

PRODUCTION OF BI-COMPONENT POLYESTER FIBRES FOR EMR (ELECTROMAGNETIC RADIATION) PROTECTION AND EXAMINING EMR SHIELDING CHARACTERISTICS

EMR (Elektromanyetik Radyasyon) KORUMA AMAÇLI BİKOMPONENT POLİESTER LİF ÜRETİMİ VE EMR KALKANLAMA ÖZELLİĞİNİN İNCELENMESİ

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ABSTRACT

In this study, multifilament polyester yarns consist of bicomponent S/C (sheath/ core) fibres were produced in order to create electromagnetic shielding properties. Yarns were produced in 260 dtex linear density with 72 bicomponent filaments. The conductive additive material was nano iron oxide 20% (w/w) in PBT (polybutylene terephthalate) masterbatch. 1, 2 and 3% masterbatch (20% nano iron oxide in PBT) were fed into the sample yarn production device, however; acceptable yarn production could only be achieved by 1% masterbatch due to the high number of machine stops at higher amounts of additive material. Shrinkage at the boil and tenacity tests were performed on the produced yarns. Also, the produced yarns were knit to form fabrics and test the EMSE (electromagnetic shielding efficiency) values by these knitted surfaces. The EMSE tests on the knitted fabric samples were performed basically according to ASTM D 4935 Coaxial Holder Method but the method used was a modified method that uses a smaller sample holder. The EMSE values at 30 MHz of the fabric samples knitted by the produced bicomponent yarns were measured as 18,78 dB and 13,59 dB for tight and loose stitch densities, respectively.

Keywords: Electromagnetic radiation (EMR) shielding, polyester, bicomponent fibres.

ÖZET

Bu çalışmada elektromanyetik radyasyondan korunma amaçlı multifilament S/C (sheath/ core) katkılı bikomponent poliester iplik üretimi gerçekleştirilmiştir. İplikler 260 dtex 72 filament olarak elde edilmiştir. Katkı malzemesi öncelikle taşıyıcı malzeme olarak PBT kullanılarak %20 nano demiroksit ile masterbatch şeklinde hazırlanmıştır. Bikomponent lifin merkezinde katkı malzemesi olarak % 20'lik nanodemiroksit/ PBT masterbatch%1 oranında kullanılmıştır. %2 ve %3 oranları da denenmiş fakat akıştaki bozukluk ve kopukluklardan dolayı üretim yapılamamıştır. Üretilen ipliklere kaynama çekmesi ve mukavemet testleri yapılmıştır. Elde edilen ipliklerle iki farklı sıklıkta örme kumaş üretilmiştir. Üretilen kumaşların EMR koruma etkinliği araştırılmış 30 MHz' de % 1 demiroksit katkılı kumaşın ekranlama etkinliği daha sık olan kumaşta 18,78 dB iken, daha seyrek kumaşta 13,59 olarak ölçülmüştür.

Anahtar Kelimeler: Elektromanyetik radyasyon koruma, poliester, bikomponent lif.

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1. INTRODUCTION

Industrial development and technical progress result the use of a wide variety of electronic devices that generate electromagnetic radiation (EMR). Indeed, EMR sources such as mobile communications, wireless access networks and television broadcasting are placed in urban areas. Consequently, the entire human habitat remains under the influence of electromagnetic pollution. Radiation from these sources may be dangerous depending on exposure

intensity, duration and frequency range. As a result, research on EMR shielding materials increased. Furthermore, textile materials are frequently studied in EMR shielding studies for being lighter and more flexible alternatives (1-7).

However, conventional textile materials do not provide appropriate conductivity for EMR shielding purposes. Therefore, several methods are used in order to enhance conductivity to the conventional textile fibres. The generally

recognised methods include blending conductive metal fibres by conventional fibres (8-17) and coating of the textiles by conductive materials (18-26).

Electromagnetic Shielding

Electromagnetic radiation has two components those are electric and magnetic field components, and they oscillate in phase perpendicular to each other and perpendicular to the direction of energy propagation (1). EMR is not only susceptible of health hazards but also causes electromagnetic interference (EMI) that is the interference of EMR from one electronic device to another electronic device. EMR shielding is required for both cases. The practical approach to create EMR shielding is creating a Faraday cage by means of conductive materials. Shielding is defined as confining radiated energy within a specific region or prevention of radiated energy from entering into a specific region. It is mostly processed in screened or shielded room, known as Faraday cage. The electromagnetic shielding effectiveness (EMSE) can be measured by several methods described by standards of the Institute of Electrical and Electronics Engineers (IEEE) Std. 299, the American Society for Testing and Materials (ASTM) D4935, the Turkish Standards (TS) EN 50147-1, 2005, the Military (MIL) Standards 285 (withdrawn). Principle of EMSE measurement is mostly performed in two steps. Shielding efficiency is enumerated from transmission between two antennas with setting of an open door and close door of the enclosure. The shielding efficiency (SE) is a difference of these two values (in decibel (dB) unit) (4).

Blending Conductive Metal Fibres by Conventional Fibres

Conductive metals and alloys are the conventional materials for EMR shielding structures; however, these materials have some disadvantages such thermal expansion and corrosion problems. Hence, conductive textile-based but metal blended composite materials are gaining importance by being better alternatives owing to their light weight, flexibility and versatility. Örtlek et al. (8-10) and Bedeloğlu (11) investigated electromagnetic and shielding properties of the knitted textile surfaces made up of conductive hybrid yarns composed of cotton yarns and stainless steel. Chen et al. (12) produced conductive hybrid yarns consist of copper wire and polyamide filament fibres by the metal wire in the outer surface of the yarn. Cheng et al. (13) produced conductive core-spun yarns including stainless steel wire. Çeken et al. (14) produced conductive copper/ polyacrylic and stainless steel/polyacrylic yarns. Tezel et al. (15) produced conductive yarns consist of stainless steel and copper wires along with cotton fibres. The researchers reported increased EMR shielding performances by use of metal components to produce conductive hybrid yarns (8-17).

Coating of the Textiles by Conductive Materials

Textile surfaces may be coated by metals, metal oxides, metal salts or a variety of self-conductive polymers in order to impart electrically conductivity. Such methods consist of metal foil and the lamination process, chemical polymerisation method, vacuum deposit method and electroless method (18-26).

Avloni et al. (16) investigated the electromagnetic interference shielding effectiveness of polypyrrole (PPy)-coated polyester textiles and reported comparable shielding effectiveness reported for polyaniline systems or metal-coated carbon fibre composites. Hakansson et al. (17, 18) also reported the electromagnetic interference shielding effectiveness of polypyrrole (PPy)-coated nylon-lycra (17) and polypyrrole - coated polyester (18) fabrics. Neelakandan ve Madhusoothanan (19) investigated the effects of polyaniline (PANI) coating of polyester fibres on the conductivity. Both polypyrrole and polyaniline are known as intrinsic conducting polymers (ICP). Their metallic nature created interest in these polymers in many fields, such as electromagnetic shielding materials. Kim et al. (20) described conductive fibers production using two experimental processes (melt spinning and coating process) by polyaniline, polypyrrole and graphite. Lee et al. (21) reported the electromagnetic shielding results for polypyrrole and silver-palladium (AgPd) coated textile surfaces. Lai et al. (22) used silver, copper, aluminium and titanium to produce metal coated surfaces via a vacuum evaporation deposition technique with the woven fabrics made of metal/polyester filaments and reported different EMSE values for different coating materials. Proudnik et al. (23) coated various fabrics made up of polyester, cotton and polyester/cotton by Cu and Ti coatings were created in the vacuum and in the presence of carbon dioxide and concluded that light, strong, durable and attractive decorative shielding materials, as well as radar absorbing materials with masking capabilities in microwave band could be created by their method. Feng et al. (24) described an electric conductive and magnetic permeable composite coating with different mass fractions of multiwalled carbon nanotubes and cobalt-base amorphous powder was synthesized for wide frequency electromagnetic interference (EMI) shielding in their study. Carbon nanotubes (CNT) has been known as a nano-material with a well-defined structure and high conductivity and EMI shielding is one of the promising applications of them.

Bicomponent Fibres for Electromagnetic Shielding

This study aims the production of bicomponent fibres with a conductive core. Bicomponent (two-component) fibres production is one of the most interesting developments in the field synthetic fibres. Bicomponent fibres consist of two or more polymers having different physical or chemical properties, the polymers in the fibre may be placed nested or side by side. Bicomponent fibres are generally named according to their cross-sectional shape; side-by-side, islands in the sea or segmented pie bicomponent fibres (27).

Production of bicomponent fibres for EMR shielding is a considerably novel topic and limited studies are reported in the surveyed literature. Straat et al. (28) used a pilot-scale bicomponent melt spinning set-up to produce core/sheath fibres with fibre titers between 13 and 47 dtex. The sheath material was polyamide 6 (PA6) or polypropylene (PP) and the core material was a conductive polymer composite (CPC). The CPCs used were; polypropylene (PP) with carbon black (CB) and polyethylene (PE) with multiwalled carbon nanotubes (MWNT) (28). Hagstrom (29) reported the

spinnability and the conductivity of carbon black (CB)/polypropylene (PP) composites. Melt spinning of bi-component sheath/core fibres, confining the CB/PP composite to the core, was reported to produce fibres with high electrical conductivity and maintained spinnability (29).

In this study, bicomponent multifilament S/C (sheath/ core) polyester fibres were produced in order to impart electromagnetic shielding properties.

2. MATERIALS AND METHOD

2.1. Material

The list of chemical materials used in the experiments is presented in Table 1. The properties and purpose of use are also listed in Table 1 for each material. Nano iron oxide was purchased from a local supplier considering the particle size (20-50 nm) and narrow size distribution. PET (polyethylene terephthalate) chips were chosen for the sheath since PET is the most widely used synthetic polymer for textile applications. PBT chips were chosen because of its lower melting point compared to PET chips for ease of operation during bicomponent fibre production. Tegomer was used by the manufacturer of masterbatch (Setaş Kimya Sanayi A.Ş.) for uniform dispersion during masterbatch production.

2.2. Method

In this study, bicomponent multifilament S/C (sheath/ core) polyester yarns were produced to create fabrics able to shield electromagnetic field.

Yarns produced had the linear density of 260 dtex with 72 filaments. The linear density of each fibre was calculated as 3,61 dtex by dividing linear density of the yarn to the filament number.

The sequence for the production of bicomponent yarns was:

1. Production of conductive material (nano iron oxide) containing masterbatches. The production of masterbatch was required for uniform distribution of the conductive material in the core of the bicomponent fibre. Direct addition of the conductive material to the extruder resulted agglomeration of the conductive material, therefore, masterbatches of the conductive material were produced in a special masterbatch preparation machine. The masterbatches were produced by 20% (w/w) nano iron oxide in PBT chips.
2. The produced masterbatch chips were mixed with PBT chips to adjust the amount of the conductive material in core and this mixture was added to the first extruder (for

core) of the bicomponent yarn production machine (Figure 1).

3. PET chips were added to the second extruder (for sheath) of the bicomponent yarn production machine.
4. The feeding ratio of core and sheath components of the bicomponent fibres were adjusted as 30/70 (core/sheath) via adjustment of the pump speeds.

The conductive additive material was nano iron oxide in 20% (w/w) PBT masterbatch. The masterbatch production was made by the facilities of Setaş Kimya A.Ş. (İstanbul, Turkey). PBT chips were used as the carrier material of the masterbatch, also 3% Tegomer was used in the masterbatch production in order to prevent agglomeration of the conductive nano iron oxide particles.

The masterbatch production device was a Krauss Maffei Berstorff (Munich, Germany) brand with two screw extruders. The operating parameters were: speed 400 rpm, cutter speed 5 rpm, holes 2 and L/D ratio (Length/ Diameter ratio for the extruder) 42.

Bicomponent yarns were produced on a pilot scale bicomponent yarn production device (Figure 1). The produced nano iron oxide masterbatch and PBT chips were fed into the first extruder to form the core of the bicomponent fibres in the yarn. PET chips were fed into the second extruder to form the sheath of the bicomponent fibres in the yarn. Production of the bicomponent yarn was conducted by a feeding ratio of 30/70 for core/sheath. The PET and PBT chips were dried for 5 h before production at the temperatures 160°C and 130°C for PET and PBT, respectively.

The machine setup during bicomponent yarn production is given in Table 2. The spinneret had 72 holes to produce a 72 filament yarn. There were two extruders; one for the core and the other for the sheath of the bicomponent fibre. Each extruder had four heating zones. Also three more heating zones were present before spinneret but after the extruders for the combined core and sheath. The temperatures adjusted through the four heating zones of the extruders are given in Table 2 as $T_{extruder1}^a$ and $T_{extruder2}^a$ for extruders 1 and 2, respectively. Also, the temperatures of the three heating zones before spinneret but after the extruders are given as T_{final}^a in Table 2. A spin finish was applied to the drawn yarns with Limanol T35 spin finish oil. Several speed and pressure adjustments were tested to obtain continuous and uniform flow of the fibres, the optimum speed and pressure values reached are given in Table 2 for each pump, extruder and winder.

Table 1. Chemical materials used in the experiments.

Material	Brand-Supplier	Properties	Purpose of use
PBT chips	Shinkong Synthetic Fibers Corporation, Taipei, Taiwan	Viscosity 0,9 dl/g, Melting point 225 °C	Masterbatch production – carrier
Tegomer	Setaş Kimya Sanayi A.Ş., İstanbul, Turkey	Dust, density 0,95 g/cm ³ , synthetic wax	Masterbatch production – dispersant
Nano iron oxide	Grafen Kimya Sanayi A.Ş., Ankara, Turkey	20-50 nm	Masterbatch production – conductive additive
PBT chips	Polyteks A.Ş., Bursa, Turkey	Viscosity 0,978 dl/g Melting point 240°C	The core of the bicomponent fibre
PET chips	Polyteks A.Ş., Bursa, Turkey	Viscosity 0,655 dl/g Melting point 260°C	The sheath and the core of the bicomponent fibre

Table 2. Machine setup during production of bicomponent yarns.

Spinneret	72 holes - 0,3 mm (<i>diameter of the spinneret hole</i>)						
T ^a _{extruder1} (°C)	290 – 295 – 300 – 300						
T ^a _{extruder2} (°C)	290 – 295 – 300 – 300						
T ^a _{final} (°C)	310 – 310 – 310						
	% 1	% 2	% 3		% 1	% 2	% 3
Speed _{pump} (rpm)	6,22	6,22	6,22	Speed _{takeoff} (m/min)	929	-	-
Speed _{extruder1} (rpm)	37,00	37,00	37,00	Speed _{godet1} (m/min)	994	-	-
Pressure _{pump1} (bar)	19,80	21,40	23,00	Speed _{godet2} (m/min)	1,446	-	-
Pressure _{extruder 1} (bar)	60,00	60,00	60,00	Speed _{godet3} (m/min)	2,482	-	-
Speed _{pump2} (rpm)	7,01	7,01	7,01	Speed _{godet4} (m/min)	2,588	-	-
Speed _{extruder2} (rpm)	37,00	37,00	37,00	Speed _{winder} (m/min)	2,590	-	-
Pressure _{pump2} (bar)	35,00	35,00	35,00	T ^a _{godet1} (°C)	80	-	-
Pressure _{extruder2} (bar)	60,00	60,00	60,00	T ^a _{godet2} (°C)	100	-	-
Tangle _(bar)	1	1	1	T ^a _{godet3} (°C)	110	-	-
				Draw ratio	2,79	-	-

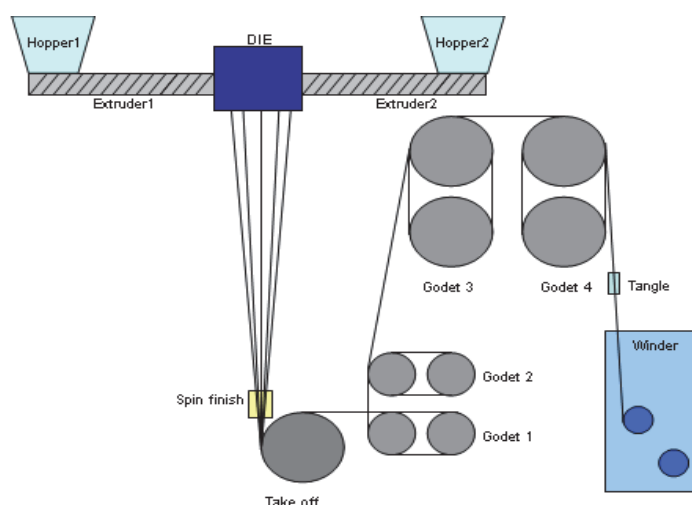


Figure 1. Pilot bicomponent yarn production device.

The following test methods were used for the evaluation of produced yarns and fabrics:

- The linear density of the yarns produced was measured according to DIN EN ISO 2060 (30). The tests were repeated five times, the average values are presented in Table 4.
- Strength tests were performed according to DIN EN ISO (German Institute of Standards) 2062 by a Statimat Me+ device(31). The tests were repeated twenty times, the average values are presented in Table 4.
- Shrinkage tests were performed according to DIN 53866 by a Texturmat Me+ device (32). The tests were repeated five times, the average values are presented in Table 4.
- Harry Lucas (Neumünster, Germany) brand socks knitting apparatus (Figure 2) were used to knit the yarns and form appropriate surfaces for the EMSE tests. Samples were knit in two separate machines (14 and 22 fein) in two densities. Fein number indicates the number of the needles in one inch of the knitting machine, thus, knitting with higher fein results tighter fabric structures. The features of the knitting machines are given in Table 3.
- The EMSE tests on the knitted fabric samples were performed basically according to ASTM D 4935 Coaxial

Holder Method (33) but the method used was a modified method that uses a smaller sample holder, detailed explanation and figures of the apparatus is present in the cited references (8, 9). The tests were repeated three times, the average values are presented in Table 4.

- Cross-sections of the fibres were visually examined by a Leitz Wetzlar (Wetzlar, Germany) microscope.
- The surface analysis was made by taking SEM (scanning electron microscopy) micrographs on a Carl Zeiss Evo 40 (Jena, Germany) instrument operating at an accelerating voltage of 5kV. In order to avoid problems due to charge build-up, the samples were previously sputter-coated with gold-palladium for two min. in a BAL-TEC SCD 005 (Witten, Germany) sputter-coating unit.

Table 3. Technical features of the Harry Lucas socks knitting machines.

Machine model number	7701	8264
Machine diameter	3,5"	3,5"
Machine fein	22	14
Number of needles	240	154



Figure 2. Socks knitting machines used.

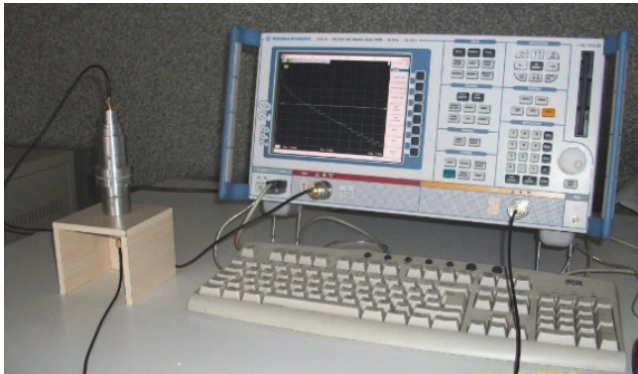


Figure 3. The EMSE test device.

3. RESULTS AND DISCUSSION

The results for 1% additive material usage are presented below. Although the test were started by three additive material ratios (1, 2 and 3%) as given in Table 2, only 1% could be produced properly. As the ratio of the additive material increased, the flow at the exit of the spinneret started to show disorders, consequently high numbers of machine stops were faced. Hence, proper fibre production could be achieved at 1% additive material ratio.

3.1. Physical appearance of the produced bicomponent yarns

The SEM photos of the samples to show the physical appearance of the bicomponent yarns with and without nano iron oxide additive are shown on Figure 4. The general appearance is almost the same. However, the use of nano iron oxide caused a brownish colour regarding the iron oxide particles in it.

Also, the physical appearance of the tighter and looser knitted samples is shown in Figure 5 in order to exhibit the change of the porosity of the surfaces. This porosity difference is effective on EMSE properties as discussed during presentation of the EMSE values.

3.2. Physical properties of the produced bicomponent yarns

Yarns without any additive material were also produced in order to use as reference during comparison of the physical properties. The physical tests results of the yarns with and without additive material are presented in Table 4.

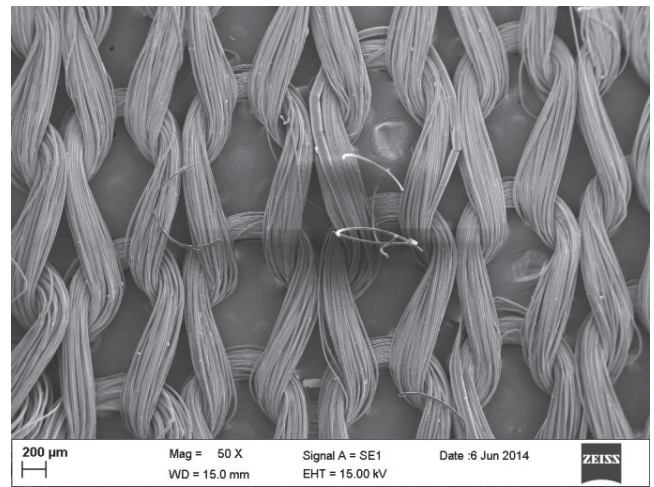
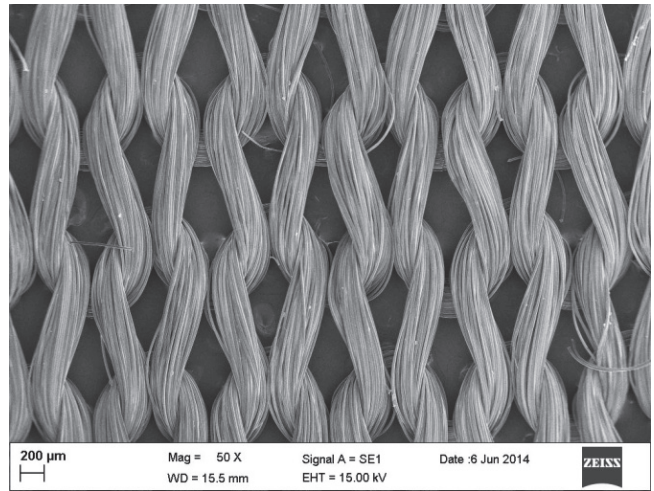


Figure 4. The SEM photos of the knitted samples; without additive on the left, with nano iron oxide additive on the right.

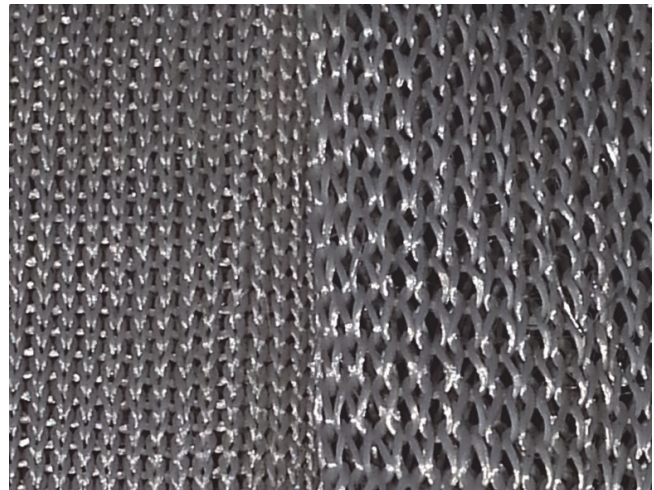


Figure 5. Photos of the knitted surfaces produced by the produced bicomponent yarns, tight fabric on the left hand side and loose fabric on the right hand side.

The linear density of the produced yarns was around 260 dtex for both fibres either containing additive or not. However, the linear density of the yarn with nano iron oxide additive is slightly higher (268,14 dtex) compared to that of the yarn without additive (260,16 dtex). This difference obviously occurs from the additive material input.

The shrinkage tests resulted a little difference between yarns with and without additive. The addition of the nano iron oxide additive slightly reduced the shrinkage (%) value from 11,84 to 9,57. This decrease is attributed to the placement of nano iron oxide additive in the fibre. Since the additive is not a polymer, it neither exhibits an orientation nor crystallization; in fact it probably hinders the orientation and crystallization within the core segment. This conclusion is supported by the strength tests results discussed below.

The load at the break (cN) and the tenacity (cN/dtex) values of the yarns with additive were less compared to the yarns without additive. The orientation of the polymers as well as the crystallization determines the strength properties and the dimensional stability for a polymer type. The modulus and the strength of the fibres increase as the crystallinity of the fibre increases (34, 35).

Since the additive material (nano iron oxide) forms aggregates and place between the polymer molecules (Figure 6), losses in the crystallinity as well as the strength properties were faced. These conclusions are compatible with the related literature (36). Such kind of aggregates, as shown on Figure 6, is reported to cause strength losses in the literature (36).

3.3. EMSE properties of the produced bicomponent yarns

The produced yarns were knit to form fabric surfaces to test the EMSE (electromagnetic shielding efficiency). The samples were knit in two stitch densities (Figure 5). The stitch densities were 9 and 8 stitch/cm, and the row densities were 10 and 8 row/cm, for tight and loose knitted fabrics, respectively.

The EMSE test results are presented on Figure 7. The EMSE values at 30 MHz of the fabric samples knitted by the produced bicomponent fibres were measured as 18,78 dB and 13,59 dB for tight and loose stitch densities, respectively. For comparison, the EMSE values of the samples knitted by the fibres without additive was 9,21 dB.

The SE of all materials dramatically decreases about frequency range 1100 –1500 MHz by the increasing frequency, as can be seen on Figure 7. This is due to the decrease in the wavelengths by the increase in the frequency; the decreased wavelengths can penetrate the fabric structure (pass through the spaces in the textile surface) resulting decrease in the EMSE values. However, the rate of differences among the tested sample stands along until the frequencies of 1200 MHz.

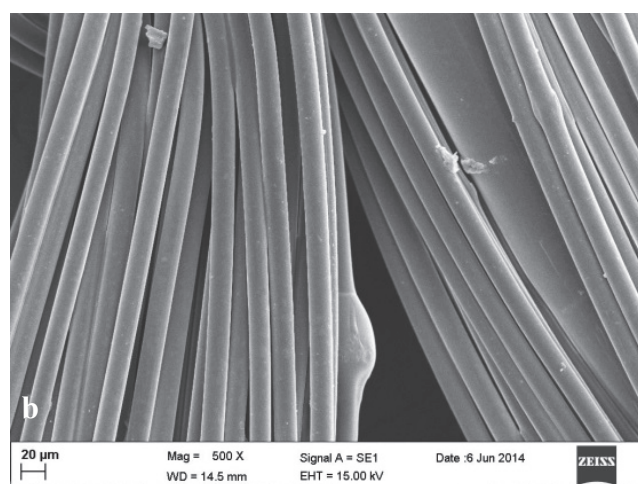
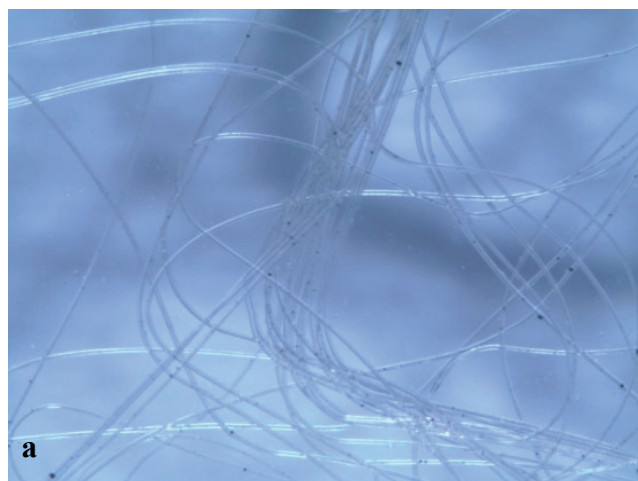


Figure 6. a. Microscope b. SEM images of the fibres with 1% nano iron oxide additive.

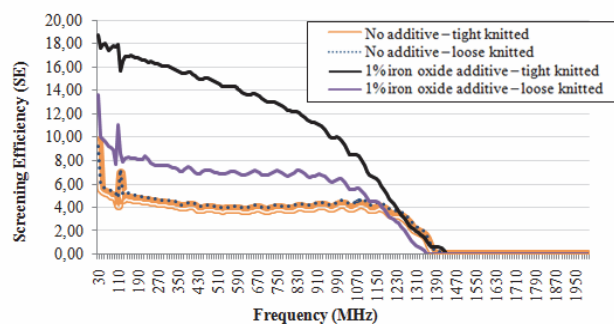


Figure 7. The effects of nano iron oxide additive material and stitch density on the EMSE properties of the knitted surfaces.

Table 4. The physical tests results of the yarns with and without additive material.

Yarn type		Linear density (dtex)	Shrinkage (%)	Elongation (%)	Load at the break (cN)	Tenacity (cN/dtex)
Without additive material	mean	260,16	11,84	31,54	663,79	2,53
	Sd	3,13	0,48	10,95	3,78	0,13
With 1% nano iron oxide additive	mean	268,14	9,57	48,82	396,25	1,51
	Sd	3,36	0,49	10,00	6,3845	0,99

These results approve the increase of the EMSE properties of the bicomponent yarns by using a conductive additive, nano iron oxide at this case. This result is promising, because there was a risk of agglomeration of the conductive nano iron oxide particles which might result in failure of the EMR protection.

On the other hand, the stitch density also had a considerable effect on the EMSE properties. The tighter knitted fabric had much higher EMSE values compared to the loose knitted one by using the same bicomponent yarns. Similar results were reported in the literature, concluding the increase of the EMSE values by the increased fabric densities (13, 37). This phenomenon is attributed to the less porosity (in case of the conductive material containing segments) of the tighter produced surface.

Analysis of variance (ANOVA) table is shown in Table 5 for statistical evaluation of the results. All H_0 hypothesis were rejected in table indicating that alternative hypothesis (H_a) were approved concluding the variables had effect on the EMSE values at 95% confidence intervals. Moreover, lower and upper bounds of the estimated marginal means are presented on Table 6. The 95% confidence intervals of tight and loose samples overlap for the samples without conductive material (nano iron oxide). However, the 95% confidence intervals of tight and loose samples do not overlap for the samples with conductive material indicating the effect of the conductive material in the core of the bicomponent fibres.

4. CONCLUSIONS

In this study, bicomponent multifilament S/C (sheath/ core) polyester yarns were produced in order to create electromagnetic shielding properties. Yarns were produced in 260 dtex linear density with 72 filaments. The conductive additive material was nano iron oxide 20% (w/w) in PBT masterbatch.

1, 2 and 3% masterbatch (20% nano iron oxide in PBT) were fed into the sample yarn production device, however; acceptable yarn production could only be achieved by 1% masterbatch due to the high number of machine stops at higher amounts of additive material.

Shrinkage at the boil and tenacity tests were performed on the produced yarns. The tenacity values of the yarns with additive were less than those of the yarns without additive. This result was concluded by changes the orientation of the polymers as well as the crystallinity, which occurred by the placement of non-polymer iron oxide compounds between the polymer fragments.

Also, the produced yarns were knit to create surfaces to test the EMSE (electromagnetic shielding efficiency) values. The EMSE values at 30 MHz of the fabric samples knitted by the produced bicomponent yarns were measured as 18,78 dB and 13,59 dB for tight and loose stitch densities, respectively.

Table 5. ANOVA table for statistical evaluation.

Source of Variation	Df (Degrees of freedom)	SS (Sum of squares)	MS (Mean of the Squares)	F (F- statistic)	H_0 (null hypothesis)
Factor -additive ratio	1	2243,37	2243,378	134,036	Reject
Factor – fabric tightness	1	662,44	662,113	39,56	Reject
Additive ratio * fabric tightness	1	795,424	795,424	47,525	Reject
Error	788	13188,822	16,737		
Total	791	16889,737			

H_0 (Null hypothesis): The population means of the first factor (additive ratio) are equal; there is not a significant difference among the additive ratio means at 95% confidence intervals.

H_a (Alternative hypothesis): The population means of the first factor (additive ratio) are not equal; there is a significant difference among the additive ratio means at 95% confidence intervals.

H_0 (Null hypothesis): The population means of the first factor (fabric tightness) are equal; there is not a significant difference among the fabric tightness means at 95% confidence intervals.

H_a (Alternative hypothesis): The population means of the first factor (fabric tightness) are not equal; there is a significant difference among the fabric tightness means at 95% confidence intervals.

H_0 (Null hypothesis): The population means of the first factor (interaction: additive ratio and fabric tightness) are equal; there is not a significant difference among the interaction: (additive ratio and fabric tightness) means at 95% confidence intervals.

H_a (Alternative hypothesis): The population means of the first factor (interaction: additive ratio and fabric tightness) are not equal; there is a significant difference among the interaction: (additive ratio and fabric tightness) means at 95% confidence intervals.

Table 6. Estimated marginal means (dependent variable: EMSE value)

		95% confidence level			
Additive ratio	Fabric tightness	Mean	Standard Error	Lower bound	Upper bound
No additive	Tight	2,734	0,291	2,163	3,304
	Loose	2,909	0,291	2,338	3,480
1%	Tight	8,104	0,291	7,533	8,675
	Loose	4,271	0,291	3,700	4,842

Both iron oxide usage and stitch densities had statistically considerable effect on the EMSE properties of the surfaces knitted by the bicomponent yarns.

The reached EMSE values can be acceptable for daily use products. The future challenge may be the increase of the additive material which could not be achieved in this study

due to the flow disorders and machine stops. The increased additive material may result in higher EMSE values.

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REFERENCES

1. Ciesielska-Wrobel, I., Grabowska, K., 2012, "Estimation of the EMR Shielding Effectiveness of Knit Structures", *Fibres & Textiles In Eastern Europe*, 20(2:91), pp:53-60.
2. Dvurechenskaya, N., Bajurko, P.R., Zieliński, R.J., Yashchynshyn, Y., 2013, "Measurements of Shielding Effectiveness of Textile Materials Containing Metal by The Free-Space Transmission Technique With Data Processing in The Time Domain", *Metrol. Meas. Syst.*, 20(2), pp:217-228.
3. Kayacan, O., 2014, "The Effect of Washing Processes On The Electromagnetic Shielding of Knitted Fabrics", *Tekstil ve Konfeksiyon*, 24(4), pp:356-362.
4. Palamutcu, S., Özek, A., Karpuz, C., 2010, "Electrically Conductive Textile Surfaces and Their Electromagnetic Shielding Efficiency Measurement", *Tekstil ve Konfeksiyon*, 20(3), pp:199-207.
5. Duran, K., Bahtiyari, M.I., Atav, R., 2003, "Protective Nonwoven Technical Textiles", *Tekstil ve Konfeksiyon*, 14(4), pp:174-177.
6. Lichawska, J., Aniolczyk, H., Koprowska, J., 2004, "Application of Electrically Conductive Textiles as Electromagnetic Shields in Physiotherapy", *Fibres & Text. in East. Eur.*, 12(4):48, pp:47-50.
7. Lou, C.W., 2005, "Process of Complex Core Spun Yarn Containing a Metal Wire", *Textile Research Journal*, 75(6), pp:466-473.
8. Örtlek, H.G., Güneşoğlu, C., Okyay, G., 2012, "Investigation of Electromagnetic Shielding and Comfort Properties of Single Jersey Fabrics Knitted From Hybrid Yarns Containing Metal Wire", *Tekstil ve Konfeksiyon* 22(2), pp: 90-101.
9. Örtlek, H.G., Kılıç, G., Okyay, G., Bilgin, S., 2011, "Electromagnetic Shielding Characteristics of Different Fabrics Knitted From Yarns Containing Stainless Steel Wire" *Industria Textila*, 62(6), pp:304-308.
10. Örtlek, H.G., Alpyıldız, T., Kılıç, G., 2013, "Determination of Electromagnetic Shielding Performance of Hybrid Yarn Knitted Fabrics With Anechoic Chamber Method", *Textile Research Journal*, 83(1), pp:90-99.
11. Bedeloğlu, A., 2013, "Electrical, Electromagnetic Shielding, and Some Physical Properties of Hybrid Yarn Based Knitted Fabrics", *The Journal of The Textile Institute*, 104(11), pp:1247-1257.
12. Chen, H.C., Lee, K.C., Lin, J.H., 2004, "Electromagnetic and Electrostatic Shielding Properties of Co-Weaving-Knitting Fabrics Reinforced Composites", *Composites Part A: applied science and manufacturing*, 35(11), pp:1249-1256.
13. Cheng, K.B., Cheng, T.W., Lee, K.C., Ueng, T. H., Hsing, W.H., 2003, "Effects of Yarn Constitutions and Fabric Specifications on Electrical Properties of Hybrid Woven Fabrics", *Composites Part A: Applied Science and Manufacturing*, 34(10), pp:971-978.
14. Çeken, F., Kayacan, Ö., Özkurt, A., Uğurlu Ş.S., 2012, "The Electromagnetic Shielding Properties of Some Conductive Knitted Fabrics Produced on Single or Double Needle Bed of a Flat Knitting Machine", *Journal of The Textile Institute*, 103(9), pp:968-979.
15. Tezel, S., Kavusturan, Y., Vandenbosch, G.A.E., Volski, V., 2014, "Comparison of Electromagnetic Shielding Effectiveness of Conductive Single Jersey Fabrics With Coaxial Transmission Line and Free Space Measurement Techniques", *Textile Research Journal*, 84(5), pp:461-476.
16. Özdemir, H., Özkurt, A., 2013 "The Effects of Weave and Conductive Yarn Density On The Electromagnetic Shielding Effectiveness of Cellular Woven Fabrics", *Tekstil ve Konfeksiyon*, 23(2), pp:124-135.
17. Duran, D., Kadoğlu, H., 2012, "A Research On Electromagnetic Shielding With Copper Core Yarns", *Tekstil ve Konfeksiyon*, 22(4), pp:354-359.
18. Avloni, J., Florio, L., Henn, A.R., 2008, "Electromagnetic Shielding With Polypyrrole-Coated Fabrics", *Journal Of Industrial Textiles*, 38(1), pp:55-68.
19. Hakansson, E., Amiet, A., Nahavandi, S., 2007, "Electromagnetic Interference Shielding and Radiation Absorption in Thin Polypyrrole Films", *European Polymer Journal*, 43(1), pp:205-213.
20. Hakansson, E., Amiet, A., Nahavandi, S., "Electromagnetic Shielding Properties of Polypyrrole/Polyester Composites in The 1-18 GHz Frequency Range", *Synthetic Metals*, 156(14-15), pp:917-925.
21. Neelakandan, R. and Madhusoothanan, M., 2010, "Electrical Resistivity Studies on Polyaniline Coated Polyester Fabrics", *Journal of Engineered Fibers and Fabrics*, 5(3), pp:25-29.
22. Kim, B., Koncar, V., Devaux, E., Dufour, P., 2004, "Electrical and Morphological Properties of PP and PET Conductive Polymer Fibers", *Synthetic Metals*, 146, pp:167-174.
23. Lee, C.Y., Lee, D.E., Jeong, C.K., 2002, "Electromagnetic Interference Shielding by Using Conductive Polypyrrole and Metal Compound Coated On Fabrics" *Polymer For Advanced Technologies*, 13, pp:577-583.
24. Lai, K., Sun, R.J., Chen, M., 2007, "Electromagnetic Shielding Effectiveness of Fabrics With Metallized Polyester Filaments", *Textile Research Journal*, 77(4), pp:242-246.
25. Proudnik, A., Zamastotsky, Y., Siarheyev, V., 2012, "Electromagnetic Interference Shielding Properties of the Cu, Ti and Cr Coatings Deposited by Arc-PVD On Textile Materials", *Przegląd Elektrotechniczny (Electrical Review)*, 88(6), pp:81-83.
26. Feng, M., Wang, X., Zeng M., 2008, "Shielding Properties of Carbon Nanotubes-Amorphous Composite Coatings, *Asia-Pacific Symposium on Electromagnetic Compatibility & 19th International Zurich Symposium on Electromagnetic Compatibility*, 19-22 May 2008, Singapor, pp 899-902
27. Oh, T.H., 2006, "Effects of Spinning and Drawing Conditions on the Crimp Contraction of Side-by-Side Poly (trimethylene terephthalate) Bicomponent Fibers" *Journal of Applied Polymer Science*, 102(2), pp:1322-1327.
28. Straat, M., Rgdahl, M., Hagström B., 2012, "Conducting Bicomponent Fibers Obtained By Melt Spinning Of PA6 And Polyolefins Containing High Amounts Of Carbonaceous Fillers", *Journal of Applied Polymer Science*, 123 (2), pp: 936-943.
29. Hagström, B., 2008, "Electrical Conductivity and Process Ability of Monocomponent and Bi-component Melt Spun Polypropylene Fibres Containing a Highly Conductive Carbon Black", *Proceedings: Ambience'08 Smart Textiles -Technology and Design Conference, Boras-Sweden*, pp.20-25.
30. ISO 2060, 1993, International Organization for Standardization.
31. ISO 2062, 1994, International Organization for Standardization.
32. DIN 53866, 1979, Testing of Textiles Shrinkage of Single and Plied Yarns: Determination of shrinkage in water.
33. ASTM D4935-99, 1999, Standard Test Method for Measuring the Electromagnetic Shielding Effectiveness of Planar Materials.
34. McIntyre, J.E., 2005, Synthetic fibres: nylon, polyester, acrylic, polyolefin, *Woodhead Publishing Limited*, England.
35. Sperling, L.H., 2006, Introduction to physical polymer science, *John Wiley & Sons.*, NYSE, USA.
36. Erickson J., 2003, "Incorporating carbon nano tubes into polypropylene Fibers", NCSU, Department Of Textile and Apparel Technology And Management, *Mater of Science Thesis*, Raleigh, USA.
37. Poci, M.R., Bottari, E., 1999, "Electromagnetic characterization of protective clothing". *Electromagnetic compatibility. IEEE International Symposium*, Tokyo, pp:516-519.