Erhan Kenan Çeven[1]*,
Hüseyin Aytaş[2]

Investigation of Tensile and Stiffness Properties of Composite Yarns with Different Parameters

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[1]**Uludag University**
Faculty of Engineering,
Textile Engineering Department
Görükle Campus,16059-Nilüfer-Bursa-Turkey
*E-mail: rceven@uludag.edu.tr

[2]**Uludag University**
Graduate School of Natural and Applied Science
Görükle Campus,16059-Nilüfer-Bursa-Turkey

Abstract

In this experimental study, we investigated the effects of core yarn diameter and cover yarn type on the mechanical properties of composite yarns produced using a hollow spindle twisting machine according to the method of covering. Composite yarns containing stainless steel (SS) metal wires with diameters of 50 µm and 100 µm were produced with seven different cover yarns varying in their raw material and structure. These cover yarns were as follows: polypropylene, cotton, core-spun polyester/cotton, continuous filament polyester, continuous filament polyamide 6.6, core-spun polyester/polyester, and polyester cut fibre yarns. The mechanical properties measured were tensile behaviour and stiffness. According to the findings of the statistical analyses performed using the experimental values, the core yarn diameter, cover yarn type and the interactions of these factors were all significant factors affecting the tenacity, elongation at break, work of rupture and stiffness properties of the composite yarns. Composite yarns containing continuous filament polyamide 6.6 cover yarn showed higher tenacity values, while the maximum elongation at break was obtained for the composite yarns containing continuous filament polyester cover yarn. Both polyester and polyamide 6.6 possessed higher work of rupture values among the other types of cover yarns. An increase in the SS wire diameter resulted in a significant increment in stiffness values. The results of this study implied that it is important to give importance to component yarn types when designing composite yarns with desired physical properties.

Key words: *composite yarn, stainless steel, tensile strength, stiffness, hollow spindle.*

Introduction

The forms in which technical textile products are available are thread, tape, woven, knitted, braided, knotted and non-woven fabric. Of all these forms, only non-woven products are made straight from staple fibres or short natural fibres, whereas for the rest the basic raw material is yarn. Technical yarns can be classified on the basis of raw material or the structure and form. Depending upon the fibre used, they can be classified as natural or artificial and tenacity-wise as low, high and very high tenacity. Yarns can be designated as filament, tape, spun, core spun, plied, braided, etc. It is possible that many yarns may have a dual use in both non-technical and technical applications [1]. Metallic fibres are used to produce textile yarns. But there are processing difficulties associated with the weaving or knitting of bare metallic wires. Hence, various methods like core spinning, friction spinning, twisting and covering or cross covering are followed to produce composite yarn comprising metallic wires and textile fibres. Composite yarns are easy to process and the fabrics made out of them show improved textile properties.

Composite yarns containing metal wires are used for two main purposes. The first usage area is for functional purposes like protection, health, communication or automation as a technical yarn. Metal-based conductive composite yarns, which can be used to develop smart textiles and electrotextiles, are being increasingly considered for the fabrication of conducting textiles. Having excellent permanent conductivity among all of its conductive fibres, metal wire exhibits electrostatic charging or discharging during various industrial processes because of friction, separation or conduction between objects [2].

Metal based conductive textile fabrics, because of their structural order and ability to flex and conform to shapes most desired, offer a great opportunity to develop a new generation of multifunctional and interactive textiles. Such fabrics have desirable properties in terms of flexibility, stiffness, tensile properties, abrasion resistance, electrostatic discharge, electromagnetic wave protection and low weight in various industrial processes [3, 4].

Today, conductive composite yarns used for electromagnetic protection are utilised to fulfil different requirements in warning controllers, power transfer, sensors, transmitters and microcontrollers. [5]. Conductive composite yarns can be produced from conductive wires and can also be manufactured by different tech-

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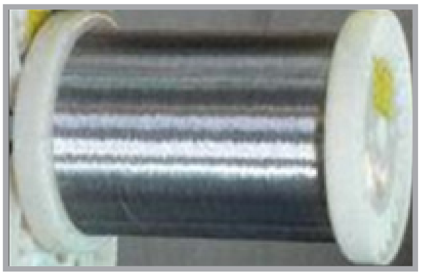

Figure 1. *Metal wire (316 L type monofilament SS wire).*

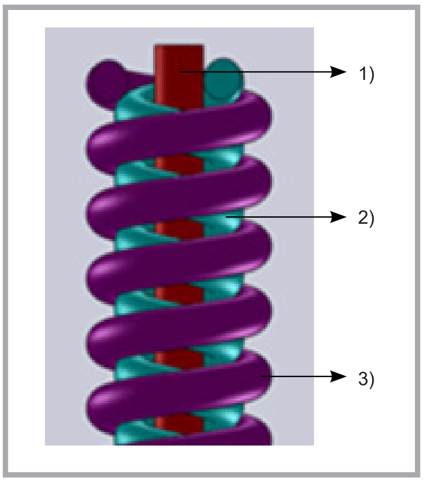

Figure 2. *Illustration of the components of cross covered composite yarn: 1) SS wire, 2) first covering yarn, 3) second covering yarn [24].*

niques such as spinning or wrapping of conductive and nonconductive fibres together. The other usage area of composite yarns containing metal wires is basically for decorative purposes as fancy yarns. Metal wires are twisted or covered with other yarns composed of fibres such as wool, nylon, cotton, and synthetic blends to produce yarns which add novelty effects to the end cloth or trim. ***Figure 1*** shows an image of a 316 L type monofilament SS metal wire.

An increasing number of researches on conductivity and electromagnetic shielding effectiveness properties of fabrics consisting of metal based conductive composite yarns have been published in the literature [6 - 17].

However, besides understanding the electro-conductive properties of this type of yarn, it is important to investigate the mechanical characteristics as well. Conductive composite yarns with metal monofilaments integrated into textiles require to be stressed during production and use. Thus their fragility will lead to a major problem for their application in textiles. A literature survey showed that limited research on the physical properties of composite yarns containing metal wires has been found in various publications.

Bedeloglu et al. measured the hairiness and tensile properties of composite yarns produced by wrapping copper and stainless steel-based wires around cotton yarn [5]. Örtlek et al. investigated the physical properties of hybrid yarns containing copper wire which are produced with 5 different production methods at three different twist levels [18]. Perumalraj and Dasadaran produced copper core spun yarns of different counts on Dref friction spinning and modified ring spinning machines and investigated the effects of the process variables on tensile properties of these yarns [19]. Bedeloglu and Sunter produced polyacrylic (PAC)/metal wire complex yarns with wires of different diameter using core spinning and wrap spinning. They investigated the physical properties of these yarns in terms of yarn hairiness, tenacity and count [20]. Bedeloglu et al. investigated the bending rigidity, tensile and hairiness properties of hybrid yarns consisting of cotton yarn as well as copper and stainless steel wire [21]. Schwarz et al. analysed the mechanical behaviour of elastic, electro-conductive hybrid yarns [22]. Lou investigated the tenacity and hairiness of complex core spun yarns containing metal wires with respect to parameters like twist level and core materials [23].

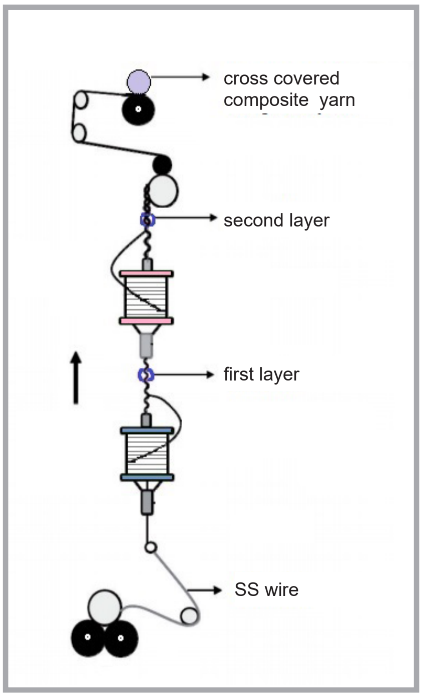

Figure 3. *Illustration of the hollow spindle principle.*

However, there is no research on the tensile and stiffness properties of composite yarns containing core yarn of SS wire with different diameters and containing different cover yarn types produced by the hollow spindle technique. Tensile and stiffness properties of metal-containing composite yarns are important features which affect quality and product performance. Yarn stiffness is a factor affecting the bending rigidity and drape behaviours of fabrics, while the tenacity of yarns affects the tensile and tear strength of fabrics. The main objective of this research work is filling the gap in the literature by contributing to the investigation of the interactions and specific influences of composite yarn production parameters (properties of the input yarns) like the cover yarn type and metal wire diameter on the tensile and stiffness properties of composite yarns.

Experimental part

Production of Composite Yarns

Fourteen different composite yarns were produced via the the hollow spindle pro-

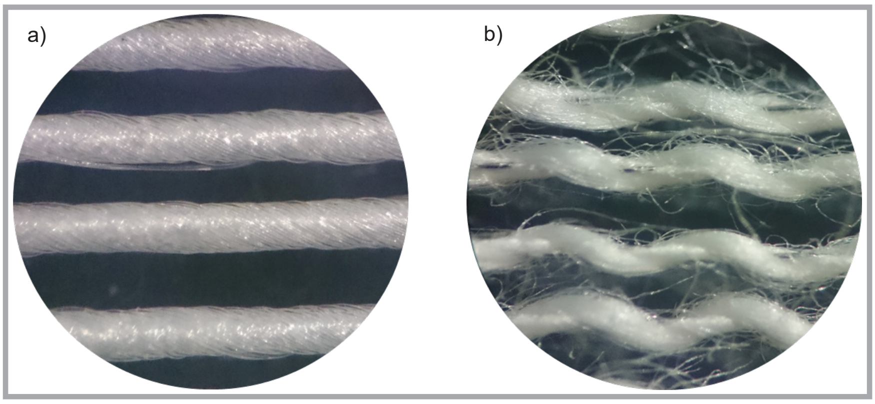

Figure 4. *Stereomicroscopic Images (20×) of the a) C15 coded composite yarns, (Double layer SS/ Continuous Filament PA 6.6 wrapped yarns made with 50 µm SS) and b) C22 coded composite yarns (Double layer SS/ CO wrapped yarns made with 100 µm SS).*

cess by using an S & Z MX model Sapru Machines Pvt. Ltd. twisting machine (S & Z MX Model, India). They were all designed according to the same principle of cross covering.

Yarns varying in their raw materials and structures were used as cover yarns and SS wires were applied as core yarns. Polypropylene, cotton, core-spun polyester/cotton, continuous filament polyester, continuous filament polyamide 6.6, core-spun polyester / polyester, and polyester cut fibre yarns were used as the cover yarn component, while 316 L type SS metal wires (supplied by Orbital Foreign Trade LLC, Turkey) varying in diameter (50 µm and 100 µm) were used as the core yarn component. The twist of the first layer was selected as 300 turns/meter (wrapped count: 3 turn/ cm) in the S direction and that of the second layer was selected as 300 turns/meter (wrapped count: 3 turn/ cm) in the Z direction. An illustration of the basic structure of cross covered composite yarns consisting of two covering yarns and one core yarn is shown in ***Figure 2***. ***Figure 3*** illustrates the hollow spindle process.

A covered yarn is composed of a straight core which is wrapped with two covering yarns. At the initial stage of the wrapping process, the first layer is composed of a core yarn and one covering yarn. Finally the second layer is composed of the first layer covered by a second covering yarn.

Yarn coding

Coding of the composite yarns according to structural parameters is given by:
C_{ab} : (a) core yarn diameter, (b) cover yarn type
for a : 1 stands for 50 µm (150 dtex) SS;
2 stands for 100 µm (600 dtex) SS
for b : 1 stands for polypropylene, 330×2 dtex
2 stands for cotton, 310×2 dtex
3 stands for core-spun polyester/cotton, 346×2 dtex
4 stands for continuous filament polyester, 295×2 dtex
5 stands for continuous filament polyamide 6.6, 312×2 dtex
6 stands for core-spun polyester / polyester, 305×2 dtex
7 stands for polyester cut fibre, 320×2 dtex

For example, C 27 means that the composite yarn is produced by cross covering a 316 L type SS metal wire core with a diameter of 100 µm with two 320 dtex count polyester cut fibre cover yarns.

Table 1. *Codes and linear density values of the composite yarns.*

Composite yarn code / composite yarn linear density, dtex (Nm)		Core yarn (SS) diameter	
		50 µm	100 µm
Cover yarn type and yarn count expressed in dtex, Nm	polypropylene, 330×2 (30/2)	$c_{1,1}$/900 (11)	$c_{2,1}$/1402 (7)
	cotton, 310×2 (32/2)	$c_{1,2}$/824 (12)	$c_{2,2}$/1310 (8)
	core-spun polyester/cotton, 346×2 (29/2)	$c_{1,3}$/943 (11)	$c_{2,3}$/1461 (7)
	continuous filament polyester, 295×2 (34/2)	$c_{1,4}$/802 (12)	$c_{2,4}$/1292 (8)
	continuous filament polyamide 6.6, 312×2 (32/2)	$c_{1,5}$/837 (12)	$c_{2,5}$/1340 (8)
	core-spun polyester / polyester, 305×2 (33/2)	$c_{1,6}$/812 (12)	$c_{2,6}$/1305 (8)
	polyester cut fibre, 320×2 (31/2)	$c_{1,7}$/868 (12)	$c_{2,7}$/1369 (7)

Figure 4 shows stereomicroscopic images of the C15 and C22 coded composite yarns.

The codes and linear density values of the fourteen different composite yarns produced within the scope of the study are given in ***Table 1***.

Method

Prior to measurements and tests, all the yarn samples were acclimatised at standard atmosphere (20 ± 2 °C, 65 ± 2 % RH) conditions for 48 hours [25]. In order to investigate composite yarn physical properties and behaviours in further textile manufacturing stages, measuring of the yarn count and testing of the tenacity, elongation at break, work of rupture (toughness) and stiffness characteristics were performed. The yarn count was measured by using a classical count winder and assay balance according to the ISO 2060 standard [26].

Tensile test

Tensile strength tests of the composite yarns were performed on an Instron tensile tester (Model 4301, USA) according to the ISO 2062 standard [27]. Tenacity in cN/tex, elongation at break in % and work of rupture (toughness) in cN×cm properties of the yarns were measured with test parameters of 500 mm gauge length, 10 cN pre-tension, 5 kg load cell and 500 mm/min test speed. The tenacity of the yarns produced was calculated after all measurements were made using breaking load in cN and yarn count in tex values. Ten tests were performed for each composite yarn type. The values are recorded for the mean.

Stiffness test

A laboratory test method proposed by Coats Technology Center was used for determination of the stiffness of the composite yarns. The test method was

Figure 5. *Photo of the stiffness tester (Testometric M250-2.5 CT Modified).*

Table 2. *Multivariate ANOVA results.*

			Tenacity		Elongation at break		Work of rupture	
Source		df	F	Sig.(p)	F	Sig.(p)	F	Sig.(p)
Main effect	Core yarn diameter (D)	1	1501.21	0.000	88.82	0.000	2293.52	0.000
	Cover yarn type (T)	6	632.46	0.000	504.74	0.000	1291.43	0.000
Interaction	D x T	6	63.59	0.000	12.08	0.000	165.08	0.000

Table 3. *Student-Newman-Keuls test for tenacity, elongation at break and work of rupture.*

Parameter		Tenacity, cN/tex	Elongation at break, %	Work of rupture, cN×cm
Core yarn diameter (D)	50 µm	18.50 a	19.24 a	16685 a
	100 µm	29.83 b	21.11 b	30957 b
Cover yarn type (T)	cotton	12.43 a	7.63 a	2423 a
	polyester cut fibre	18.97 b	19.43 b	16911 b
	core-spun polyester/cotton	18.88 b	21.85 d	18329 c
	core-spun polyester / polyester	22.02 c	20.59 c	20644 d
	polypropylene	22.03 c	23.46 e	24524 e
	continuous filament polyester	34.61 d	25.97 f	41893 f
	continuous filament polyamide 6.6	40.21 e	22.28 d	42022 f

designed by making some modifications on a Testometric M250-2.5 CT tensile tester (U.K.) located in the Coats Technology Center, Physical Testing and Analysis Laboratory. ***Figure 5*** shows an image of the modified tensile tester. A rectangular-shaped metal apparatus was assembled on the lower jaw. The test method is based on passing a yarn sample of 3 cm length through the hole of the upper jaw, with the yarn sample suspended at its centre. Then the upper jaw moves up with a speed of 12.5 mm/min. The yarn sample starts to bend while passing through the hole of the metal apparatus. The resistance of the yarn to bending by tensile force is accepted as the stiffness value of the yarn. Three tests were performed for each composite yarn type. Values are recorded for the mean.

Statistical evaluation

The SPSS 17.0 Statistical software package was used for all statistical procedures. Completely randomised two-factor analysis of variance (ANOVA) was used for determination of the statistical significance of the composite yarn's structural parameters such as core yarn diameter and cover yarn type for tensile and stiffness properties of the composite yarns in the study. Student-Newman-Keuls (SNK) tests were used to compare the means. Means marked by a different letter (a, b, c) showed that they were significantly different. A 95 % confidence interval was selected for all statistical evaluations.

Results and discussion

Tensile behaviour

Tensile behaviours of the composite yarns were evaluated according to tenacity in cN/tex, elongation at break in % and work of rupture in cN×cm values. Diagrams for the tenacity, elongation at break and work of rupture values of the composite yarns are demonstrated in ***Figures 6, 7*** and ***8***, respectively. The p-values associated with F-tests for a two-way completely randomized ANOVA are given in ***Table 2***, while the SNK test values for the tenacity, elongation at break and work of rupture results are presented in ***Table 3***.

The different letters next to the counts indicate that they are significantly different from each other at a significance level of 5%

The cross covered composite yarns had complex structures by combining cover yarns and core yarns. When the cover yarns and core metal wires are put together under tension the cover yarns are subjected to shear force, whereas the core metal wire is subjected to normal force. Accordingly the straightened yarns suffer normal force and break first, making the core yarn break. After the core yarn is broken the cover yarns are then stretched until the yarns become straight and then suffer breakage. The breaking mechanism of these types of yarns should be known when inspecting the tensile results.

According to ***Figure 6***, it was observed that the minimum tenacity was obtained as 11.84 cN/tex for the composite yarn (C12 coded yarn) produced with core yarn of SS metal wire with 50 µm diameter and cover yarn of cotton, while the maximum tenacity was obtained as 49.95 cN/tex for the composite yarn (C25 coded yarn) produced with core yarn of SS metal wire with 100 µm diameter and cover yarn of continuous filament polyamide 6.6.

The results of the ANOVA test given in ***Table 2*** indicated that there were statistically significant (5% significance level) differences between the tenacity values of the composite yarns with different core yarn diameters and between those of the composite yarns with different cover yarn types. The effect of the interaction between the core yarn diameter (D) and cover yarn type (T) on thw tenacity was significant.

The SNK test results given in ***Table 3*** revealed that the composite yarns with different core yarn diameters possessed statistically different tenacity values. The tenacity value for the core yarn diameter of 50 µm was 18.50 cN/tex, while that for the core yarn diameter of 100 µm was 29.83 cN/tex. According to ***Figure 6***, tenacity values of the composite yarns with 100 µm metal wire were more than those of the composite yarns with 50 µm metal wire. The core yarn diameter difference led to an increase in tenacity values by 18 – 86% depending on the cover yarn type.

According to ***Table 3***, the composite yarns of different cover yarn types possessed statistically different tenacity values. The tenacity value for the cotton cover yarn type was 18.97 cN/tex, while that for continuous filament polyamide 6.6 cover yarn type was 40.21 cN/tex. According to ***Figure 6***, tenacity values of the composite yarns with cotton cover yarn type were less than those of the composite yarns with cover yarn of continuous filament polyamide 6.6. The cover yarn type difference led to a decrease in tenacity values by 157 – 283% depending on the core yarn diameter. As composite yarn structural parameters like the twist levels of the first and second layer cover yarns were kept constant in this study, it was obvious that the composite yarns' cover yarn type had a great influence on the yarn tenacity. This is due to the better packing efficiency of the composite yarns produced with polyamide fibres. The polyamide fibre wrap contributes to the overall yarn strength.

As a result of the inspection of the elongation at break in % values of the composite yarns shown in ***Figure 7***, it was observed that the minimum percentage was obtained as 6.71% for the composite yarn (C22 coded yarn) produced with core yarn of SS metal wire with a 100 µm diameter and cover yarn of cotton, while the maximum percentage was obtained as 26.96% for the composite yarn (C24 coded yarn) produced with core yarn of SS metal wire with a 100 µm diameter and cover yarn of continuous filament polyester.

It can be observed from ***Table 2*** that the elongation at break is being borne by the core yarn diameter and structural parameters of the cover yarn type. Statistically significant (5% significance level) differences occurred between the elongation at break values of the composite yarns with different core yarn diameters and between the elongation at break values of the composite yarns with different cover yarn types. The effect of the interaction between the core yarn diameter (D) and cover yarn type (T) on elongation at break was significant.

The SNK test results given in ***Table 3*** revealed that the composite yarns with different core yarn diameters possessed statistically different elongation at break values. The composite yarns containing coarser metal wire have considerably greater elongation at break due to the presence of a stiffer core component. The elongation at break value for a core yarn diameter of 50 µm was 19.24%, while that for a core yarn diameter of 100 µm was 21.11%. According to ***Table 3***, the composite yarns with different cover yarn types possessed statistically different elongation at break values. The elongation at break value for the cotton cover yarn was 7.63% while that for continuous filament polyester cover yarn was 25.97%.

As a result of the inspection of the work of rupture (cN×cm) values of the composite yarns shown in ***Figure 8***, it was observed that the minimum value was obtained as 2311 cN×cm for the composite yarn (C22 coded yarn) produced with core yarn of SS metal wire of 100 µm diameter and cover yarn of cotton, while the maximum value was obtained as 2311 cN x cm for the composite yarn (C24 coded yarn) produced with core yarn of SS metal wire of 100 µm diameter and cover yarn of continuous filament polyester.

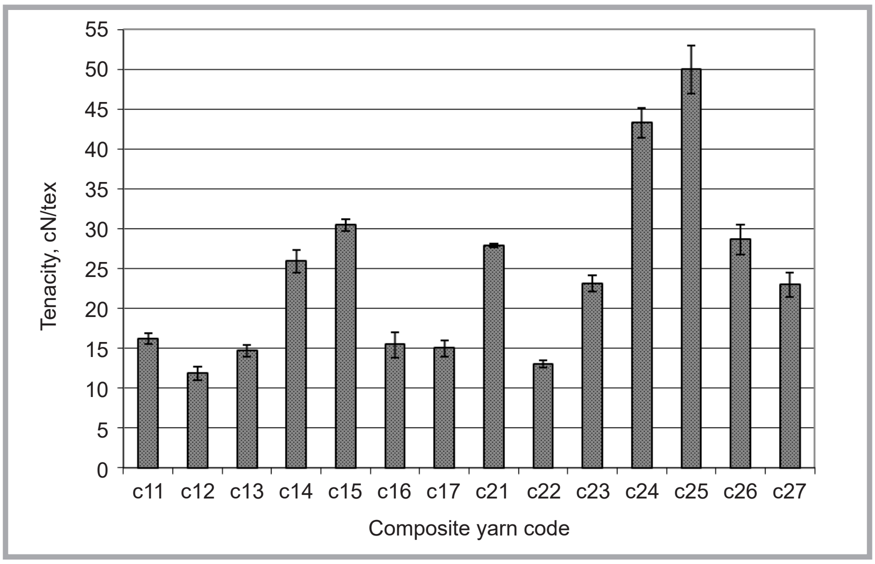

Figure 6. *Tenacity in cN/tex values for composite yarns versus yarn codes (Error bars indicate a confidence interval of 95 %).*

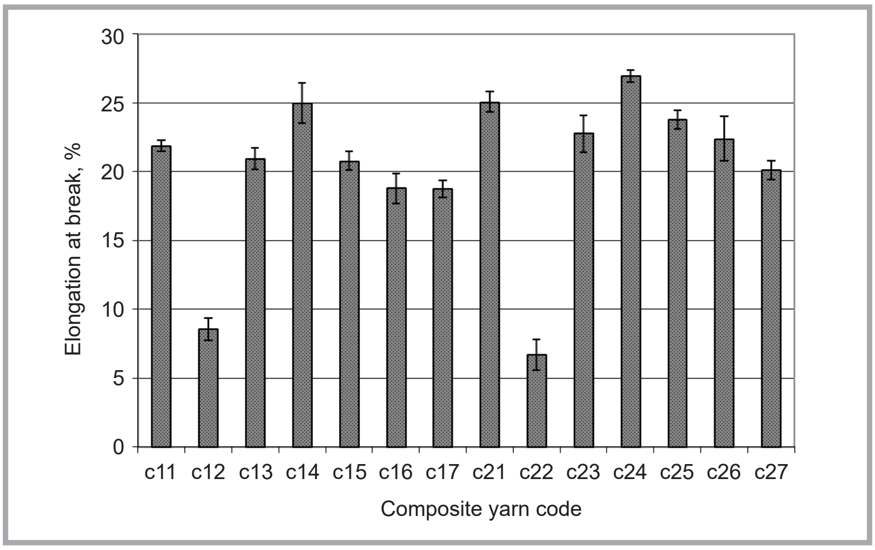

Figure 7. *Elongation at break in % values for composite yarns versus yarn codes (Error bars indicate a confidence interval of 95 %).*

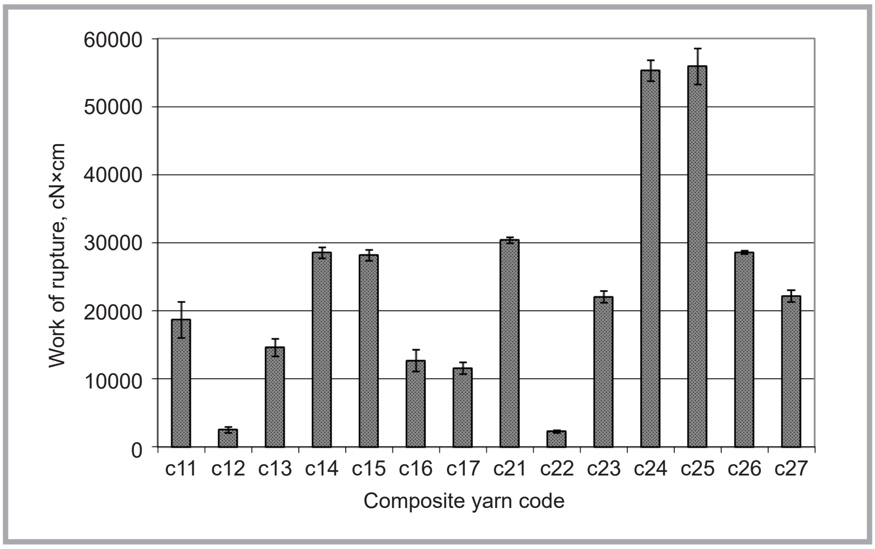

Figure 8. *Work of rupture in cN×cm values for composite yarns versus yarn codes.*

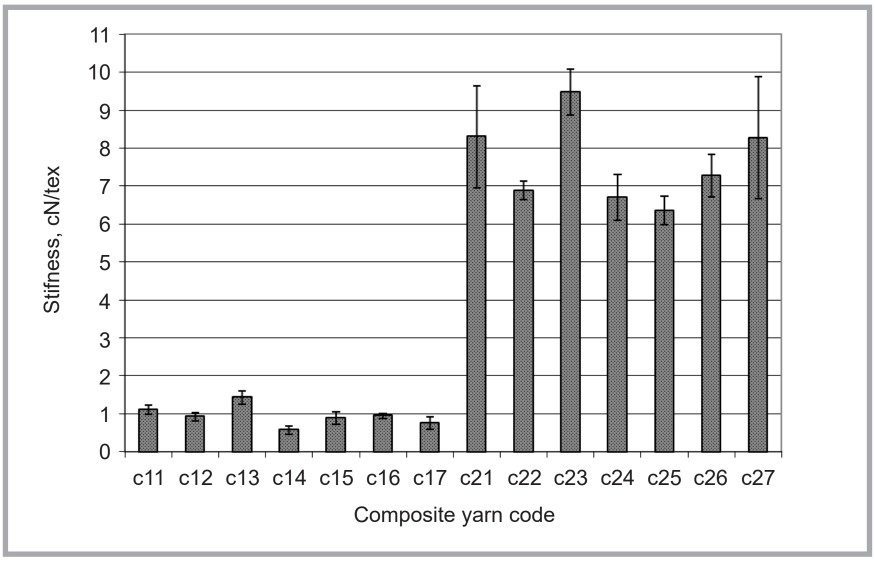

Figure 9. *Stiffness in cN/tex values for composite yarns versus yarn codes.*

Table 4. *Univariate ANOVA results for the friction coefficient.*

Source		df	F	Sig. (p)
Main effect	Core yarn diameter (D)	1	1509.863	0.000
	Cover yarn type (T)	6	8.496	0.000
Interaction	D x T	6	4.237	0.004

Table 5. *Student-Newman-Keuls test for stiffness*

Parameter		Stiffness, cN/tex
Core yarn diameter (D)	50 µm	0.94 a
	100 µm	7.61 b
Cover yarn type (T)	continuous filament polyamide 6.6	3.62 a
	continuous filament polyester	3.64 a
	cotton	3.90 ab
	core-spun polyester / polyester	4.11 ab
	polyester cut fibre	4.51 ab
	polypropylene	4.71 b
	core-spun polyester/cotton	5.45 c

The P values given in ***Table 2*** indicated that there were statistically significant (5% significance level) differences between the work of rupture values of the composite yarns with different core yarn diameters and between the work of rupture values of the composite yarns with different cover yarn types. The effect of the interaction between core yarn diameter (D) and cover yarn type (T) on work of rupture was significant.

The SNK test results given in ***Table 3*** revealed that the composite yarns with different core yarn diameters and cover yarn types possessed statistically different work of rupture values. The work of rupture value for a core yarn diameter of 50 µm was 16685 cN×cm, while that for a core yarn diameter of 100 µm was 30957 cNxcm. The work of rupture value for the cotton cover yarn type was 2423 cN×cm, while that for cover yarn of continuous filament polyamide 6.6 was 42022 cN×cm.

Stiffness

A diagram for stiffness values of the composite yarns is demonstrated in ***Figure 9***. The p-values associated with F-tests for a two-way completely randomised ANOVA are given in ***Table 4***, while SNK test values for the stiffness results are presented in ***Table 5***.

As a result of the inspection of the stiffness values of the composite yarns shown in ***Figure 9***, it was observed that the minimum stiffness value was obtained as 0.57 cN/tex for the composite yarn (C14 coded yarn) produced with core yarn of SS metal wire of 50 µm diameter and cover yarn of continuous filament polyester, while the maximum value was obtained as 9.47 cN/tex for the composite yarn (C23 coded yarn) produced with core yarn of SS metal wire of 100 µm diameter and cover yarn of core-spun polyester/cotton

The P values in ***Table 4*** indicated that there were statistically significant (5% significance level) differences between the stiffness values of the composite yarns with different core yarn diameters. Another aspect of the stiffness test results was that there were significant differences between the stiffness values of the composite yarns with different cover yarn types. The effect of the interaction between the core yarn diameter (D) and cover yarn type (T) on stiffness was significant.

The SNK test results given in ***Table 5*** revealed that the composite yarns with different core yarn diameters possessed statistically different stiffness values. The stiffness value for a core yarn diameter of 50 µm was 0.94 cN/tex, while that for a core yarn diameter of 100 µm was 7.61 cN/tex. According to ***Figure 9***, stiffness values of the composite yarns with 100 µm metal wire were more than those of the composite yarns with 50 µm metal wire. The core yarn diameter difference led to a minimum increase of 5.6 times and maximum of 10.8 times in stiffness values depending on the cover yarn type. In this situation, it should be taken into account that all the composite yarns were produced with a constant wrapped count. These results can be interpreted as follows: the metal wire diameter increase at a constant wrapped count renders the yarn stiffer. It is stated in the literature that yarn stiffness is influenced by the yarn type and fibre content [28].

According to ***Table 5***, the composite yarns with different cover yarn types possessed statistically different stiffness values. The rank for the stiffness values from the lowest to the highest value was as follows: continuous filament polyamide 6.6, continuous filament polyester, cotton, core-spun polyester/polyester, polyester cut fibre, polypropylene, core-spun polyester/cotton. The minimum stiffness value was 3.62 cN/tex for the cover yarn type with continuous filament polyamide 6.6, while the maximum stiffness value was 5.45 cN/tex for the cover yarn type with core-spun polyester/cotton. Stiffness values of composite yarns with cover yarn types with continuous filament polyamide 6.6, continuous filament polyester, cotton, polyester/core-spun polyester, and polyester cut fibre were statistically the same. This situation can be attributed to the fact that the use of SS wire as the core component in the cross covered composite yarn structure weakened the influence of the cover yarn type on stiffness. The stiffness value of composite yarn with polypropylene cover yarn is statistically greater than those of composite yarns with cover yarn of continuous filament polyamide 6.6 and continuous filament polyester. The stiffness value of composite yarn with cover yarn *T* of core-spun polyester/cotton is statistically different from those of all other composite yarns with various cover yarn types. According to ***Figure 9***, the stiffness value of the C14 coded composite yarn was less than that of the C13 coded composite yarn by 60%, while the stiffness value of the C24 coded composite yarn was less than that of the C23 coded composite yarn by 29%. When a constant twist level for the production is taken into consideration, it is obvious that a decrease in percentage values from 60% to 29% can be ascribed to fact that the usage of coarser SS wire as a core component weakened the influence of the cover yarn type factor on stiffness.

Conclusions

The objective of this study was to investigate the influences of composite yarn production parameters like core yarn diameter and cover yarn type on the tensile and stiffness properties of composite yarns.

- According to the statistical tests performed on the measurements, the effect of the core yarn diameter on the tenacity of composite yarns was significant. Tenacity values of the composite yarns increased with the usage of core yarns with a coarse diameter.
- Overall it was clearly demonstrated by the statistical tests that both the elongation at break and work of rupture values of the composite yarns depend on the core yarn diameter. The elongation at break and work of rupture increased significantly with an increase in the core yarn diameter. These results can be interpreted as being due to the presence of a stiffer core component in the composite yarn.
- The composite yarns with metal wires of different diameters possessed statistically different stiffness values. Stiffness values of the composite yarns increased significantly with an increase in the SS metal wire diameter, caused by the fact that the metal wire diameter increase at a constant wrapped count rendered the yarn stiffer.
- The most obvious finding to emerge from the physical parameters is that the yarn tenacity, elongation at break and work of rupture values of the composite yarns were affected statistically by the cover yarn types. This situation can be explained by the fact that composite yarns with continuous filament polyamide 6.6 and continuous filament polyester cover yarns were shown to be better in tenacity than those with cotton cover yarns due to a better packing efficiency produced with polyamide and polyester filaments. The polyamide and polyester filament wrap contributes to the overall yarn strength, elongation at break as well as work of rupture.
- This study evidenced that the composite yarns with different cover yarn types possessed statistically different stiffness values. But the stiffness values of composite yarns with cover yarn types with continuous filament polyamide 6.6, continuous filament polyester, cotton, polyester/core-spun polyester, polyester cut fibre were statistically the same. This situation was caused by the fact that the existence of metal wire as a core component in the cross covered composite yarn structure may lead to a reduction in the impact of the cover yarn type on stiffness.
- Finally it could be concluded that it will be useful to make further studies on determining the effect of composite yarn parameters on other physical properties of these yarns. The physical properties which should be highlighted are shrinkage and yarn liveliness.

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References

1. Alagirusamy R, Das A. Technical Textile Yarns. Woodhead Publishing Series in Textiles No. 101,U.K, 2010, ISBN 1 84569 549 6, pp. 259-260
2. Lou CW. Process of Complex Core Spun Yarn Containing a Metal Wire. Textile Research Journal 2005;75,6:466–473.
3. Bedeloglu AÇ, Bozkurt Y. Textiles Types, Uses and Production Methods. Nova Science Publishers, USA, New York, 2012, ISBN 978-1-62100-239-0, 317-329.
4. Perumalraj R, Dasaradan BS, Nalankili G. Copper, Stainless Steel, Glass Core Yarn, and Ply Yarn Woven Fabric Composite Materials Properties. Journal of Reinforced Plastics & Composites 2010;29,20:3074-3082.
5. Bedeloglu A, Sunter N, Bozkurt Y. Manufacturing and Properties of Yarns Containing Metal Wires. Materials and Manufacturing Processes 2011;26,11:1378-1382.
6. Bedeloglu A. Investigation of Electrical, Electromagnetic Shielding and Usage Properties of Woven Fabrics Made from Different Hybrid Yarns Containing Stainless Steel Wires. Journal of the Textile Institute 2013;104,12:1359-1373.
7. Po-Wen H, An-Pang C, Ching-Wen L, Jia-Horng L. Electromagnetic Shielding Effectiveness and Functions of Stainless Steel/Bamboo Charcoal Conductive Fabrics. Journal of Industrial Textiles 2014;44,3:477-494.
8. Ortlek HG, Kılıc G, Okyay G, Bilgin S. Electromagnetic Shielding Characteristics of Different Fabrics Knitted from Yarns Containing Stainless Steel Wire. Industria Textila 2011;62,6:304–308.
9. Su CI, Chern JT. Effect of Stainless Steel Containing Fabrics on Electromagnetic Shielding Effectiveness. Textile Research Journal 2004;74,1:51-54.
10. Chen HC, Lin JH, Lee KC. Electromagnetic Shielding Effectiveness of Copper/Stainless Steel/Polyamide Fiber Co-Woven-Knitted Fabric Reinforced Polypropylene Composites. Journal of Reinforced Plastics and Composites 2008;27,2:187-204.
11. Ozen MS, Sancak E, Beyit A, Usta İ, Akalin M. Investigation of Electromagnetic Shielding Properties of Needle-Punched Nonwoven Fabrics with Stainless Steel and Polyester Fiber. Textile Research Journal 2013;83,8:849-858.
12. Rajendrakumar K, Thilagavathi G. A Study on the Effect of Construction Parameters of Metallic Wire/Core Spun Yarn Based Knitted Fabrics on Electromagnetic Shielding. Journal of Industrial Textiles 2013;42,4:400-416.
13. Shyr TW, Shie JW. Electromagnetic Shielding Mechanisms Using Soft Magnetic Stainless Steel Fiber Enabled Polyester Textiles. Journal of Magnetism and Magnetic Materials 2012;324, 23:4127–4132.
14. Perumalraj R, Dasaradan BS, Anbarasu R, Arokiaraj P, Leo Harish S. Electromagnetic shielding effectiveness of copper core-woven fabrics. Journal of The Textile Institute 2009; 100,6:512–524.

15. Deniz DD, Kadoğlu H. Electromagnetic Shielding Characterization of Conductive Woven Fabrics Produced with Silver-Containing Yarns. Textile Research Journal 2015;85,10:1009-1021.
16. Das AJ, Krishnasamy JR, Alagirusamy RA, Basu A. Electromagnetic Interference Shielding Effectiveness of Ss/Pet Hybrid Yarn Incorporated Woven Fabrics. Fibers and Polymers 2014;15,1:169-174.
17. Zhe L, Yongheng Z, Xing R, Xiuchen W. Influence of Metal Fibre Content of Blended Electromagnetic Shielding Fabric on Shielding Effectiveness Considering Fabric Weave. Fibres & Textiles in Eastern Europe 2015; 23,4: 83-87.
18. Örtlek HG, Çalışkan Ç, Kurban R. A Comparative Study on the Physical Properties of Hybrid Yarns Containing Copper Wire. Journal of Textiles and Engineer 2013;20,89:11-20.
19. Perumalraj R, Dasaradan BS. Tensile Properties of Copper Core Yarn. Journal of Reinforced Plastics and Composites 2010;29,11:1688-1701.
20. Bedeloglu A, Sunter N. Investigation of Polyacrylic/Metal Wire Composite Yarn Characteristics Manufactured on Fancy Yarn Machine. Materials and Manufacturing Processes 2013;28,6:650-656.
21. Bedeloglu A, Sunter N, Yildirim B, Bozkurt Y. Bending and Tensile Properties of Cotton/Metal Wire Complex Yarns Produced for Electromagnetic Shielding and Conductivity Applications. Journal of the Textile Institute 2012;103, 12: 1304-1311.
22. Schwarz A, Kazani I, Cuny L, Hertleer C, Ghekiere F, Clercq DG, Langenhove LV. Comparative Study On The Mechanical Properties Of Elastic, Electro-Conductive Hybrid Yarns and Their Input Materials. Textile Research Journal 2011;81,16:1713-1723.
23. Lou CW. Process of Complex Core Spun Yarn Containing a Metal Wire. Textile Research Journal 2005;75,6:466-473.
24. Örtlek HG. Developing of Innovative Core-Spun Yarns for Denim Fabrics. In “Proc. UTİB 5th International R&D Brokerage Event”, Bursa, Turkey, 2013, pp.305-306, ISBN: 978-605-5919-05-4
25. ISO 139:2005. Textiles — Standard Atmospheres for Conditioning and Testing
26. ISO 2060:1994. Textiles -- Yarn from packages -- Determination of linear density (mass per unit length) by the skein method
27. ISO 2062:2009. Textiles - Yarns from packages - Determination of single-end breaking force and elongation at break using constant rate of extension (CRE) tester
28. Ghosh A, Patanaik A, Anandjiwala RD, Rengasamy RS. A Study on Dynamic Friction of Different Spun Yarns. Journal of Applied Polymer Science 2008;108:3233- 3238.

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INSTITUTE OF BIOPOLYMERS AND CHEMICAL FIBRES

LABORATORY OF BIODEGRADATION

The Laboratory of Biodegradation operates within the structure of the Institute of Biopolymers and Chemical Fibres. It is a modern laboratory with a certificate of accreditation according to Standard PN-EN/ISO/IEC-17025: 2005 (a quality system) bestowed by the Polish Accreditation Centre (PCA). The laboratory works at a global level and can cooperate with many institutions that produce, process and investigate polymeric materials. Thanks to its modern equipment, the Laboratory of Biodegradation can maintain cooperation with Polish and foreign research centers as well as manufacturers and be helpful in assessing the biodegradability of polymeric materials and textiles.

The Laboratory of Biodegradation assesses the susceptibility of polymeric and textile materials to biological degradation caused by microorganisms occurring in the natural environment (soil, compost and water medium). The testing of biodegradation is carried out in oxygen using innovative methods like respirometric testing with the continuous reading of the CO_2 delivered. The laboratory’s modern MICRO-OXYMAX RESPIROMETER is used for carrying out tests in accordance with International Standards.

The methodology of biodegradability testing has been prepared on the basis of the following standards:

- **testing in aqueous medium:** ’Determination of the ultimate aerobic biodegrability of plastic materials and textiles in an aqueous medium. A method of analysing the carbon dioxide evolved’ (PN-EN ISO 14 852: 2007, and PN-EN ISO 8192: 2007)
- **testing in compost medium:** ’Determination of the degree of disintergation of plastic materials and textiles under simulated composting conditions in a laboratory-scale test. A method of determining the weight loss’ (PN-EN ISO 20 200: 2007, PN-EN ISO 14 045: 2005, and PN-EN ISO 14 806: 2010)
- **testing in soil medium:** ’Determination of the degree of disintergation of plastic materials and textiles under simulated soil conditions in a laboratory-scale test. A method of determining the weight loss” (PN-EN ISO 11 266: 1997, PN-EN ISO 11 721-1: 2002, and PN-EN ISO 11 721-2: 2002).

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The following methods are applied in the assessment of biodegradation: gel chromatography (GPC), infrared spectroscopy (IR), thermogravimetric analysis (TGA) and scanning electron microscopy (SEM).

Contact:

INSTITUTE OF BIOPOLYMERS AND CHEMICAL FIBRES
ul. M. Skłodowskiej-Curie 19/27, 90-570 Łódź, Poland
Agnieszka Gutowska Ph. D.,
tel. (+48 42) 638 03 31, e-mail: lab@ibwch.lodz.pl