EFFECT OF CORE TYPE AND SIZE ON MECHANICAL PROPERTIES OF COMPOSITE FRICTION SPUN YARNS

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Abstract - Composite yarns consist of two distinct components, i.e., core and sheath. Different types and combinations of core and sheath are used to make composite yarns with varying properties. In this paper the focus is on selected parameters that influence the mechanical properties of DREF 3 composite yarns. Core material and yarn linear density were changed to make 18 different types of composite yarns having linear densities 118, 98 and 84 tex. Two types of core materials stainless steel (S.S) and E-glass were used having linear densities 11, 17 (0.4 & 0.5 micron) and 5.5, 11, 17, 33 tex respectively. Sheath material was Kevlar®29 in all the yarns. The sheath portion was kept between 95% and 60%. The performance test selected for these yarns was tensile strength. Mechanical tests of the yarns were statistically analyzed and the analysis showed a significant effect of core type and core-sheath ratio on tensile properties of composite yarns. Tensile strength of the composite yarns significantly improved in the glass core yarns while Elongation at break was better for steel core yarns.

Key Words - DREF 3 Composite yarns, Friction Spun yarns,Mechanical Properties, Elongation at break, Time to break

I. INTRODUCTION

Composite yarn is a type of yarn that has two distinct components, i.e., core and sheath. Core is in the form of either mono or multifilament while sheath is always in the form of staple fiber. DREF 3000 (Friction) spinning system is one of the promising spinning methods to produce yarns for technical textile applications [1]. It offers less spinning tension to the core and core is positioned exactly at the centre of the yarn. Due to complete cover of the core filaments, yarns can be produced with required tensile properties by altering core proportion. These yarns are also characterized by superior mechanical properties and high material efficiency with low scrap [2].

With an increase in the use of protective clothing [3] for personal protection the importance of composite yarns such as those made on DREF 3000 machine has also increased. Compared to conventional personal protective equipment (PPE) made from steel or metal, textile based PPE is lightweight, flexible and provides greater comfort along with protection [4, 5]. All these are made possible by using high performance fibers that provide properties such as high cut resistance, high operating temperature, heat resistance, flame retardancy, chemical resistance and tensile strength [6]. However, sometimes, these high performance fibers cannot serve the purpose alone[reference]. They need to be reinforced with filaments of some even higher strength materials such as glass, steel which alone cannot be used in performance apparel; steel is harsh and is highly temperature conductive while glass fiber due to its brittle nature breaks easily and itches the skin. That's why composite yarns generally are of more importance than standard or conventional yarns of same materials [7]. Composite yarns are made with varying combinations of stainless steel, fiberglass, and other synthetic fibers. Linear density of the yarn also affects the performance characteristics [8]. Yarns with lesser linear density are found to be more flexible, having better dexterity and result in less body fatigue, while on the other hand, the heavy styles generally provide more protection [9]. Research has also been done to use composite yarns with metal core for other applications like conductive textiles [10,11].

Most of the researchers have tried conventional fibers as sheath of the composite yarns. In this research, main objective was to develop DREF 3 composite yarns with the aid of the high performance fibers both in sheath and core and analyze the effect of core type and core-sheath ratio on tensile properties of the manufactured composite yarns.

II. MATERIALS AND METHODS

Kevlar®29 staple fiber obtained from Dupont, USA was used as sheath material in all of the composite yarns produced. Reason of using Kevlar®29 was its excellent mechanical properties which make it suitable for cut resistant applications. Typical physical and mechanical properties of Kevlar®29 fibers are listed in Table 1.

Two types of core materials were used in the experimental work to make composite yarns. One of which was E-glass obtained from AGY, USA while

the other was stainless steel obtained from GargInox Limited, India. E-glass was in the form of multifilament yarn while stainless steel was in monofilament form. Four levels of E-glass multifilament yarn i.e. 5.55tex (50 denier), 11.11tex (100 denier), 16.66tex (150 denier) and 33.33tex (300 denier) were used to make composite yarns. Only two levels of stainless steel monofilament i.e., 11.11tex (100 denier) and 16.66tex (150 denier) were used. Typical properties of glass and steel yarns are listed in Table 1.

Table 1. Properties of Kevlar, E-glass multifilament and Steel yarns

Sr. No.	Parameter	Kevlar®29	E-Glass Filament Yarn				S.Steel
			5.55tex	11.11tex	16.66tex	33.33tex	
1	Tensile strength (GPa)	2.9	2.7	5.8	8.9	17.8	1.77
2	Tensile Modulus (GPa)	60	72	72	72	72	200
3	Elongation at break (%)	4	4.8	4.8	4.8	4.8	11
4	Moisture Regain (%)	4.3	0	0	0	0	0
5	Density (g/cm^3)	1.44	2.6	2.6	2.6	2.6	7.86

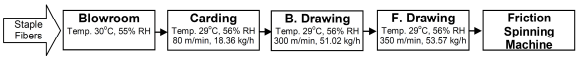


Figure 1. Process flow of composite yarn manufacturing

For preparing the sheath material for the composite yarn, Kevlar® staple fibers were manually opened and fed to the fine opener of blow room line. Opened material was fed to the carding machine in the form of a batt. Sixty grains per yard (gr/y) sliver was produced at 90% running efficiency. Six carded slivers were then fed to breaker drawing. Fifty grains/yard drawn sliver was produced at 80% running efficiency. Break draft of the breaker drawing frame was kept at1.61. Again, six drawn slivers delivered from the breaker drawing were fed to the finisher drawing. Forty five (45) grains/yard finisher drawn sliver was produced at 80% running efficiency. Relative humidity and temperature of the drawing department were kept same as in the carding department.Each of the finished drawn slivers were fed to friction spinning machine with varying core types, sizes and drafts to produce resultant counts of 118.1tex (Ne 5), 98.4tex (Ne 6) and 84.35tex (Ne 7).
Three sheath slivers were fed to the opening zone of the machine to form the outer cover of composite yarn. One core sliver was passed through the drafting zone to form the bottom cover over core filament. All the core and sheath slivers were of Kevlar®. Both core and sheath slivers formed the sheath portion of composite yarn.E-glass and stainless steel filaments formed the core of composite yarns. Four levels of E-glass and two levels of stainless steel filament were used. Each of the core material was used in all the yarns. Combination was such that in composite yarn of 118.1tex (Ne 5), all the six types of core materials, i.e. four types of E-glass and two types of stainless steel were used. This resulted in six different composite yarns of count 118.1tex (Ne 5). The same procedure was repeated for yarn counts of 98.4tex (Ne 6) and 84.35tex (Ne 7). Yarn coding was done such that composite yarn of 118.1tex (Ne 5) with 50 denier E-glass was termed 5G50, with 100 denier stainless steel was termed 5S100 and so on. Details of the yarn coding are listed in Table 2.

Table 2

Sample No.	Sample Code	Composite Yarn Count (Ne/tex)	Core Type/denier
1	5G50	5/118	Glass/50
2	5G100	5/118	Glass/100
3	5G150	5/118	Glass/150
4	5G300	5/118	Glass/300
5	6G50	6/98	Glass/50
6	6G100	6/98	Glass/100
7	6G150	6/98	Glass/150
8	6G300	6/98	Glass/300
9	7G50	7/84	Glass/50
10	7G100	7/84	Glass/100
11	7G150	7/84	Glass/150
12	7G300	7/84	Glass/300
13	5S100	5/118	S.S/100
14	5S150	5/118	S.S/150
15	6S100	6/98	S.S/100
16	6S150	6/98	S.S/150
17	7S100	7/84	S.S/100
18	7S150	7/84	S.S/150

III. RESULTS AND DISCUSSIONS

Mechanical properties of composite yarns were found to change considerably with change of core type and/or size for a particular yarn count. These properties are discussed as below;

3.1 Influence of core type and size on yarn properties

Mechanical properties along with yarn coefficient of friction, as affected by changing core type and size are listed in Table 3.

Table 3. Composite yarn properties

Yarn Sampling code	Breaking force cN	Elongation at break %	Tenacity cN/tex	Time to break S
5G50	837	2.16	7.09	5.4
5G100	1270	2.14	10.76	5.4
5G150	1662	2.48	14.08	6.2
5G300	2259	2.23	19.13	4.6
6G50	766	1.54	7.79	3.2
6G100	1082	2.09	11	4.3
6G150	1271	2.04	12.91	4.2
6G300	1544	2.09	15.69	4.3
7G50	946	1.65	11.22	3.4
7G100	1095	2.02	12.89	4.2
7G150	1435	1.99	16.61	4.1
7G300	1501	1.78	17.85	3.7
5S100	621	1.55	5.26	3.2
5S150	556	2.68	4.7	5.5
6S100	629	2.21	6.39	4.6
6S150	431	3.67	4.38	7.6
7S100	444	1.6	5.26	3.3
7S150	320	3.33	3.79	6.9

F-values and p-values of the ANOVA models are listed in table 4 below.

Table 4. F-values and p-values of Response surface models

Response	Sample	F-value	p-value prob> F
Breaking force	Glass-core spun yarns	64.5	< 0.0001 *Significant*
	Steel-core spun yarns	14.26	0.0294 *Significant*
Elongation	Glass-core spun yarns	5.09	0.0361 *Significant*
	Steel-core spun yarns	9.64	0.0494 *Significant*
Tenacity	Glass-core spun yarns	71.23	< 0.0001 *Significant*
	Steel-core spun yarns	9.72	0.0489 *Significant*
Time to break	Glass-core spun yarns	8.69	0.0102 *Significant*
	Steel-core spun yarns	9.63	0.0495 *Significant*

3.1.1 Effect of changing core size on Tensile Strength

Tensile strength is the force required to stretch the yarn to its breaking point. It is expressed in Newton (N) or centi-newton (cN). Comparison of tensile strength of different yarns obtained by changing yarn count, core size and type is shown in Figure 2.

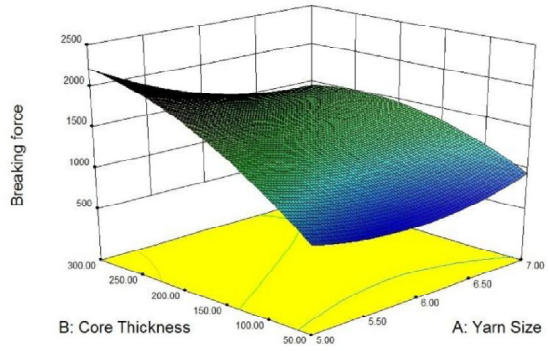


Figure 2 Effect of Yarn size and core thicknesson the Tensile Strength of Glass core spun composite yarn

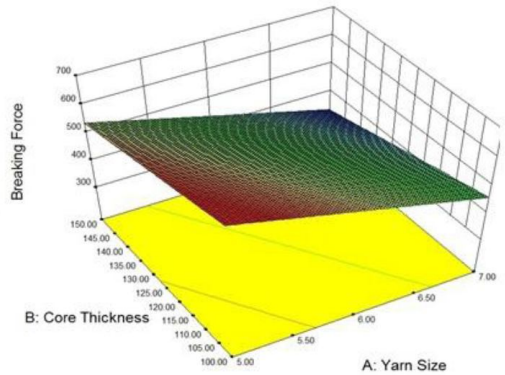


Figure 3 Effect of Yarn size and core thickness on the Tensile Strength of Steel core spun composite yarn

It is clear from the figure 1 that tensile strength of all the yarns which had glass as core material increased with increasing core size and vice versa. For all the three yarn counts, maximum tensile strength (2259 cN) was shown by composite yarn of 118 tex (Ne 5) with 300 denier glass core while minimum tensile strength (766 cN) was shown by composite yarn of 98 tex (Ne 6) with (50 deneir) glass core. Also for the same size of glass in the core, tensile strength was found to decrease in most of the cases for finer counts. With (300 denier) glass in the core, composite yarn of 118 tex (Ne 5) showed maximum value (2259 cN) compared to that of 98 tex (Ne 6) and 84 tex (Ne 7) which had tensile strength values of 1544 cN and 1501 cN, respectively. As in core yarns, sheath fibers slippage occur(ed/s) over the core during breaking process and core material contributes greatly to the tensile force, therefore stronger the core material higher will be the yarn tensile strength.

Opposite effect was observed in composite yarn in which stainless steel was used in the coreas in figure 3. For all the yarn counts, tensile strength was found to decrease with increasing stainless steel core size. Maximum value of tensile strength was observed for composite yarn of 98 tex (Ne 6) with 100 denier stainless steel core while minimum value was found for that of 84 tex (Ne 7) with 150 denier core. For same size of stainless steel core material, tensile strength increased for coarser counts. It may be due to the fact that stainless steel monofilament has less tensile strength than Kevlar®. With an increase in core proportion, sheath material decreased which resulted in lesser tensile strength.

3.1.1.1 Effect of changing core type on yarn Tensile Strength

Influence of the core type on tensile strength of composite yarn is shown in Figure 2 and 3. Analysis shows significant change in tensile strength while changing core type from glass to steel. For all yarn counts, greater tensile force was shown by glass core due to the greater tensile force of glass than steel. Minimum tensile force (320 cN) was observed for composite yarn of 84 tex (Ne 7) with 150 denier steel in core.

3.1.2Effect of changing core type and size on yarn Elongation at break

The elongation at break of yarn is the increase in its length by stretching it to the breaking point. Figure 4 and 5 show the comparative analysis of elongation at break of all the composite yarns obtained by changing core type and size.

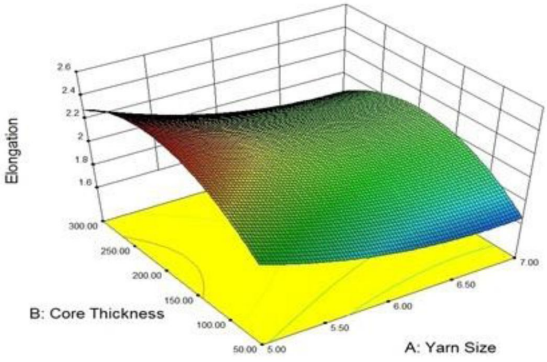


Figure 4 Effect of yarn size and core thickness on "Elongation at Break" of Glass core spun composite yarn

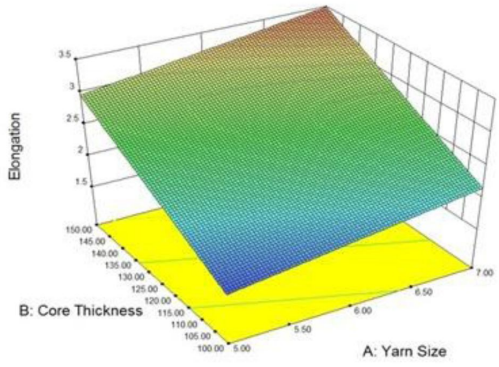


Figure 5 Effect of yarn size and core thickness on "Elongation at Break" of Steel core spun composite yarn

Changing glass core size on all counts had little effect on elongation at break of the composite yarns as in figure 4. Effect was more significant when stainless steel was used in the core, as steel has greater elongation at break than glass. Maximum elongation at break (3.67%) was observed for composite yarn of 98 tex (Ne 6) with 150 denier steel in core, while minimum value (1.54%) was found for the composite yarn of 98 tex (Ne 6) with 50 denier glass in core.

3.1.3 Effect of changing core type and size on yarn Tenacity

Tenacity is calculated from the yarn breaking force and its linear density, and is expressed in centi newton per tex (cN/tex). Effect of changing core size and type on tenacity is significant for composite yarns made from both types of cores as shown in Figure 6 and 7. For all yarn counts having glass in core, increasing core size resulted in an increase in yarn tenacity with maximum value (19.13 cN/tex) for 118 tex (Ne 5) with 300 denier core, and minimum value (7.09 cN/tex) for 118 tex (Ne 5) with 50 denier. In core yarns, sheath fibers slippage occur (ed/s)over the core during breaking process hence main role is played by the core material and, therefore, stronger the core material higher will be the yarn tenacity.

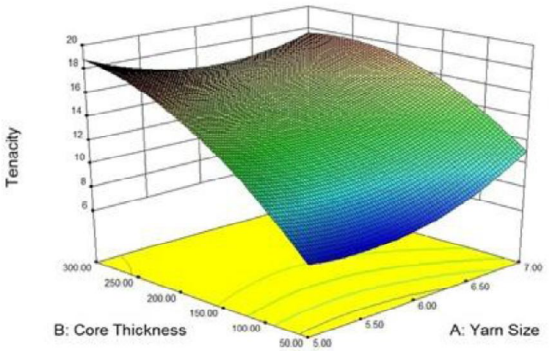


Figure 6 Effect of yarn size and core thickness on the Tenacity of Glass core spun composite yarn

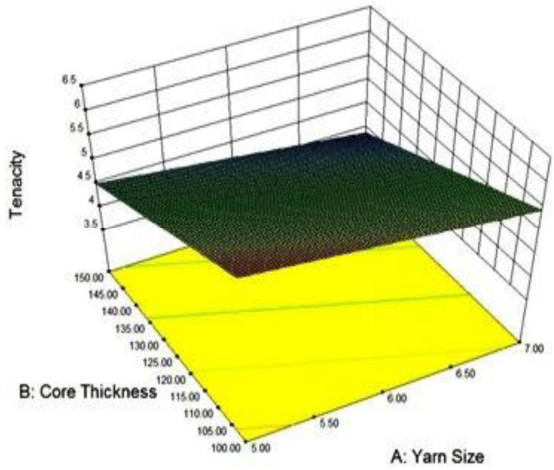


Figure 7 Effect of yarn size and core thickness on the Tenacity of Steel core spun composite yarn

Results were reversed with steel in the core, i.e. increasing core size resulted in decrease of yarn tenacity for each count. With stainless steel in the core, maximum value of yarn tenacity (6.39 cN/tex) was observed for composite yarn of 98 tex (Ne 6) with 100 denier and minimum value (4.38 cN/tex) for 98 tex (Ne 6) with 150 denier core.

Changing core type had a very significant effect on tenacity of yarn. For same yarn count and core size, 118 tex (Ne 5) and 150 denier), composite yarn with glass core, due to higher tenacity of glass than steel, had very high value (14.08 cN/tex) compared to steel (4.7 cN/tex).

3.1.4 Effect of changing core size and type on yarn Time to break

Yarn time to break is the amount of time in seconds during which, yarn extends or tends to extend before broken by tensile force.

Comparison of yarn time to break for all the counts on different core types and sizes is shown in Figure 8 and 9.

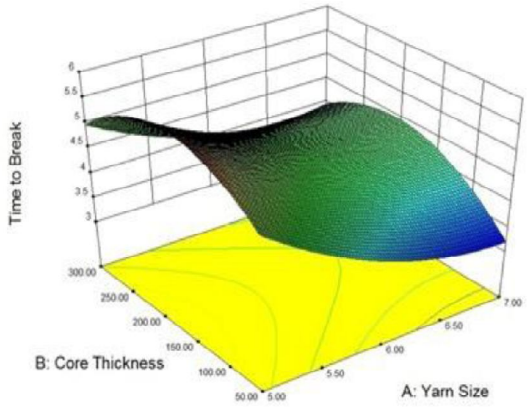


Figure 8 Effect of yarn size and core thickness on "Time to Break" of Glass core spun composite yarn

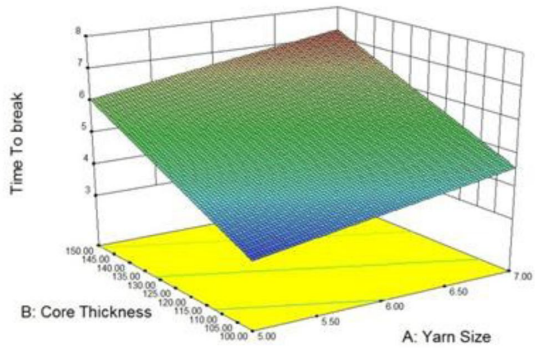


Figure 9 Effect of yarn size and core thickness on "Time to Break" of Steel core spun composite yarn

Changing glass core on all counts had a little effect on yarn time to break. Effect was more significant when steel was used as core material due to the greater elongation at break of steel. Maximum value (7.6 s) was observed for steel core of 150D in 98 tex (Ne 6) yarn.

CONCLUSIONS

Based on experimental results, following conclusions are made;

- For all the yarn counts, increasing glass core size resulted in an increase in tensile strength and tenacity of the yarn whereas increasing steel core size, resulted a decrease in the tensile strength and tenacity for the same yarn count.
- For all the counts, composite yarns with glass core had greater tensile strength and tenacity than composite yarns with steel cores.
- Changing glass core size had insignificant effect on yarn elongation at break and time to break for all counts of composite yarns. However increasing steel core size resulted inan increase in yarn elongation at break and time to break.
- Yarn coefficient of friction was almost the same for all the composite yarns with different core types and sizes.

FUTURE RESEARCH RECOMMENDATIONS

Future research work can further be extended to study the effect on mechanical and physical properties of yarn by;

- Using Kevlar filament yarn in core with Kevlar staple fiber as sheath
- Using Kevlar filament yarn in core with Dyneema staple fiber as sheath
- Using Dyneema staple fibers as sheath material with glass and steel in core

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