Mechanical and FR Properties of Different Ratios of Cotton/Polysulfonamide (PSA) Core Spun and Blended Yarns

Lloyd N. Ndlovu, Cunchao Han, Chongwen Yu

College of Textiles, Donghua University, Shanghai CHINA

Correspondence to:
Chongwen Yu email: yucw@dhu.edu.cn

ABSTRACT

The textile and its allied industries have had its research focus on ways of alleviating the risks and losses posed by uncontrolled fires. Textiles have been chemically modified to impart flame/fire retardancy (FR) properties and also studies have been done on inherently FR fibers. This research focuses on Polysulfonamide (PSA) fiber, an inherently FR fiber developed by Shanghai Textile Research Institute and Shanghai Synthetic Fiber Research Institute. The purpose of this research is to study ways of incorporating PSA into yarns that will utilize the benefits of the PSA fiber while compensating for its limitations. The 100% PSA yarn and five different percentage variations of PSA/cotton blended yarns were produced by ring spinning. The blending methods were intimate blending and core spinning, with cotton yarns being used as core and PSA fibers as sheath. The tensile, evenness, hairiness and FR properties of these yarns together with the blending methods were studied and compared. The results showed that the blended yarn yielded better tensile and hairiness properties whereas the core spun yarn had better evenness and flame retardancy properties.

Keywords: blend ratio, blended yarn, core spun yarn, flame retardancy (FR), Polysulfonamide (PSA) fibers

INTRODUCTION

Polysulfonamides (PSA) fiber is a high-temperature resistance fiber initially developed in China by Shanghai Textile Research Institute and Shanghai Synthetic Fiber Research Institute in 1974 [1,2]. It has the conjugated aromatic rings and the additional sulfone group structure in its molecular main chain PSA fiber cannot be easily destroyed at high temperature hence its better performance in thermal stability than aramid fiber [3,4]. The limiting oxygen index of PSA fiber may reach up to 33, higher than that of nomex fiber. However, the fiber has high VSR (volume specific resistance) and initial modulus, instability of crimp and low friction coefficient, which makes processing difficult in spinning and fabric formation. Despite good tensile properties, yarns made from PSA have high hairiness properties because of the static charge in the fibers[5].Industrial and academic research activities are focusing in developing efficient flame retardant systems for blends of PSA fibers, since this issue is also of very considerable economic importance. The outcome so far is, some fibers can be blended with PSA fibers to achieve acceptable properties for protective textiles [6,7]. This study is therefore a continuation of research on utilization of the benefits of the PSA fiber while compensating for its limitations.

METHODS

Materials

The materials used were Polysulfonamide (PSA) fibers (length 51 mm, fineness 1.96 dtex, tenacity 4.23 cN/dtex, elongation 25.11%) and cotton fibers (average length 29.5 mm, fineness 1.44 dtex, tenacity 4.03 cN/dtex, elongation 7.41%). Five different counts of combed cotton ring spun yarns (spun by Handan cotton spinning mill in China) were used as cores for core spinning and their properties are shown in *Table I*. Flame Retardant Finishing Agent FPK8001 (supplied by Herst International Group in Shanghai) was used for yarn finishing.

TABLE I. Properties of combed ring spun cotton yarns.

Properties	Yarn linear Density (tex)				
	5.9	7.8	9.8	11.8	13.8
Composition to PSA/cotton yarn (%)	85/15	80/20	75/25	70/30	65/35
Evenness (%)	15.97	15.60	14.45	15.14	14.99
Tenacity (cN/tex)	23.38	23.37	18.76	18.59	16.50
Variation of Tenacity (CV%)	7.03	6.96	6.60	7.19	6.56
Elongation at Break (%)	4.74	5.18	5.37	6.01	5.49

Yarn Preparation

Five PSA/cotton fibers with percentage ratio of 85/15; 80/20; 75/25; 70/30; 65/35 were spun to produce a 39 tex yarn for both intimate blended yarn and core spun yarn. Intimate blending for each PSA/cotton percentage ratio was done at the carding stage and then drafted and drawn into sliver in draw frames. The slivers were converted to rovings and then ring spun into yarns. 100% PSA fibers were also carded, drafted and converted into roving. Some of the roving was spun into 100% PSA yarn and some used as sheath to cover the cotton cores to produce five different variations of PSA/cotton yarns.

Test Procedures

The yarn samples' tensile properties were tested in accordance to ASTM D2256-01 standards using YG061 electronic yarn strength tester. Each sample was clamped at a clamping distance of 500 mm and a force applied to it until it broke. The samples were tested 50 times each and their tensile properties were obtained. Yarn evenness testing was done according to ASTM D1425-96 standards using YG135G evenness test analyzer. Each yarn sample of length 400 m was passed through the sensing device of the evenness tester at constant speed of 200 m/min. The yarn irregularity properties were obtained. Yarn hairiness was tested using the YG172 yarn hairiness tester in accordance to ASTM D5647-01 standards. The hairiness tester recorded hairiness index per 10m of a 100 m yarn sample at a speed of 30 m/min. The average results of the hairiness index were noted.

Related studies have shown that the fabric FR properties mainly depend on the raw material used [8]. Therefore, preliminary FR testing of yarns can be used to predict and give an overview of the FR performance of the resulting fabrics [6]. Beroes [9] postulated that textiles burn more slowly in the horizontal direction than inclined or at 45 degrees angle. The reason being that the heat energy producing hot pyrolysis gas cannot rise into the material to pyrolyse it. Therefore an inclined 45 degrees and/or vertical flammability testing can give a better evaluation on FR properties of textiles. However, in this study, an inclined 45 degrees angle was used since the sample could be clamped at both ends at a controlled tension. *Figure 1* depicts an improvised simpler and quicker method used to test and evaluate the FR properties of yarn. A horizontal FR tester equipment was used to test the yarn samples at an inclined angle of 45 degrees. 120 yarns were slightly twisted together to form a yarn bundle which was used as a sample. The yarn bundle, 70.7 mm in length, was then clamped in a sample holder at an angle of 45 degrees and then exposed for 3 seconds to a flame of length 45 mm as shown in *Figure 1*, the flame was withdrawn and the burning with flame and without flame times were recorded. The damaged length was measured and noted. The experiment was repeated eight times for each of all the ratios of PSA/cotton blended and core spun yarns including the 100% PSA. The yarns were then treated with a 50% (o.w.f) FPK 8001 FR finish as specified by the material safety data sheet (MSDS) supplied by Herst International Group. The treatment was done by dipping the yarns for 10 minutes in a solution of FPK 8001 and then dried in oven at 100 °C for 30 minutes. The FR testing was repeated the same way it was done on unfinished yarns.

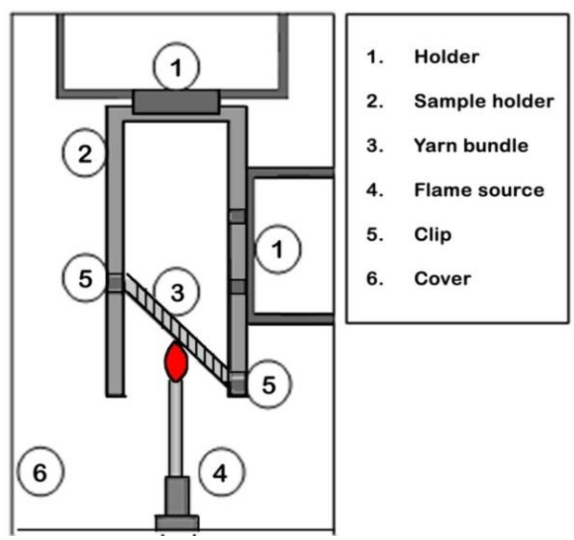

FIGURE 1. Schematic diagram of improvised flame retardant yarn tester.

Thermogravimetry analysis (TGA) was carried out using NETZSCH TG 209F1 instrument on 100% PSA yarn, 15/85, 25/75, 35/65 blend ratios of core spun and blended yarns. Each sample weighing 5mg was heated from ambient temperature to 800°C in nitrogen atmosphere. Thermograms were recorded under temperature rise rate of 10°C per minute. Analysis on sample weight loss was carried and thermograms were obtained.

RESULTS AND DISCUSSION

Tensile Properties

The tensile properties of blended yarns are related to the blend ratios, the corresponding tensile properties of each component and the interactions of the components themselves. In *Figure 2* and *Figure 3*, the tenacity and breaking elongation for both the core spun yarn and the blended yarn reduce as the PSA percentage ratio is reduced. This trend is the same for both the blended yarn and the core spun yarn. PSA has higher breaking strength and elongation than the cotton fibers hence it (PSA) contributed more strength and elongation percentage in the yarn. Since the cotton fibers have lower strength and elongation than the PSA fiber, both the PSA/cotton core spun and blended yarn will have reduced strength and elongation as cotton percentage ratio is increased. The blending of a relatively weaker fiber (cotton) with a stronger fiber (PSA) leads, as expected, to some losses in yarn strength. The loss of strength in the blended yarn is attributed to the differences in the breaking elongation of both cotton and PSA fibers. When the PSA/cotton yarn was subjected to increasing load, the cotton fibers with smaller elongation broke first, and then PSA fibers were exposed to entire load. The remaining PSA fibers in the yarn were not enough to carry the entire load, which lead to a loss of strength in the PSA/cotton yarn.The PSA/cotton blended yarn has higher breaking strength and elongation than the core spun yarn at all blend ratios. The intimately blended PSA and cotton fibers in the blended yarn work together to share and distribute the load throughout the yarn hence good strength and elongation properties [10]. Ruppenicker et al. [11] postulated that the core contributes more to tensile properties since it carries most of the load. Therefore in this study, the lower strength cotton core in the core spun yarn causes a reduction in strength and elongation. Fiber length and length uniformity have an influence on yarn strength [12], because they affect yarn evenness. The blended yarn showed a slight increase in unevenness with increase in cotton ratio (*Figure 4*). Unevenness affects the twist distribution and hence reduces the strength and elongation in blended yarn. Despite the losses in tensile properties, the results prove to be better when compared with other inherently FR fibers blended with cotton. The tensile properties of PSA/cotton are better compared to Basofil/cotton yarn [13]. The breaking elongation is also higher than that of Kevlar/cotton yarn, although Kevlar/cotton yarns have better tenacity[14].

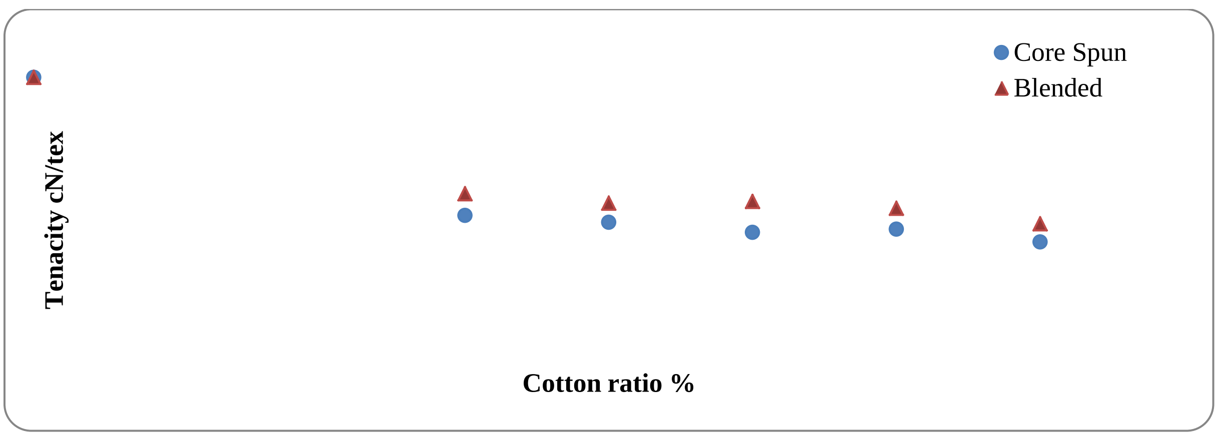

FIGURE 2. Tenacity of core spun yarn and blended yarn at different PSA/cotton ratios.

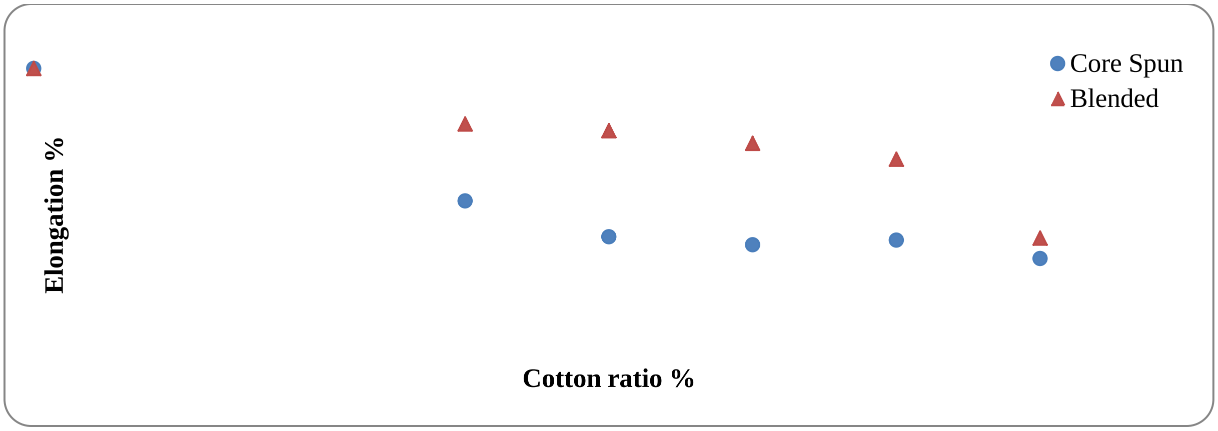

FIGURE 3. Elongation at break of core spun yarn and blended yarn at different PSA/cotton ratios.

Evenness

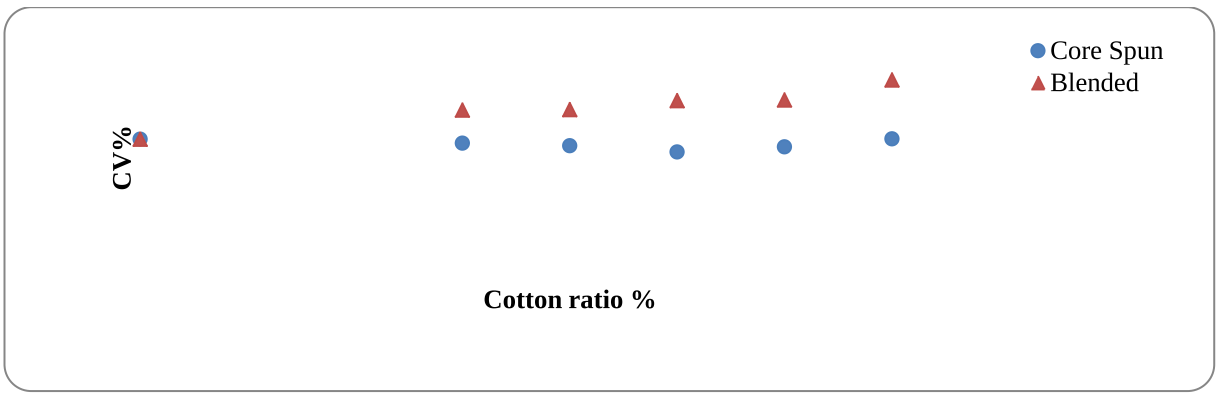

FIGURE 4. Evenness of core spun yarn and blended yarn at different PSA/cotton ratios.

Yarn evenness which basically deals with the variations in yarn fineness, is one of main indexes that determine the quality of yarns and fabrics. The unevenness of yarns deteriorates the strength of the yarn, increase the end breakages during fabric formation and hence reduce the productivity. Unevenness of yarns can also influence the appearance quality of textiles. Yarn evenness variations, especially in blended yarns, are inevitable because they arise from the fundamental nature of the constituent fibers and from their resulting arrangement in the yarn. *Figure 4* shows that the core spun yarn has better evenness properties than the blended yarn. This is because combed cotton yarns with good and almost similar evenness properties (*Table I*) were used as cores in the core spun yarn. Thus the core spun yarn has better evenness properties despite the changes in PSA/cotton blend ratio. The unevenness of the blended yarn increased slightly as the cotton ratio increased in the yarn. This was caused by the differences in nature of cotton fibers and the PSA fibers and also by the mechanical constraints. Douglas [15] stated that there is close correlation between fiber fineness and yarn evenness. In this case the cotton fibers and the PSA fibers have different fineness which in turn affects the yarn evenness. Fiber length, length variations and variations in the number of fibers in the yarn cross section affect yarn evenness [16]. The effect can be explained by the floating fiber mechanism, thus fibers not held by either nip point are not properly drafted which decrease the evenness properties [17]. In this case where drafting rollers are set to accommodate the long length PSA fibers, the floating fiber mechanism is likely to occur due to the presence of cotton fibers which are much shorter than the PSA fibers. The PSA/cotton blended yarn therefore has low fiber length uniformity. Thus increase of cotton fibers in the PSA/cotton blended yarn means an increase in the short fiber content and hence an increase in yarn unevenness which is seen from the obtained results.

Hairiness

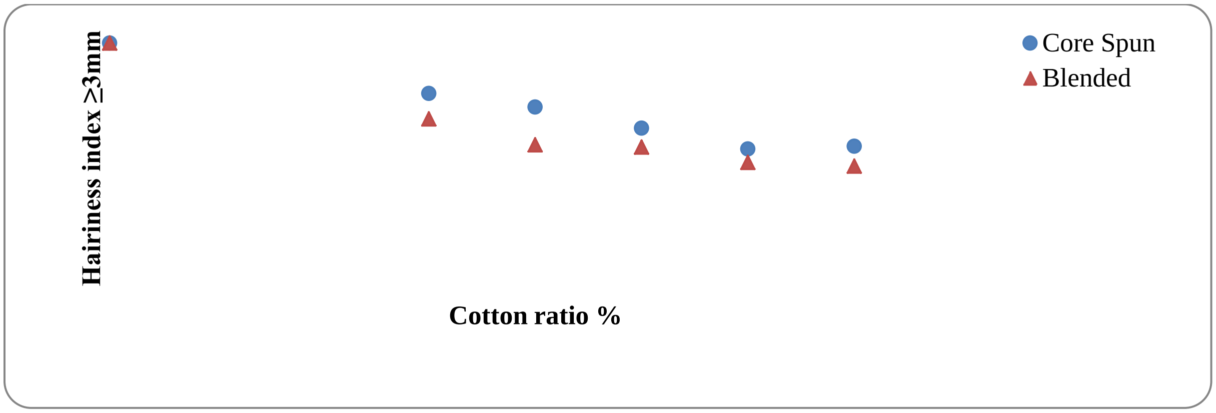

FIGURE 5. Hairiness of core spun yarn and blended yarn at different PSA/cotton ratios.

Hairiness is an important aspect as it adversely affects the appearance of yarns and fabrics. It is one of the factors that determine the appearance grade of the yarn, thus higher hairiness downgrades yarn appearance grade. Hairiness can be influenced by the characteristics of the fibers.

Blending has been found to have a significant effect on yarn hairiness. Jackowski [18] found blended yarns have higher hairiness than yarns made from component fibers. Conversely, Barella and Vigo [19] found that hairiness was more in polyester than cotton yarn and intermediate for their 50/50 blend. of these fibers has an value. The differences in these findings may be attributed to the differences in fiber fineness and length of the blended fibers. Most synthetic fibers are prone to static generation which generally results in more hairy yarns because of repulsion of fibers. This is the reason why most synthetic fiber yarns are more hairy than natural fiber yarns [20]. Thus PSA yarns have been found to more hairy than other synthetic yarns. The problem of yarn hairiness is one of the key factors that devaluate the PSA yarn quality [5] In *Figure 5*, the hairiness index seems to reduce with the reduction in the ratio of PSA fibers for both core spun and the blended yarn. PSA fibers tend to accumulate a static charge during processing which might cause some difficulties of the fiber adhering on the yarn surface and henceforth causing hairiness. Therefore higher percentage ratio of PSA fibers in the yarn will yield higher hairiness[5]. With all being said, the blended yarn has better hairiness properties than the Core spun yarn. This is because the blended yarn has both cotton and PSA fibers on its surface whereas the core spun yarn has PSA fibers as the sheath. Thus the cotton fibers on the blended yarn’s surface help decrease hairiness.

Flame Retardancy (FR)

TABLE II. Flame retardancy results for blended and core spun yarn at different PSA/cotton ratios.

Parameter	Yarn state	Yarn Type	PSA/cotton ratio (%)					
			100/0	85/15	80/20	75/25	70/30	65/35
Burning with flame time (s)	Unfinished	100% PSA	0	-	-	-	-	-
		Core spun	-	0	0	0	0	0
		Blended	-	0	0	0.5	0.6	1.7
	Finished	Core spun	-	0	0	0	0	0
		Blended	-	0	0	0	0	0
Burning without flame time (s)	Unfinished	100% PSA	0	-	-	-	-	-
		Core spun	-	0	0	0	0	0
		Blended	-	0	0	0.2	0.2	0.3
	Finished	Core spun	-	0	0	0	0	0
		Blended	-	0	0	0	0	0
Average damage length (mm)	Unfinished	100% PSA	7.8	-	-	-	-	-
		Core spun	-	14.1	16.8	17.6	18.9	20.0
		Blended	-	20.0	20.5	20.8	21.9	23.4
	Finished	Core spun	-	14.3	16.3	17.4	18.3	18.9
		Blended	-	18.3	19.4	20.3	20.9	21.0

Table II shows that the core spun yarn has better FR properties than the blended yarn for both finished and unfinished yarn bundles. This is because the PSA fiber, which is a flame retardant fiber, is used as the sheath of the core spun yarn. The finished and unfinished core spun yarn, for all different PSA/cotton percentage ratios, did not burn during the experiment. However the yarn bundles for all the different PSA/cotton percentage ratios experienced some damages due to the flame exposure. There was also a slight change in the damage length between the finished and unfinished core spun yarns. The finished core spun yarns yielded better results than the unfinished core spun yarns. The measured damage length increased with the reduction of PSA percentage ratio. On the other hand the finished blended yarn had better results than the unfinished blended yarn in both burning time and damage length tests. The unfinished blended yarn started to experience burning (with/without flame) from the 75/25 to 65/35 blend ratios. The burning time increased with the increase in cotton ratio, this is because cotton fibers have lower LOI value as compared with the PSA fibers [1,2]. All the FR tests proved that the PSA fibers provide good FR properties to the yarn.

Thermogravimetric Analysis (TGA)

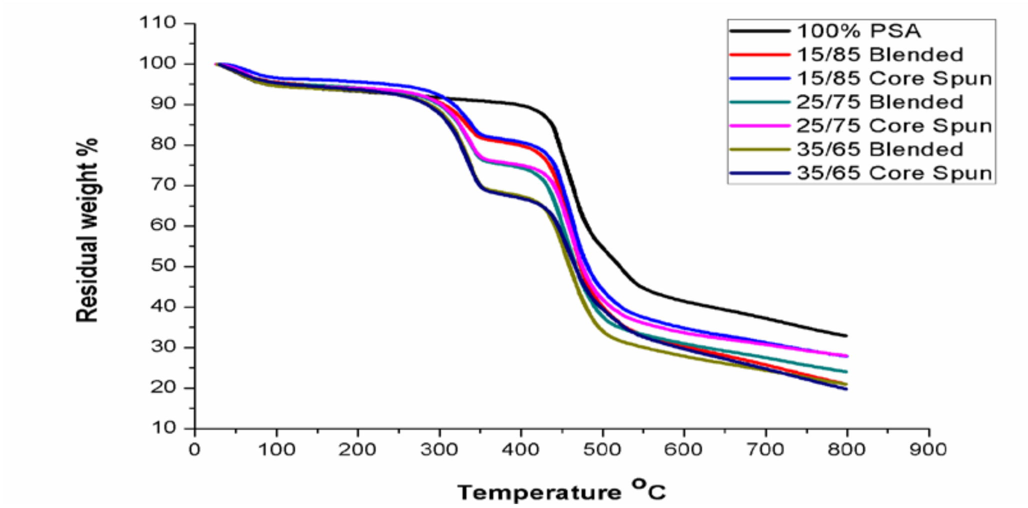

FIGURE 6. Themogravimetic analysis of different ratios of unfinished corespun and blended yarns.

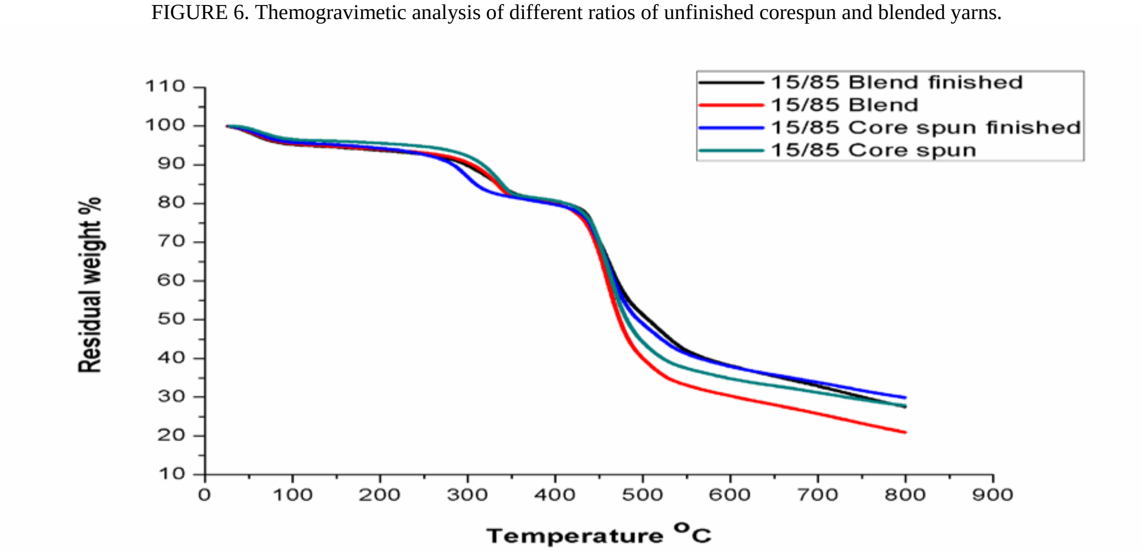

FIGURE 7. Themogravimetic analysis of 15/85 PSA/cotton ratio of finished corespun and blended yarns.

For the thermogravimetric analysis results in *Figure 6* and *Figure 7*, the thermograms are divided into three sections. Section one is between 37ºC and 100ºC, followed by a plateau section and then second section between 280ºC and 500°C. Finally, the third section which is between 500ºC and 800ºC. In the first section, the 100% PSA thermogram show a very low weight loss caused by dehydration of the PSA fibers. As the temperature increased, PSA polymer chain segment movement rate gradually increased. In the second section, weight loss rate began to accelerate. The PSA polymer chains began to break thereby generating smaller molecules and releasing gases, thus causing a major weight loss. This major weight loss began at the PSA decomposition temperature of around 420°C, slightly higher than that of Nomex and Aramid 1313, which shows better thermal performance of PSA[21,22]. In the third section, Weight loss rate was gradually decreased. The PSA/cotton blended yarn and core spun yarn showed the same trend. The increase of cotton ratio in the yarn presented a reduced trend. Core spun yarn showed better thermal decomposition than blended yarns because of the PSA sheath. In the first section of the curve, The mass loss observed is mainly due to dehydration of the fibers. In the second section, the trends show a steep increase in weight loss rate. The mass loss is due to thermal decomposition into gases (SO_2, N, H_3 or CO_2) and carbonaceous char in case of PSA; in case of cotton, oxidative decomposition into gases (CO, CO_2) and formation of carbonaceous char [23,24].

It can be noticed that in the second section, there are two distinctive weight losses in the sample trends, thus between 280°C and 350°C and between 400°C and 400°C for the first and the second part respectively. The first one is due to the thermal degradation of cotton which begins at a lower temperature than that for PSA thermal degradation. Thus the cotton acts as initial source of ignition in the PSA/cotton yarns. The second one, the mass loss is mainly due to complete decomposition of cotton and partial decomposition of PSA. As the temperature is raised, heat is produced from the combustion of cotton decomposition products. The PSA component supply an additional fuel to a gas phase which then increase energy of gas phase oxidation. In the third section the rate of weight loss is reduced. In this section, the char component undergoes oxidative decomposition resulting in weight loss. At 800 °C, the remaining weight is between 20% and 35%, with blends having high ratio of PSA showing greater remaining weight. The thermal degradation of PSA and its cotton blends can be compared with other inherently FR fiber blends. The decomposition temperature for nomex, and its Lenzing viscose blends was between 220°C and 400°C and the wool/PPTA blends were completely decomposed at a temperature around 600°C [22,25]. Thus PSA and its cotton blends showed superior thermal degradation results compared to Nomex, Nomex/Lenzing viscose blends, and wool/PPTA blends.

In *Figure 7* it can be noticed that the thermograms for the finished core spun and blended yarn have no significant difference. However when compared to their unfinished counterparts, they show better thermal degradation. This proves that FR finish played a significant role in thermal degradation of the core spun and blended yarns.

CONCLUSION

The blended yarn yielded better tensile and hairiness properties whereas the core spun yarn had better evenness, FR and thermal properties. Thus either core spinning or intimate blending can be used with regard to the desired yarn properties. Blending PSA and cotton reduces tensile, FR and thermal properties of PSA, however the yarn hairiness is improved. PSA can therefore be blended with cotton to attain desired and acceptable yarn properties in a cost effective way.

REFERENCES

[1] Chen, Z.; Wang, X. F.; Flame Retardance and Thermal Stability of Polysulfonamide Fiber, *Synthetic Fiber in China,* 40, 2011, 11.

[2] Liu, L.; Zhou, J.; Gao, T.; Recent Advance in Study of Polysulfonamide, *Journal of functional materaials*, 42, 2011, 5.

[3] Wang, X. F.; Zhang, Y. H.; Properties and application of aramid fibers, *China Textile Leader*, 1, 2005, 18-23.

[4] Zhang, L.; Li, Y. B.; Liu, J. Z.; Research on heat resistance of polysulfonamide fibers, *Tianjin Polytechnic University*, 25, 2006, 17.

[5] GAO, J.; Wang, F. Q.; Research on PSA yarn hairiness reduction by use of sirospun, *Shanghai Textile Science & Technology*, 2006, 07.

[6] Zhu, Y. Q et al..; Design of polysulfonamide fire-retardant yarn, *Progress in Textile Science and Technology*, 2008, 6.

[7] LIU, S. R.; Properties of flame-retardant fabrics for semi-worsted polysulfonamide/wool blended fabric, *Wool Textile Journal*, 2010, 11.

[8] Weimin, S; Huang, X. A.; Peilan, C.; Flame retardant fiber and fabric, *Textile Industry Press* 247, 1990, 32.

[9] Beroes, C. S.; The dangerous flammable fabrics: Burning ourselves, our children and our senior citizens, AuthorHouse, 2004, 3.

[10] Rhodes, P. L.; Graham, C. O.; Evaluation of Cotton/Kevlar Blends, *Textile Research Journal*, 49, 1979, 28.

[11] Ruppenicker, G. F. et al; Comparison of Cotton/Polyester Core and Staple Blend Yarns and Fabrics, *Textile Research Journal*, 59, 1989, 12.

[12] Ahmed, I.; Nawaz, S. M.; Tayyab, M.; Interaction study of staple length and fineness of cotton with ultimate yarn regularity and hairiness, *Journal of Applied Sciences 4*, 1, 2004, 48-52.

[13] Murugesan, B.; Gowda, R. V. M.; Characterization of Flammability and Low Stress Mechanical Properties (Compression and Shear) of Basofil Fibers and its Blends, *Chemical Science Review and Letters* 2012, 1(1), 35–44.

[14] Ruppenicker, G. F.; Development of high cotton-content fire-retardant fabrics for navy protective clothing. *Technical report / navy clothing and textile research facility 1992.*

[15] Douglas; Measurement of the quality characteristics of cotton fibers, *Uster News Bulletin, Zellweger Uster AG* 38, 1991, 12-18.
[16] Yang, S.; Gordon, S.; Wu, L.; Cottonspec-A cotton fiber and yarn quality management tool; 2011 Beltwide Cotton Conference, Altanta, United States, 4-7 January 2011. *National Cotton Council of America*. 1486-1494.
[17] Chen, K. Z.; Huang, C. Z.; Chen, S.; Developing a New Drafting System for Ring Spinning Machines, *Textile Research Journal*, 70, 2000, 154.
[18] Jackowski T.; *Textol Textile Industry, USSR*, 5, 1961, 28.
[19] Barella A. and Vigo J. P.; *Annual, Science, Text, Belges*, 23, 1975, 133.
[20] Das D.; Ishtiaque S. M.; Mac T.; D Viet; Gries T.; A Quick Reliable and Economic Method for Evaluating the Properties of Rotor Spun Yarns, *Autex Research Journal*, 4, 3, 2004, 123.
[21] Sui W. M.; Huangxiang A., Chen P. L.; Flame retardant fibers and fabrics, Beijing: *Textile Industry Press*, 1990, 247-249.
[22] Gu H.; Research on thermal properties of Nomex/Viscose FR fiber blended fabric, *Materials and Design* 30, 2009, 4324–4327.
[23] Ying Z. X., Cheng J., Zhao J. B.; Polymer Chemistry, Beijing, *China Light Industry Publishing Press*, 2000, 285.
[24] Gu H.; Research on thermal properties of Nomex/Viscose FR fiber blended fabric, *Materials and Design* 30, 2009, 4324–4327.
[25] Flambard X; Bourbigot S.; Ferreira M.; Vermeulen B.; Poutch F.; Wool/para-aramid fibers blended in spun yarns as heat and fire resistant fabrics, *Polymer Degradation and Stability* 77, 2002, 279–284.

AUTHORS' ADDRESSES
Lloyd N. Ndlovu
Cunchao Han
Chongwen Yu
College of Textiles
Donghua University
2999 North Renmin Road
Shanghai 201620
CHINA