fibres protruding from the main body of the yarn [25]. In this study, an Uster Tester-5 was used and hairiness (H) was calculated as the total length in centimetres of all hairs within one centimetre of yarn. The hairiness results of viloft/polyester and viloft/cotton blended yarns are given in ***Figure 7***. It can be inferred from the figure that viloft-polyester blended yarns show higher hairiness than cotton blended ones. In addition, increasing the viloft proportion in the yarn structure results in more hairiness in both cotton and polyester blends. The maximum hairiness was obtained in pure viloft, which may be related to the cross section of viloft fibre, since it has a flat form. Hence the rigidity of the fibres increases and keeping the fibre in the yarn body will be difficult. Viloft fibres tend to protrude from the main body of the yarn and hairiness occurs.

Viloft-rich blended yarns have high hairiness values. Viloft fibre enhances air gaps in the yarn structure when using polyester and cotton in the blend and maintains thermal insulation, as mentioned above. However, hairiness on the yarn structure also creates air gaps in the fabrics. Hence thermal insulation is provided not only by air gaps in the yarn structure but also by those in the fabrics produced.

Conclusions

In this study polyester and cotton blends of a novel fibre called "viloft", which has a flat cross section and crenulated surface, used mainly for its thermal insulation properties in fabrics, were examined. Mechanical and physical yarn properties such as the breaking force, elongation, unevenness and hairiness values were examined using a simplex lattice mixture model and Tukey's test. According to the statistical study, the blend ratio is significant for elongation, breaking force, CVm% and hairiness properties for both vioft/polyester and viloft/cotton blended yarns. However, Tukey's test indicated that a few of the blends of viloft/polyester or viloft cotton yarns do not differ from each other, statistically. The regression equations developed can be used to determine the properties of polyester or cotton blended viloft yarn before production.

Polyester blended viloft yarn shows higher breaking force and elongation values compared to cotton blended ones. The breaking force decreases when increasing the viloft proportion in polyester or cotton blends. Fibre characteristics such as fibre tenacity and elongation play an important role in the elongation and breaking force properties. However, the flat cross section and crenulated surface of viloft fibre affect the breaking force of the yarn. Fibre-to-fibre friction forces increase with using pure viloft.

Polyester blended viloft yarns have lower CVm % values compared to cotton blended ones. In general increasing the viloft proportion in the blend increases unevenness, which may be related to the flat cross section and crenulated surface of viloft fibre, thereby resisting the packing of the yarn. Hence variation may be obtained in the cross section of the yarn by changing the blend ratio.

Viloft fibre enhances air gaps in the yarn structure when using polyester and cotton in the blend and maintains thermal insulation. However, hairiness on the yarn structure will also create air gaps in the fabrics. Viloft-rich blended yarns have high hairiness values. Hence thermal insulation is provided not only by the air gaps in the yarn structure, but also by those in the fabrics produced when increasing the viloft proportion in the yarn blend.

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