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Woven Fabrics Containing Hybrid Yarns for Shielding Electromagnetic Radiation

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Abstract
The aim of the study was to verify whether the construction of a specific hybrid yarn containing a ferromagnetic core and electroconductive wire introduced into woven fabric will improve the shielding effectiveness (SE) in comparison with reference fabrics made of the same raw materials but introduced into woven fabrics as plain wefts, not twisted into the hybrid yarn. Hybrid yarn made of electroconductive materials allows the creation of a set of solenoids with a ferromagnetic core made of steel yarn and a solenoid of conductive effect yarns made of copper. The woven fabric made of these yarns placed into an alternating electromagnetic field (EMF) exhibits a phenomenon where an alternating electric voltage is generated between the ends of the copper solenoid, and alternating magnetisation of the ferromagnetic core takes place. Twelve fabrics were produced, nine of which differed in the density with which the hybrid yarns were introduced as wefts, i.e. once every 25×2 tex cotton yarn, every two cotton yarns, and every three cotton yarns, and the remaining three were reference fabrics, without hybrid yarn. It was found that if measured at a frequency of 30 MHz, the fabrics containing hybrid yarns had 60% higher SE than the reference ones.

Key words: *steel yarn, copper wire, hybrid yarn, woven fabric, electromagnetic interference, shielding efficiency.*

Introduction

Propagating variable electric and magnetic fields (EMF) creates electromagnetic radiation (EMR). The manner in which the EMF propagates depends on its frequency, which determines how the EMF is generated, and on the range of applications and electromagnetic properties of the matter through which it travels, including objects on the path of propagation. The propagating EMF is subject to reflection, refraction, diffraction, interference and absorption. The range of phenomena that occur on the path of EMF propagation depends on the electric and magnetic properties of matter. EMF that enters a barrier does not propagate uninhibited; rather it undergoes damping as a function of the barrier material, thickness and construction [1, 2]. The spectrum of EMR selected may exert a harmful effect on living organisms. Exposure to EMR is a direct consequence of the development of the power and telecommunication industries [2].

In order to protect humans from these harmful effects and the numerous resulting diseases, many studies have been conducted for the purpose of developing a shield to scatter or reflect radiation.

Research on protection against EMF has focused primarily on investigating the properties of materials applied and their counteraction mechanisms against EMF. Three basic phenomena are known to reduce the energy of EMF: the reflection of an electromagnetic wave, the absorption of EMF energy by the barrier and internal scattering [2 - 4]. In the case of the macroscopic structure of textile materials used as a barrier to EMR, the phenomenon of the multiple scattering of an electromagnetic wave on the uneven structure of a metallic textile material is of special importance in EMR shielding. An electrical current flowing through a conductor creates a magnetic field around itself. Because the field changes over time, it enters the conductor as an electromagnetic wave and, due to losses within the medium, becomes dampened. For this reason, metal and metallised textile materials are of special importance in EMF shielding.

Studies have proved that shielding effectiveness (SE) decreases with an increase in the diameter of metal wires introduced into a fabric, as skin depth decreases with an increase in EMF frequency [5]. The electric field of a flat wave decreases exponentially with an increase in skin depth. Thus thinner conductive fibres guarantee a greater SE.

EMR is reflected if the wave impedance of the free space (vacuum) differs from the wave impedance of the anti-EMR barrier. Absorption involves the transformation of EMF energy into heat [6]. Absorption-based EMF shielding is independent of the wave impedance but does depend on the frequency (SE differs for different frequencies), wave polarisation and geometry of the barrier.

Materials that provide good EMF shielding can be divided into two groups: materials with a high value of relative permittivity, such as $BaTiO_3$ or carbon particles, and those with a high electrical conductivity, such as conductive polymers and ferromagnetics, such as Fe_3O_4. Textile materials with EMF shielding properties seem to be the most suitable due to their alignability, elasticity and low weight. Three basic groups of EMF-screening textile materials can be named:

1. flat textile materials laminated with conductive and ionic coating through the processes of arc-spraying zinc, vacuum metallization and vapour deposition,
2. the addition of conductive fillings such as carbon or carbon fibres, carbon nanofibres, metallised fibres and metal fibres (steel, aluminium and copper),
3. the introduction of metal fibres and yarns.

Previous studies [7] on the structure of hybrid fabric made from a metal/meta-aramid composite used the following percentage shares of Bekinox fibres (metal fibers twisted into yarn using Bekinox® by Bekaert Ltd.): 1, 3, 5, 10, 15 and 20%. The linear density of the hybrid yarns obtained amounted to 2 × 25 tex. Special yarns were used to produce the strand and warp for a fabric made with a twill weave. The highest attenuation obtained corresponded to the highest share of steel fibres,amounting to 35 dB at a frequency of 1.5 GHz. Measurements were taken using the coaxial transmission line method according to the US standard ASTM D4935:2006. A similar measurement method was used to investigate the SE of a fabric consisting of polyester fibres coated with a thin film applied using chemical vapour deposition [8]. Measurements were conducted for a frequency range of 2250 – 2650 MHz. Four substances were used as laminating material: silver, copper, aluminium and titanium. The effect of the type and thickness of the laminate on SE was assessed. The highest values of SE were obtained for a silver membrane, amounting to 80 dB, while the lowest values of SE were obtained for a titanium laminate, amounting to 30 dB. The measurements showed that SE increases with the thickness of the laminate. Extensive tests performed on knitted fabrics made of hybrid yarns proved that even relatively loose knitwear can screen cell phone signals [9].

Another study [10] used various types of metal: uninsulated copper, insulated copper and steel. Uninsulated copper showed a high SE for frequencies up to 800 MHz (60 dB), and insulated copper showed a high SE for frequencies above 800 MHz (50 dB). Steel yarn introduced into the fabric caused a decrease in SE for frequencies between 300 and 400 MHz. Copper caused a similar decrease at a frequency of about 1 GHz, which corresponded to resonance frequencies for the manufactured nets. Uninsulated copper showed a much higher SE than insulated copper for frequencies lower than 800 MHz. In turn, insulated copper showed the highest SE for frequencies above 800 MHz. Measurements were conducted according to ASTM D 4935 at frequencies ranging from 30 MHz to 1.5 GHz. The effect of the yarn and fabric on SE was investigated using yarns that included Kevlar/steel fibres, Rayon/steel fibres, Kevlar/copper yarn/steel fibres and Rayon/copper yarn/steel fibres [11]. Measurements were conducted at frequencies ranging from 300 KHz to 3 GHz. The highest SE amounted to 40 dB and was obtained for fabrics with a high share of steel fibres within a frequency range of 1800 MHz to 2450 MHz. Liu et al. [12] analysed the influence of the metal fibre content of blended electromagnetic shielding fabric on shielding effectiveness considering fabric weave. In order to scientifically describe the metal fibre content of blended EMS fabric with respect to the fabric structure, two new indicators of structure metal fibre content (SMFC) and structure equivalent thickness (SET) were constructed according to fabric structure parameters of the weft and warp density, yarn density and yarn metal content. The results presented showed that the SMFC and SET can scientifically describe the metal fibre content of the blended EMS fabric. The SMFC and SET showed positive growth along with the SE, while other parameters remain unchanged. For the basic weave, SE values were an approximate equivalence as long as the total densities are the same as the yarn density and the fibre content of the yarns is the same. The EMI properties of knitted fabrics based on stainless steel conductive yarn were analysed by Yu et al. [13]. Bamboo charcoal polyester/crisscross-section polyester (BC-PET/CSP) blended yarns were used as the back of the warp-knitted fabric, while conductive composite yarns were used as the front. The experimental results showed that increased elongation almost did not significantly affect the EM shielding behaviour of the knitted fabric in the elongation range of 0 - 40%. EMI SE measurement results showed that two layer warp knitted fabrics with a 90° interval displayed a better shielding effect against EM wave compared to that with a 0° interval.

The effect of the polymerisation of polyester fabric with polypyrrole on the surface of the fabric [14, 15] was assessed using chemical and electrochemical polymerisation (oxidation of pyrrole monomers). The polymerisation yielded a fabric with a resistivity of below 0.2 Ωcm, providing an SE of 36 dB. In another study, the in-situ deposition of polyaniline (PANI) was carried out on polyacrylonitrile (PAN) woven fabric with the reactive inkjet printing technique aimed at the manufacturing of multilayered electromagnetic interference (EMI) shields [16]. The surface resistance value of the treated fabrics steadily decreased when the number of PANI-printed layers increased, reaching the lowest surface resistance value of 20 Ω/sq. The polyaniline-printed PAN structures were characterised and evaluated in terms of their electromagnetic shielding effectiveness, absorption and reflection characteristics in the range of frequency from 2.5 to 18 GHz. Depending on the number of PANI layers inkjet printed on the PAN fabric, a EMI SE level from 5 to 22 dB was reported for the fabrics tested. The biggest disadvantage of the EMI SE shields fabricated by deposition of a conductive layer on the surface of the textiles was their limited washing resistance. The level of protection against EM radiation provided by polyamide copper-coated interlining fabric before and after dry cleaning treatment was investigated [17]. The EM protection efficiency of the interlining functional fabric was explored on both sides at frequencies of 0.9, 1.8, 2.1 and 2.4 GHz. The results obtained showed that the interlining fabric has good protective properties against EM radiation, but after dry cleaning, treatment reduction was observed.

The existing solutions presented here provide protection against EMR ranging from 300 MHz up to 1.5 GHz, but SE maximum peaks vary greatly and appear randomly in the range of frequencies mentioned. The challenge is to maintain the shielding range of the barriers, reduce their mass and maintain their flexibility. That is why one proposes to develop the shielding abilities of woven fabrics. Research on a new generation of anti-EMR fabrics was inspired by the discovery of a correlation between the structure of fancy slub yarn and the structure of an electric circuit composed of solenoids connected in series and wound on a ferromagnetic core. Slub yarn is made from three components: a core yarn, an effect yarn and bonding yarn. The effector yarn creates a cylindrical bulge on the core yarn, forming an even and dense concentration of the braid component on the core yarn. The name ‘slub yarn’ comes from the fact that the basic effect of the yarn constitutes an elongated, even, scroll-shaped lump. This is achieved by regulating the speed of the control arm of the ring doubler during twisting in order to make constant the temporary relative difference between the feeding rate of the core and effector yarns into the laying area and to guarantee a specific excess of the effector yarn.

Materials and methods

Materials

Bekinox® VN 12/2x275/175S steel yarn a diameter of ca 0.4 mm (Bekaert Ltd., Belgium) was used as a core of hybrid yarn. Enamelled copper wire of 0.08 mm diameter (SYNFLEX Elektro GmbH, Germany) was used to fabricate a coil for over the steel core. 25 × 2 tex cotton yarn was used as the warp and a part of the weft of woven fabrics containing hybrid yarns for shielding electromagnetic radiation.

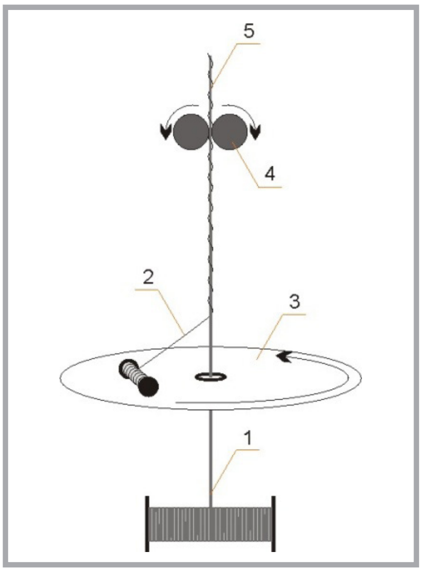


Figure 1. Copper yarn braiding on steel yarn: 1 – Bekinox VN steel yarn, 2 – copper wire, 3 – rotating disc, 4 – rollers receiving the hybrid yarn, 5 – hybrid yarn.

Fabrication of hybrid yarns

Hybrid yarns were fabricated by the wrapping technique according to the scheme presented in ***Figure 1***. For this purpose, a prototype of the wrapping machine was used. It contained core wire pulling rollers driven by a stepper motor, rotating disc with wrapping copper wire driven by a stepper motor and a computer control system with software. Three types of hybrid yarn were produced that differed in the pitch of the copper coil wrapping the steel yarn. For the fabricated hybrid yarns, the pitch of copper coil was equal to 1 mm, 2 mm and 3 mm, respectively. ***Figure 2*** presents the structure of the hybrid yarn.

Fabrication of hybrid yarn based woven fabrics

Hybrid yarn based woven fabrics were fabricated using a hand weaving loom with double shuttles according to the scheme presented in ***Figure 3***. The first shuttle was loaded with 25 × 2 tex cotton and the second one with the hybrid yarns, respectively.

Nine types of woven fabrics of plain weave (A1, A2, A3, B1, B2, B3, C1, C2, C3) of 15 cm width were produced. The warp and weft densities for all woven fabrics were 18 and 12 yarns/cm, respectively. The surface weight was comparable for all woven fabrics and was equal to ca. 145 g/cm^2. They differed in the density with which the hybrid yarns were introduced as wefts, i.e. once every 25 × 2 tex cotton yarn, every two cotton yarns, and every three cotton yarns. In ***Table 1*** the plan of the experiment for the main part of the research is presented. ***Figure 4*** presents the example structure of the fabric produced based on the hybrid yarn.

Table 1. Plan according to which the woven fabrics were produced.

Wefts scheme	Pitch of copper coil, mm		
	1	2	3
1 Hybrid yarn/ 1 Cotton yarn	A1	A2	A3
1 Hybrid yarn/ 2 Cotton yarns	B1	B2	B3
1 Hybrid yarn/ 3 Cotton yarns	C1	C2	C3

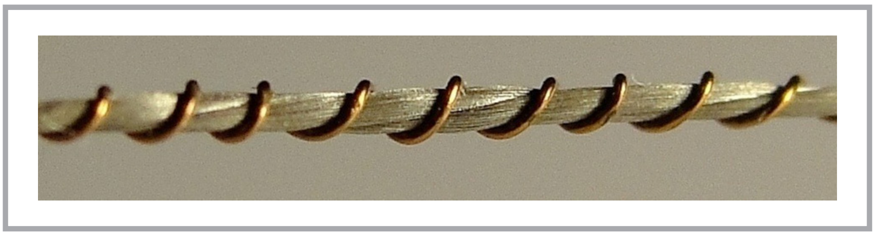


Figure 2. Hybrid yarn: copper wire wrapped on a steel yarn.

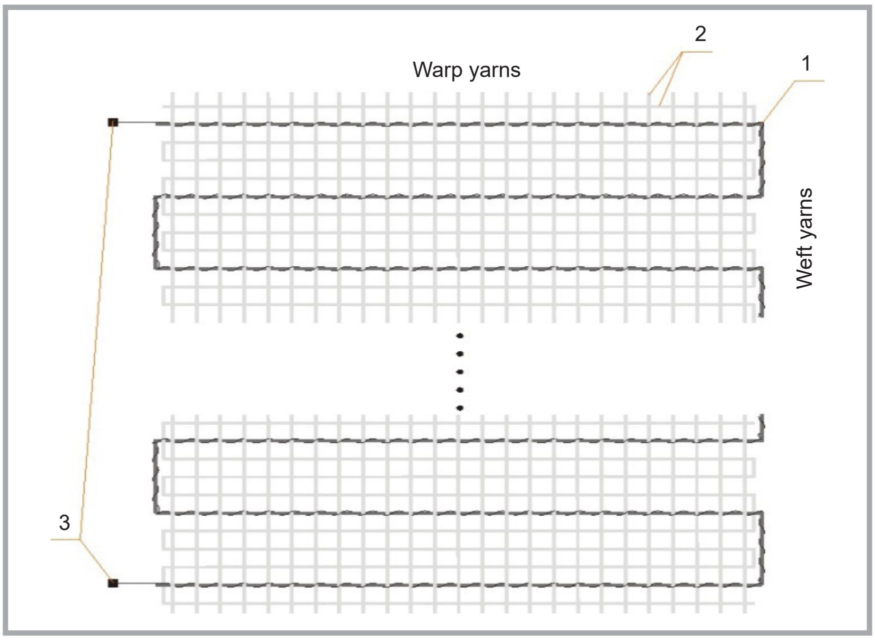


Figure 3. Fabrication scheme of hybrid yarn based woven fabric: 1) hybrid yarn, 2) cotton yarns, 3) copper wire ends.

Three reference fabrics (a1, b2, and c3) were produced. The percentage share of copper, steel and cotton yarns equalled that of fabrics A1, B2 and C3; however, the conductive yarns were introduced into the reference fabrics without twisting them into hybrid yarns, as wefts parallel to each other. The comparison between a1 versus A1, b2 versus B2, and c3 versus C3 was to test whether the structure of the hybrid yarn introduced as the weft into the fabric provides better SE than a parallel alignment of component yarns in the fabric, which was proposed in the case of fabrics a1, b2, and c3.

EMI SE measurements

The EMI SE value of the fabrics with solenoids was calculated from ***Equation 1*** in accordance with the ASTM D 4935-99 standard using an FSL3 spectrum analyser (Rodhe & Schwarz, Germany) and sample holder EM 2107A (Electro-Metrics, USA). A view of the measurement setup and examples of ink-jet printed reference and load specimens used for determination of the EMI SE are presented in ***Figure 5***.

$$SE = 10\log\frac{P_1}{P_2}, \text{ dB} \qquad (1)$$

where, P_1 is the power received without the fabric present, and P_2 is the power received with the fabric present.

During EMI SE measurements, for all fabrics in which the hybrid yarn was used, the ends of the copper wire were

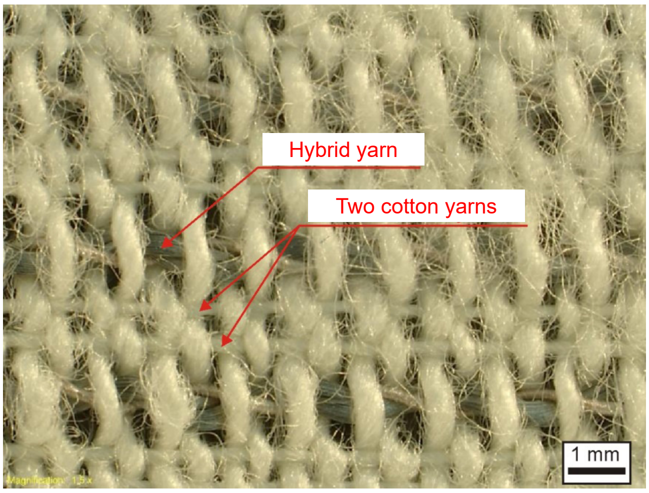


Figure 4. Example structure of fabric (B2) made of cotton and hybrid yarns. Hybrid yarn was inserted into the fabric once every two cotton yarns.

Figure 5. View of the measurement setup used for the determination of the EMI SE.

connected together for conversion of the electrical energy generated in the solenoid into heat flux. Additionally in the second step, for all fabrics in which the hybrid yarn was used, the electrical voltage generated in the copper wire forming the solenoids on the steel yarn was measured. During these measurements, the woven fabric tested was placed in sample holder EM 2107A. An incident wave in the range of frequency of 30 MHz to 1.5 GHz was generated by the FSL3 spectrum analyser and introduced to the holder. At the same time, the electrical voltage generated between the copper wire ends (***Figure 3***) was measured by the FSL3 spectrum analyser.

Results

Shielding efficiency of the reference fabrics without copper wire

In ***Figure 6*** the shielding efficiency of the reference fabrics is presented. The high efficiency of the electromagnetic field damping effect (40 dB) is detected in the case of fabrics with steel yarn inserted as the weft in the case of fabrics with an arrangement of wefts as follows: 1 steel yarn/1 cotton yarn and 1 steel yarn/2 cotton yarns. But the frequencies of the electromagnetic field which are adequate to these two peaks of the damping effect are different. In the case of fabric with a composition of the wefts of 1 steel yarn/1 cotton yarn, the frequency that corresponds is 400 MHz. In the case of fabric with wefts of 1 steel yarn/2 cotton yarns, the frequency is 600 MHz. This means that the peak of the damping effect moves in the direction of higher frequencies when the density of steel yarn as the weft in the fabric is smaller. But in the case of fabric with a composition of the weft of 1 steel yarn/3 cotton yarns, this means that steel yarn is the least effective among the fabrics investigated due to the decreased damping effect (30 dB).

Effect of copper wire pitch on shielding efficiency

In ***Figure 7*** the shielding efficiency of the fabrics of different yarn density tested is presented. In the case of group fabrics with weft composition 1 hybrid yarn/1 cotton yarn, there is a shift in frequencies which corresponds to the highest peaks of the electromagnetic field damping effect. The shift in frequencies, which is in line with the peaks of the damping effect, tends towards higher frequencies in the case of a decrease in the copper wire pitch around the steel yarn (***Figure 6.a***). The highest value of damping effect (55 dB) occurs in the case of fabric with copper yarn wrapped around steel yarn (coils) with a pitch of 3 mm, and the minimum electromagnetic damping effect detected (30 dB) occurs in the case of fabric with the weft constructed on the basis of copper solenoids of 1 mm pitch wrapped around steel yarn (***Figure 7.a***). This means that the more intensive the spiral in the solenoids is, the smaller the damping effect of the electromagnetic field. The same effect occurs in the case of fabric with weft composition 1 hybrid yarn/2 cotton yarns (***Figure 7.b***). In the case of fabric with the least frequently occurring in the hybrid yarn with solenoids, the range of frequencies of the electromagnetic field where the damping effect is at a similar level is between 500 to 800 MHz (25 dB regardless of the copper wire pitch) (***Figure 7.c***). Only in the case of fabric with weft composition 1 hybrid yarn/1 cotton yarn and a hybrid yarn pitch of 3 mm (***Figure 7.a***), the dumping effect is higher than in the case of fabric constructed

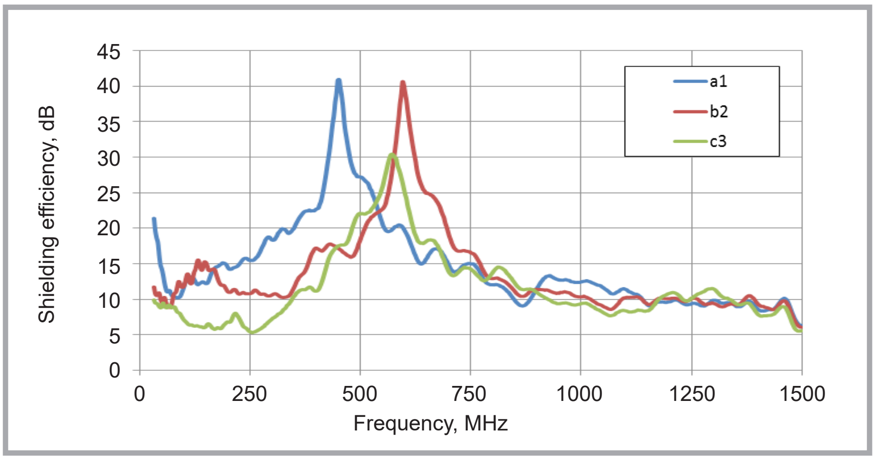
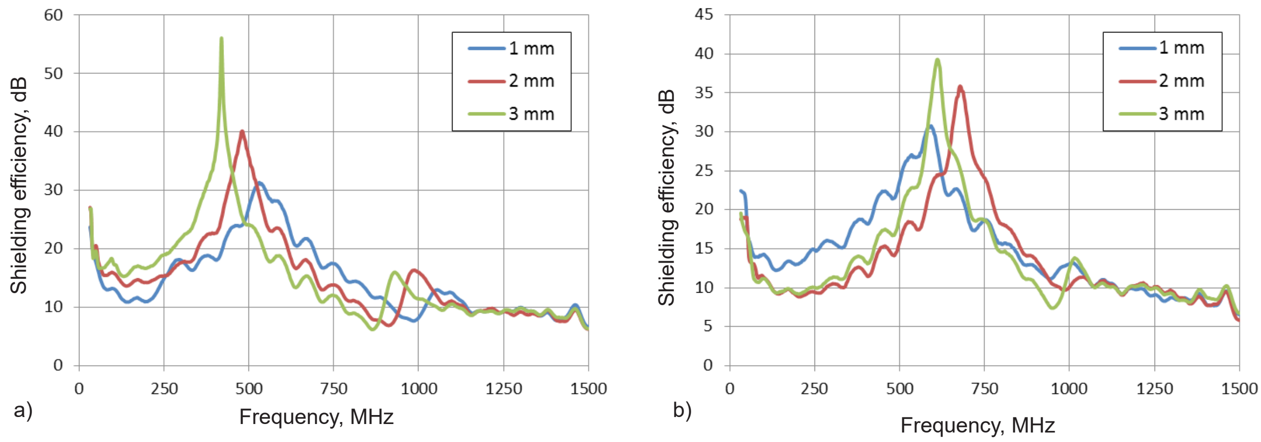


Figure 6. Shielding efficiency of the reference fabrics (a1 - 1 steel yarn/1 cotton yarn, b2 - 1 steel yarn/2 cotton yarns, c3 - 1 steel yarn/3 cotton yarns).



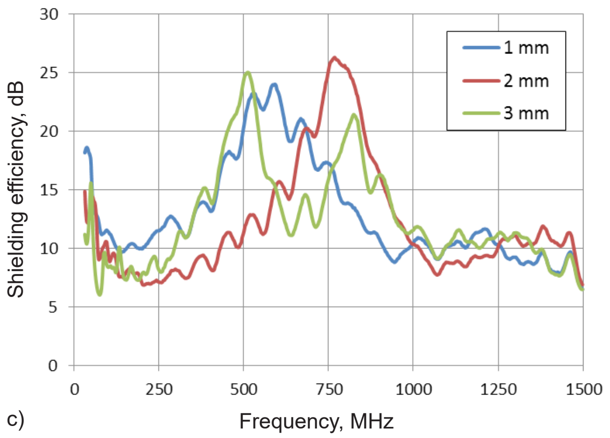
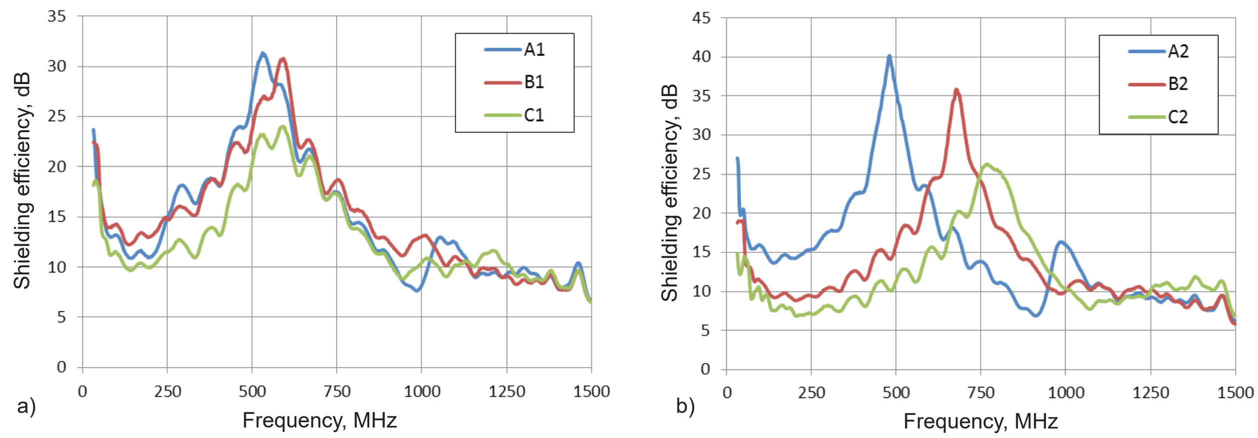


Figure 7. *Shielding efficiency of test fabrics of the following yarn density: a) 1 hybrid yarn/1 cotton yarn, b) 1 hybrid yarn/2 cotton yarns, c) 1 hybrid yarn/3 cotton yarns.*



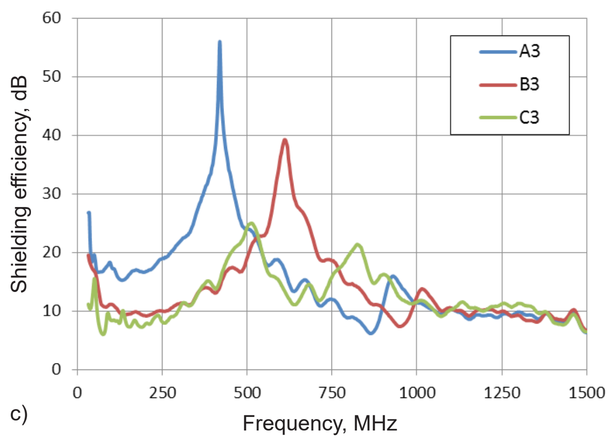


Figure 8. *Shielding efficiency of test fabrics containing steel yarns wrapped by copper wire of a) 1 mm pitch, b) 2 mm pitch & c) 3 mm pitch.*

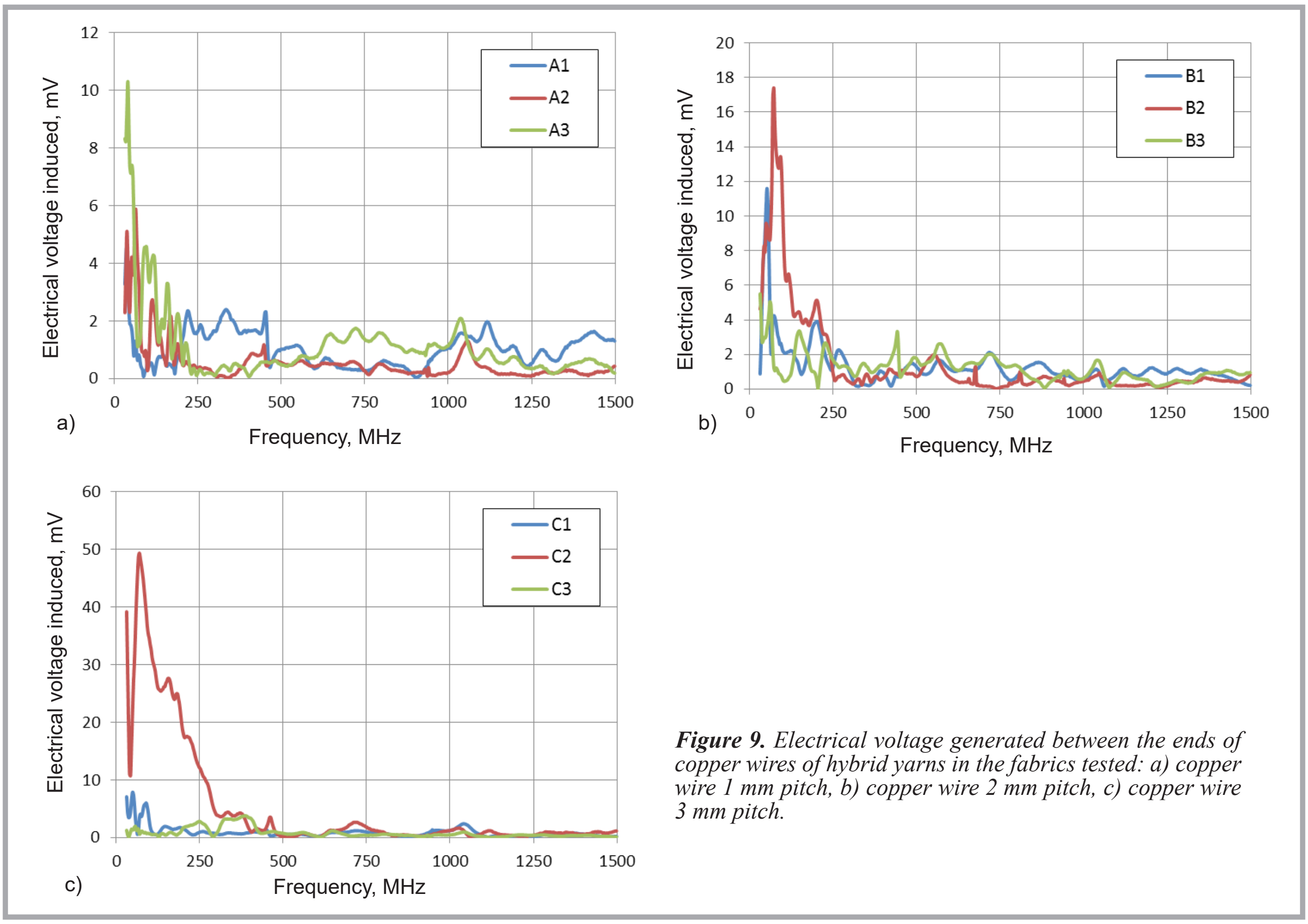


Figure 9. *Electrical voltage generated between the ends of copper wires of hybrid yarns in the fabrics tested: a) copper wire 1 mm pitch, b) copper wire 2 mm pitch, c) copper wire 3 mm pitch.*

with 100% steel yarn used as the weft. This means the higher the density of hybrid yarn used as the weft, the smaller the pitch of solenoids, and the higher the damping effect realised by the fabric.

Effect of hybrid yarn weave density on shielding efficiency

In ***Figure 8*** the shielding efficiency of the test fabrics containing steel yarns wrapped by copper wire of different pitch is presented. In the case of fabrics with a hybrid yarn composition based on coils of 1 mm pitch, the highest damping effect occurs in the case of weft compositions 1 steel yarn/1 cotton yarn and 1 steel yarn/2 cotton yarns (31 dB), and these two peaks are slightly shifted in the direction of higher electromagnetic field frequencies when the intensity of the copper wire pitch increases (***Figure 8.a***). The lowest damping effect occurs in the case of fabric with the smallest density of hybrid yarn used as the weft (24 dB).

In the case of fabrics with a hybrid yarn composition based on coils of 2 mm pitch (***Figure 8.b***), the frequency shift tends towards higher electromagnetic frequencies when the intensity of hybrid yarn occurrences decreases. The highest value of damping efficiency (40 dB) occurs in the case of fabric with weft composition 1 steel yarn/1 cotton yarn and the smallest damping efficiency is detected in the case of fabric with the lowest intensity of hybrid yarn insertion (26 dB).

In the case of fabrics with a hybrid yarn composition based on coils of 3 mm pitch (***Figure 8.c***), the highest damping effect occurs in the case of weft composition 1 steel yarn/1 cotton yarn (55 dB) and the lowest damping effect in the case of fabric with the smallest frequencies of hybrid yarn used as the weft (21 dB). When the intensity of hybrid yarn insertion as the weft into the fabric is decreased, the damping efficiency is smaller. What's more, a shift towards higher frequencies occurs among electromagnetic field frequencies which are in line with the peaks of the highest values of damping effect when the intensity of hybrid yarn insertion is decreased.

Electrical voltage generated in the coils of hybrid yarns

In ***Figure 9*** the electrical voltage generated between the ends of copper wires of the hybrid yarns in the fabrics tested is presented. As can be seen in ***Figure 9***, the values of electrical voltage generated strongly depended on the electromagnetic field frequency. The highest value of electrical voltage (50 mV) was detected in the case of fabric with medium density of hybrid yarn insertion as the weft into the fabric, which means the composition of the weft in the fabric is 1 hybrid yarn/2 cotton yarns.

In ***Table 2***, a comparison of the maximum EMI SE and voltage generated in the copper wire for fabrics containing hybrid yarns and for reference fabrics is presented. The greater the value of pitch of the copper wire on the steel yarn, the higher the SE of the fabric containing the specific hybrid yarn and the lower the peak frequency. Among the A-type fabrics, the highest EMI SE is shown by A3, which is 55 dB at 470 MHz. Above 1 GHz, the EMI SE of all A-type fabrics is 10 dB. The EMI SE of the electrical component of EMR of B-type fabrics was the highest for fabric B3, where the pitch of the copper wire on the steel yarn is the greatest: 3 mm. Similar to A-type fabrics, EMI SE is lower above 1 GHz for B-type fabrics and stabilises around 10 dB. In the case

Table 2. Comparison of maximum SE of electrical components of EMF and voltage generated between the ends of copper wire for fabrics containing hybrid yarns and for reference fabrics.

Fabrics	EMI SE at 30MHz, dB	SE at maximum peak	Voltage generated at 30 MHz, mV	Voltage generated at maximum peak
A1	24	31 dB at 600 MHz	4.6	1 mV at 600 MHz
a1	21	42 dB at 480 MHz	n/a, no solenoids	
A2	27	40 dB at 500 MHz	4.6	0.6 mV at 500 MHz
A3	27	51 dB at 480 MHz	11.0	0.2 mV at 480 MHz
B1	23	31 dB at 600 MHz	11.9	1.0 mV at 600 MHz
B2	25	31 dB at 700 MHz	17.0	1.0 mV at 700 MHz
b2	12	35 dB at 600 MHz	n/a, no solenoids	
B3	20	40 dB at 625 MHz	5.5	1.0 mV at 625 MHz
C1	18	24 dB at 625 MHz	8.0	0.5 mV at 625 MHz
C2	15	25 dB at 800 MHz	50.0	0.0 mV at 800 MHz
C3	16	25 dB at 500 MHz	2.0	0.5 mV at 500 MHz
c3	10	30 dB at 600 MHz	n/a, no solenoids	

of C-type fabrics, EMI SE achieves similar values, which do not depend on the pitch of the copper wire on the steel yarn. The lowest EMI SE among A1, B1 & C1 was discovered in the case of fabric C1, where the hybrid yarn was rarely introduced, according to the following order: 1 hybrid yarn/3 cotton yarns. The highest EMI SE, 40 dB, measured at 490 MHz, was noted for fabric A2, where one hybrid yarn was introduced into the fabric after one cotton yarn. The lowest EMI SE, 25 dB at 750 MHz, was noted for fabric C2, where one hybrid yarn was introduced into the fabric after three cotton yarns. The higher the density of the hybrid yarn in the fabrics, the higher the EMI SE of these fabrics. The value of maximum peaks is lower if the density of hybrid yarns in the fabrics is higher.

Conclusions

Steel yarn/copper wire solenoid based woven fabrics were studied as a new EMI shield. The solenoids were successfully fabricated as hybrid yarn by wrapping a copper wire around steel yarn. In the frequency range of 30 MHz–1.5 GHz, an EMI shielding effectiveness of woven fabrics from 8 to 40 dB can be achieved. For every sample of plain weave fabric differing in terms of the density at which the hybrid yarn was introduced as the weft and the pitch of the copper wire, a dominating peak was detected, which was caused by the interference of electromagnetic waves on the net built on the basis of the hybrid yarn. The peak usually corresponded to frequencies close to 500 MHz. An analysis of voltage generated between the ends of the copper wire indicates that its amplitude strongly depends on the electromagnetic field frequency and is the highest in the range of frequency of 30 - 100 MHz. It means that the electrical energy generated in solenoids can additionally increase the EMI for this range of frequency. For higher frequencies, this effect seems to be negligible for the EMI SE level. An analysis of the EMI SE provided by samples A1, B2 and C3 in comparison with reference samples a1, b2 and c3 showed that fabrics produced on the basis of the hybrid yarn provided a higher SE than the reference samples only at a frequency of 30 MHz.

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