(REFEREED RESEARCH)

TENSILE PROPERTIES OF SOME TECHNICAL CORE SPUN YARNS DEVELOPED FOR PROTECTIVE TEXTILES

KORUYUCU TEKSTİLLER İÇİN GELİŞTİRİLMİŞ BAZI TEKNİK ÖZLÜ İPLİKLERİN MUKAVEMET ÖZELLİKLERİ

Mustafa ERTEKİN, Erhan KIRTAY

Ege University Engineering Faculty Department of Textile Engineering, İzmir, Turkey

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ABSTRACT

Today high performance fibres with uniquely inherent properties are used for many technical areas such as resistance to heat and flame, chemicals, stabs and cuts; protective clothing and gloves for firefighters, military and industry. In this study, some technical core-spun yarns, which can be used in the development of protective textiles were produced with various high performance fibres in three core-sheath ratios (19/81%, 37/63%, 56/44%) by using a modified ring spinning frame. Short staple para-aramid, meta-aramid and PES Trevira® (flame retardant) fibres were used as sheath and multi filament yarns of 110 dtex linear density (E-glass, PES Trevira®, PA HT, PP, PES HT, Technora® T240 and Dyneema® SK75) as the core. The data obtained from tensile testing and the effects of sheath, core and core-sheath ratio on tensile properties were analysed statistically. The results revealed that the tensile properties of core-spun yarns show different tendencies with respect to the type of fibres in core, sheath and different core/sheath ratios. Higher tensile strength is noticed in core-spun yarns with para-aramid sheath fibres followed by PES Trevira® and meta-aramid, and vice-versa in case of elongation. Dyneema® and Technora® core-spun yarns exhibit the highest and PES-Trevira® the lowest tensile strength values. Highest elongation values were observed for core-spun yarns with PP filaments.

Keywords: Core yarn spinning, technical core-spun yarns, high performance fibres.

ÖZET

Günümüzde yüksek performanslı lifler ısıya, aleve, kimyasallara, kesme ve delinmelere karşı dayanım; itfaiyeciler, askeriye ve sanayi için koruyucu giysiler ve eldivenler gibi teknik alanlarda kullanılmaktadır. Bu çalışmada koruyucu tekstillerin geliştirilmesinde kullanılabilecek bazı teknik özlü iplikler üç farklı öz/manto oranında yüksek performanslı lifler kullanılarak ring iplik makinesinde üretilmiştir. Özlü ipliklerin üretiminde manto lifi olarak kesikli para-aramid, meta-aramid ve PES Trevira® (güç tutuşur özellikli) lifleri; öz kısmında ise aynı incelikte (110 dtex) E-cam, PES Trevira®, PA HT, PP, PES HT, Technora® T240 and Dyneema® SK75 filamentleri kullanılmıştır. Üretilen ipliklere uygulanan mukavemet testleri sonucunda özün, mantonun ve öz/manto oranının mukavemet özelliklerine etkisi istatistiksel olarak incelenmiştir. Sonuçlar göstermiştir ki; öz ve mantoda kullanılan lif tipine ve farklı öz/manto oranlarına göre özlü ipliklerin mukavemet özellikleri farklı eğilimler göstermektedir. Mukavemet açısından en yüksek değerler para-aramid mantolu özlü ipliklerde görülmüş olup bunu PES Trevira® ve meta-aramid mantolu özlü iplikler izlemiştir. Uzama özellikleri bakımından ise bu sıralamanın tam tersi bir durum görülmüştür. En yüksek mukavemet değerleri Dyneema® ve Technora® özlü ipliklerde, en düşük değerler ise PES-Trevira® özlü ipliklerde ölçülmüştür. En yüksek uzama değerleri PP filamentlerle üretilmiş özlü ipliklerde gözlenmiştir.

Anahtar Kelimeler: Özlü iplik eğirme, teknik özlü iplikler, yüksek performanslı lifler.

Corresponding Author: Mustafa Ertekin, mustafa.ertekin@ege.edu.tr

INTRODUCTION

Core yarn is the yarn type that has the filament either mono or multi, in the core and the staples in the sheath, which is used to achieve the multi-functional performance. The chief aim of using core yarn is to take advantage of the different properties of its both components. It is produced by feeding a filament into the central axis of the yarn to form a core/sheath structure. In general, core-spun yarns which may also be named as complex, compound, composite or hybrid yarns, have two types: soft (elastic) core yarns and rigid (non-elastic, hard) core yarns.

Core yarns can be produced in various spinning systems, including rotor, friction, air-jet and ring spinning system.

Among these systems, ring spinning is by far the dominant method adopted by the textile industry [1]. Because the equipment is easily mounted and the yarn quality is much better than any other yarns. Especially the structural configuration with parallel laid components can simply be realized by attaching an accessory device on the pendulum arms [2]. The quality of core yarns in the ring spinning system is thus determined by the structural characteristics, if the core filaments are firmly located at the center of the yarn and well covered by the sheath-staples. To do this, the basic principle is to feed the filament into the spinning frame at a specific tension and keep constant throughout the spinning process. It is also very important that the insertion of the filament is produced at the correct point so that it can be completely covered by the fibres; this feed position must also be kept constant in order to avoid areas of yarn where the filament cover is poor.

Nowadays, new raw materials and technologies in the textile industry have opened up new horizons for technical yarns, among which core-spun yarns have attractive development prospects with an increase in the market demand. Because core-spun yarns combine the advantages of both core and sheath fibres and as far as the raw materials are concerned, besides conventional fibres, high performance fibres can be employed to spin core-spun yarns so that the yarns and fabrics produced will have attractive functionalities.

Many researches were carried out to optimize and evaluate the physical and mechanical properties of core-spun yarns and their fabrics. Based especially on rigid core-spun yarns, concern of the studies can be summarized as:

- machine settings, modifications and process parameters [3-18]
- core yarn defects [19-22]
- core yarn and fabric properties [23-35]
- niche textile products [36-41].

Through the literature does cite studies concerning the spinning of core yarns with conventional fibres like cotton and polyester, there is hardly any study, which deals with the high tenacity fibres such as aramids, UHMWPE and E-glass.

In this research, our major objective was to develop new technical core-spun yarns with the aid of the high performance fibres to achieve the desired levels of technical performance for various safety and protective products. Other specific objectives were to analyse the effects of core, sheath and core-sheath ratio on the tensile properties of the manufactured core-spun yarns.

MATERIALS AND METHODS

Materials

Para-aramid, meta-aramid and PES Trevira® were used as the sheath and multi-filament yarns with a linear density of 110 dtex (E-glass, PES Trevira®, PA HT, PP, PES HT, Technora® T240 and Dyneema® SK75) as the core. Table 1 and 2 show the specifications of sheath and core materials, respectively.

Table 1. Specifications of the sheath fibres

Material (Sheath fibres)	Mean fibre length/Fineness	Roving count (Ne)	Tensile strength (cN/tex)	Elongation (%)
Para-aramid	38 mm/1.7 dtex	1.197	134.5	4.2
Meta-aramid	50 mm/2.2 dtex	0.987	39	37
PES Trevira®	40 mm/1.2 dtex	0.770	48	14

Table 2. Specifications of the filaments

Material (110 dtex)	Tensile strength (cN/tex)	Elongation (%)
E-glass	48.91	2.04
PES Trevira®	25.67	46.87
PA HT	51.26	27.35
PP	54.32	32.70
PES HT	65.13	13.13
Technora T240®	232.43	3.84
Dyneema SK75®	373.24	3.35

Yarn Production

A total of 63 different core-spun yarns were manufactured using a sample ring spinning frame (Pinter-Merlin) (Figure 1a) by passing filaments through the front drafting roller nip of ring frame where rovings of sheath fibres proceeding through the drafting zone of the ring frame. A diagram of the spinning process used to produce the core-spun yarns is shown in Figure 1b.

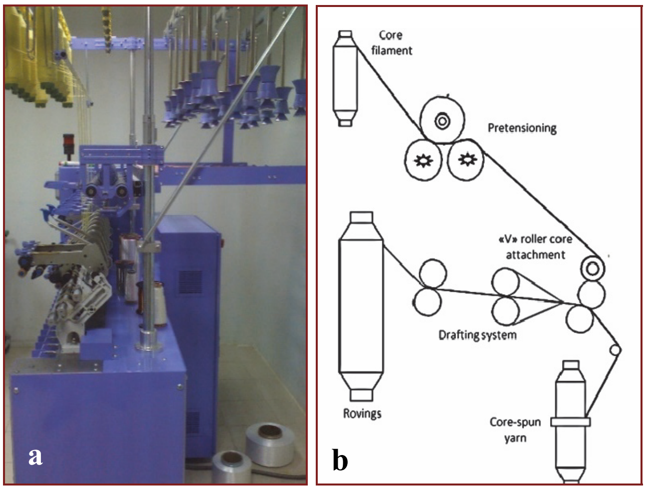

Figure 1. a) Pinter – Merlin lab ring frame b) Diagram of core yarn spinning

The feeding of the filament must be centered and monitored carefully for a flawless wrapping effect, which is the most important quality index of core-spun yarns. To cover the inner filament uniformly and completely, special additional equipment for manufacturing core-spun yarns is attached to the ring frame. The core was fed from the cone with suitable guides and through a pre-tensioning device to the front roller nip of the drafting system.

In the study reported here, core-spun yarns having the same twist factor (α_e=3.5) are produced with three core–sheath ratios of 19/81%, 37/63% and 56/44% under ideal and same conditions (Table 3). However, spinning with Technora® and Dyneema®, caution must be applied, as these filaments were not easy to break with bear hands.

Table 3. Details of the manufactured core-yarns

Sheath Fibres	Core/sheath ratio (%)	Core filaments (110 dtex)	Parent Yarn Count (Ne)
Para-aramid Meta-aramid PES Trevira®	19/81 37/63 56/44	E-glass	10 20 30
		PES Trevira®	
		PA HT	
		PP	
		PES HT	
		Technora T240®	
		Dyneema®	

Tensile Tests

All measurements were carried out under the standard testing conditions according to standard ISO 139. Tensile tests of the filaments and the core yarns produced were performed using Zwick Z010 universal tensile tester based on the standard method of ISO 2062 at 250 mm/min and the length of 250 mm of yarn. Fibre fineness and tensile properties of the sheath fibres were executed according to standard TS EN ISO 5079 and TS 2874 EN ISO 1973 respectively.

In order to determine the significance of the factors, the test results were analysed using analysis of variance (ANOVA) at the 95% level of confidence in SPSS® software, and the means were compared by Duncan's multiple-range test.

RESULTS AND DISCUSSION

The tensile properties of the manufactured core-spun yarns are presented in details in Table 4. Mean plots of tensile strength and elongation grouped by core/sheath ratio; categorized by core and sheath are illustrated in Figure 2 and 3, respectively. Variance analysis indicated that elongation and tensile strength values of core-spun yarns were all significantly affected by the sheath, core, core-sheath/ratio and the interactions of these factors (Table 5 and 6).

Table 4. Tensile properties of the core-spun yarns

Sheath Fibres		Para-aramid		Meta-aramid		PES-Trevira®	
Core/Sheath Ratio (%)	Core filaments	Tensile strength (cN/tex)	Elongation (%)	Tensile strength (cN/tex)	Elongation (%)	Tensile strength (cN/tex)	Elongation (%)
19/81	E-glass	41.42	3.03	19.42	4.67	16.8	5.51
	PES-Trevira®	48.32	3.96	22.51	19.95	27.42	14.9
	PA HT	36.41	3.63	27.41	20.79	33.66	14.91
	PP	38.12	3.82	28.69	22.82	32.49	15
	PES HT	39.2	3.94	30.49	16.94	38.78	14.63
	Technora®	78.25	3.94	45.39	5.92	42.95	5.31
	Dyneema®	90.44	3.95	67.41	6.92	67.66	6.74
37/63	E-glass	38.75	2.42	26.58	3.17	28.92	2.62
	PES-Trevira®	25.93	3.61	17.19	13.95	24.58	13.47
	PA HT	23.76	3.48	29.63	17.63	32.95	14.25
	PP	24.31	3.83	30.07	20.27	30.44	14.2
	PES HT	30.68	3.83	38.24	15.48	45.12	14.24
	Technora®	99.36	4.03	76.78	4.53	77.49	4.21
	Dyneema®	111.36	4.04	94.98	7.83	107.19	4.85
56/44	E-glass	38.81	2.37	31.54	2.16	30.87	2.07
	PES-Trevira®	17.45	4.15	15.92	14.96	17.85	12.24
	PA HT	29.55	27.76	33.52	19.62	31.59	13.92
	PP	30.21	33.43	33.01	21.9	31.99	15.37
	PES HT	40.28	13.89	45.83	15.63	49.14	14.11
	Technora®	118.82	4.23	107.12	4.45	112.72	4.5
	Dyneema®	127.52	4.6	142.88	6.06	153.97	5.35

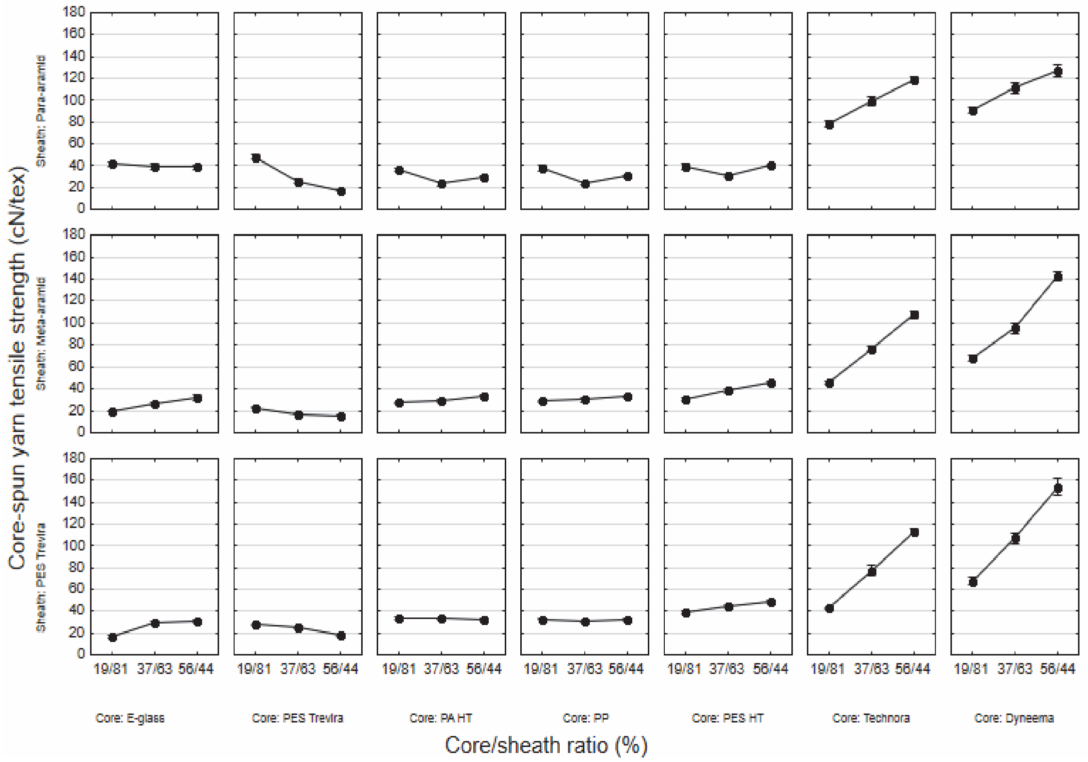

Figure 2. Mean Plot of Core-spun yarn tensile strength grouped by Core/sheath ratio; categorized by Core and Sheath

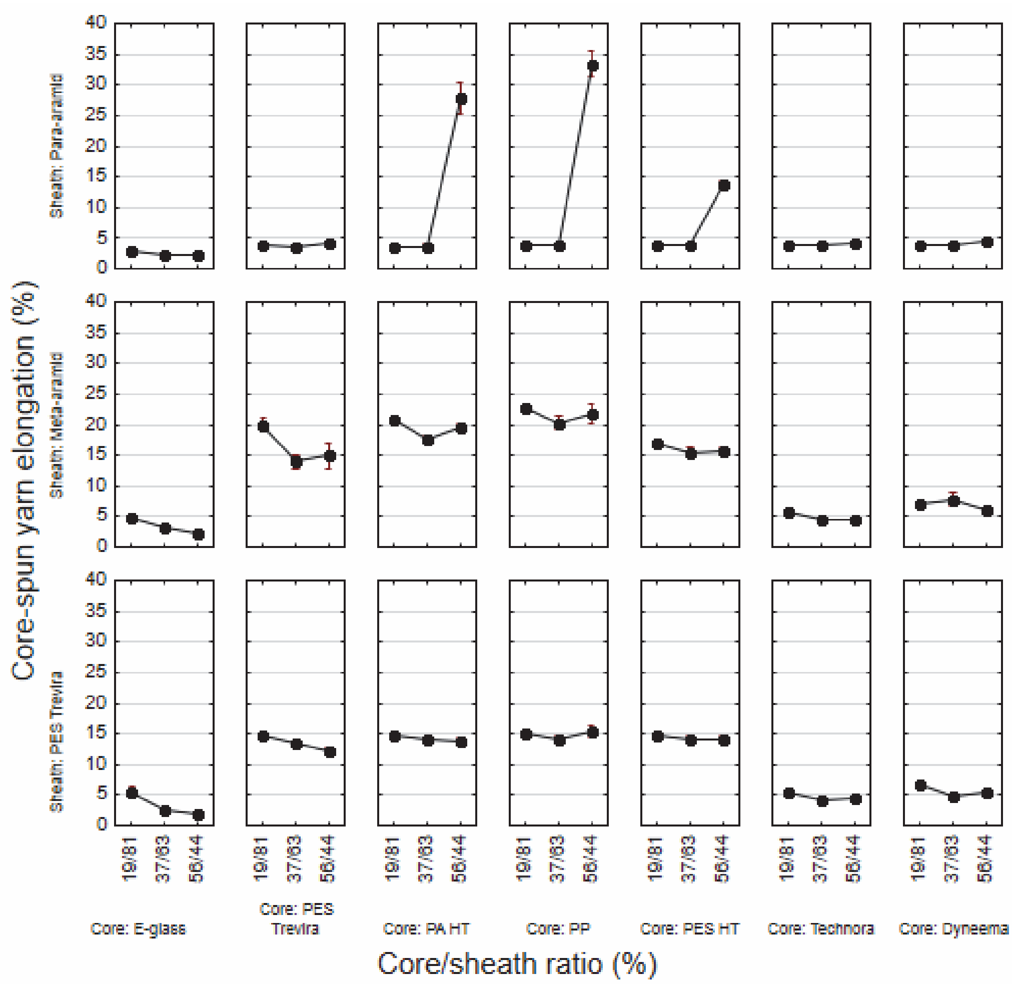

Figure 3. Mean Plot of Core-spun yarn elongation grouped by Core/sheath ratio; categorized by Core and Sheath

Table 5. Univariate analysis of variance, tests of between-subjects effects for tensile strength of core-spun yarns

Source of variation	Sum of Squares	df	Mean Square	F	p-value
Sheath fibre	6449.202	2	3224.601	264.423	.000
Core filament	568667.400	6	94777.900	7771.948	.000
Core/sheath ratio	32821.459	2	16410.730	1345.708	.000
Sheath fibre * Core filament	11472.912	12	956.076	78.400	.000
Sheath fibre* Core/sheath ratio	9705.905	4	2426.476	198.975	.000
Core filament* Core/sheath ratio	89728.418	12	7477.368	613.157	.000
Sheath fibre* Core filament* Core/sheath ratio	5226.295	24	217.762	17.857	.000
Error	6914.491	567	12.195		
Total	2284694.530	630			

Table 6. Univariate analysis of variance, tests of between-subjects effects for the elongation of core-spun yarns

Source of variation	Sum of Squares	df	Mean Square	F	p-value
Sheath fibre	3667.198	2	1833.599	1828.478	.000
Core filament	15797.725	6	2632.954	2625.601	.000
Core/sheath ratio	1082.479	2	541.239	539.728	.000
Sheath fibre * Core filament	2344.700	12	195.392	194.846	.000
Sheath fibre* Core/sheath ratio	3176.795	4	794.199	791.981	.000
Core filament* Core/sheath ratio	2750.928	12	229.244	228.604	.000
Sheath fibre* Core filament* Core/sheath ratio	3921.476	24	163.395	162.939	.000
Error	568.588	567	1.003		
Total	94326.549	630			

Effect of sheath on tensile properties

The results of the effect of sheath on the tensile strength and elongation of the sample yarns are shown in Table 7 and 8, respectively. From the Duncan's multiple-range test, it is observed that higher tensile strength is noticed in core-spun yarns with para-aramid sheath followed by PES Trevira® and meta-aramid, and vice-versa in case of elongation. This could be attributed to the tensile properties of sheath fibres, as they also follow a similar pattern (Table 1).

Elongation values of the core-spun yarns manufactured with para-aramid sheath fibres were between 3.03% and 4.6%. This indicates that para-aramid sheath fibres governed the elongation of the core-spun yarns regardless of the core filaments' elongation. However, para aramid core-spun yarns with PA HT, PES HT and PP in 56/44% core/sheath ratios had elongation values similar to the core filaments' elongation. This is due to the fact that higher core/sheath ratio induced inadequate wrapping of sheath fibres around core filaments and hence elongation values were obtained solely from core filaments during the measurement of tensile testing.

From the data in Table 4, it is apparent that PES Trevira® filaments showed the lowest tensile strength among other core filaments and had no positive effect in the parent yarn. However, it was observed that yarns with PES Trevira® filament in core and para-aramid fibres in sheath with a ratio of 19/81% had a marked increase in tensile strength. This could be ascribed to the presence of more para-aramid sheath fibres in the parent yarn.

Effect of core on tensile properties

As seen from Table 4 and 7, Dyneema® and Technora® core-spun yarns exhibited the highest tensile strength and followed by PES HT yarns. This might be explained by the fact that core filaments have a higher contribution individually in the tensile strength of the core-spun yarns. The same trend is observed for PES-Trevira® core-spun yarns, which have the lowest tensile strength. According to Duncan's test, the difference between the mean values of tensile strength for PP, PA HT and E-glass samples were found to be similar, which can also be explained as a consequence of having core filaments with close tensile strength individually.

The highest elongation values were observed for PP, whereas the lowest values were obtained for E-glass core-spun yarns. These results are consistent with the elongation values of core filaments (see Table 2); however, PES Trevira® core-spun yarns showed different behaviour and did not elongate as expected.

Table 7. Duncan Multiple Range Test (p, 0.05) for the tensile strength of the samples

The effect of sheath fibre	1	2	3
Meta-aramid	45.9555		
PES Trevira®		49.2647	
Para-aramid			53.7625
Sig.	1.000	1.000	1.000

The effect of core- sheath ratio	1	2	3
19/81 %	41.5824		
37/63 %		48.2965	
56/44 %			59.1038
Sig.	1.000	1.000	1.000

The effect of core yarn	1	2	3	4	5
PES Trevira®	24.1299				
E-glass		30.3480			
PA HT		30.9429			
PP		31.0371			
PES HT			39.7463		
Technora®				84.3758	
Dyneema®					107.0462
Sig.	1.000	.214	1.000	1.000	1.000

Table 8. Duncan Multiple Range Test (p, 0.05) for the elongation of the samples

The effect of sheath fibre	1	2	3
Para-aramid	6.7593		
PES Trevira®		10.1146	
Meta-aramid			12.6501
Sig.	1.000	1.000	1.000

The effect of core- sheath ratio	1	2	3
37/63 %	8.3792		
19/81 %		9.5855	
56/44 %			11.5593
Sig.	1.000	1.000	1.000

The effect of core yarn	1	2	3	4	5	6	7
E-glass	3.1153						
Technora®		4.5694					
Dyneema®			5.5932				
PES Trevira®				11.2437			
PES HT					12.5218		
PA HT						15.1079	
PP							16.7380
Sig.	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Effect of core-sheath ratio on tensile properties

The relationship between core/sheath ratio and tensile strength was displayed in Figure 2. As seen from the figure, the increasing trend is detected in general, assuring that tensile strength of the core-spun yarns increases with increasing core/sheath ratio except for the PES Trevira® core-spun yarns. The observed difference for PES Trevira® samples could be attributed to their low tensile strength, because increasing core-sheath ratio leads to reduced sheath content, which will be wrapped on the core filaments that then increase the contribution of core filaments, which in turn increases the tensile strength of the parent yarn.

With regard to the effect of core/sheath ratio on elongation, no obvious trend was observed for the changes in values. It is therefore likely that parent yarn may act differently than the fibres and filaments having different characteristics used for core yarn spinning.

CONCLUSIONS

In this study, various high performance core-spun yarns were manufactured in three core–sheath ratios (19/81%, 37/63%, 56/44%) by using ring spinning system with core attachments. Short staple para-aramid, meta-aramid and PES Trevira® were used as sheath and multi filament yarns of 110 dtex linear density (E-glass, PES Trevira®, PA HT, PP, PES HT, Technora® T240 and Dyneema® SK75) as the core. The data obtained from tensile testing and the effects of sheath, core and core-sheath ratio on tensile properties were analysed statistically. The results indicate that:

- The tensile properties of core-spun yarns show different tendencies with respect to the type of fibres in core, sheath and different core/sheath ratios.
- Higher tensile strength is noticed in core-spun yarns with para-aramid sheath fibres followed by PES Trevira® and meta-aramid, and vice-versa in case of elongation.
- Para-aramid sheath fibres governed the elongation of the parent yarns regardless of the core filaments' elongation except with PA HT, PES HT and PP core filaments in 56/44% core/sheath ratio.
- Core yarn spinning process reduced the tensile strength of all core filaments except for the samples with para-aramid sheath and PES Trevira® filaments.
- Dyneema® and Technora® core-spun yarns exhibit the highest and PES-Trevira® the lowest tensile strength values.
- Highest elongation values were observed for core-spun yarns with PP filaments, while the E-glass core-spun yarn samples showed the lowest due to its lower extension.
- Tensile strength of the manufactured core-spun yarns showed the tendency to increase with increasing core/sheath ratio. However, findings for PES Trevira® core-spun yarns emerged contradictory results.

In practice, it is apparent that the tensile strength of core filaments such as Technora® and Dyneema® were significantly reduced when they are produced as core-spun yarns. But at the same time, using Dyneema® with meta-aramid sheath fibres, in turn, favour enhanced resistance to heat and flame as Dyneema® fibres have a LOI index lower than 20 and melting point between 144 and 155°C [42]. Regarding Technora® filaments, as known, aramids are strong UV absorbers [43], wrapping the filaments with PES Trevira® sheath fibres can protect them from deterioration by reducing their exposure to ultraviolet light. Another instance is that when E-glass filaments are used individually, they can be broken during processes or may irritate the skin of the wearer. For this reason, using core-spun yarns instead of filaments, it would be easier to handle them in knitting and weaving processes.

It can be concluded that integrating the advantages of both core and sheath fibres by effectively, these high performance core-spun yarns may provide the potential for new technical applications such as thermal protection, fire resistance and cut resistance for personal protective equipment, defense uniforms, technical sewing threads, packing and light-weight composites, as well as offering many other functional properties.

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