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doi:10.15199/48.2021.12.26

The research and the analysis of electromagnetic field shielding properties of the textile materials with an electroconductive coating

***Abstract**. The development of technology in the field of new textronic materials allows for their wider application in everyday use. Hence the authors' interest in the use of textiles with an electroconductive coating as screens of non-ionizing electromagnetic fields. Thanks to the use of textronic materials, it is possible to obtain a flexible cover with appropriate strength, elasticity and, above all, the required functionality, which is the elimination of undesirable interference and electromagnetic radiation. The work examined material properties of samples, shielding effectiveness and measurements of volume and surface resistance.*

Streszczenie.** Rozwój technologii w zakresie nowych materiałów tekstronicznych pozwala na ich szersze zastosowanie w codziennym użytkowaniu. Stąd zainteresowanie autorów wykorzystaniem tekstyliów z powłoką elektroprzewodzącą jako ekranów niejonizujących pól elektromagnetycznych. Dzięki zastosowaniu materiałów tekstronicznych możliwe jest uzyskanie elastycznej osłony o odpowiedniej wytrzymałości, elastyczności, a przede wszystkim wymaganej funkcjonalności, jaką jest eliminacja niepożądanych zakłóceń i promieniowania elektromagnetycznego. W pracy zbadano właściwości materiałowe próbek, skuteczność ekranowania oraz pomiary rezystancji objętościowej i powierzchniowej. (**Badania i analiza właściwości ekranujących pole elektromagnetyczne materiałów tekstylnych z powłoką elektroprzewodzącą)

Keywords: shield of electromagnetic field, electromagnetic field, textronics.
Słowa kluczowe: ekrany pola elektoromagnetycznego, pole elektromagnetyczne, tekstronika.

Introduction

The development of technology in the field of new textronic materials allows for their wider application in everyday use. Textronics is one of the areas of science and technology that can meet today's requirements for the production of specialized electronic systems. Textronics is a young but dynamically developing field of science. The development of intelligent textiles is an interdisciplinary issue, textronics combines the science of textile materials, electronics, metrology, as well as materials science and computer science [1]. As new technologies evolve, a range of new possibilities for increasing the functionality of textiles is expanding, ranging from new properties of the fiber structure, through the use of composite materials and coatings at nano and micro levels, to the integration of electronic devices with clothing. Due to their innovation, textronic materials have found a number of applications [2]. Hence the authors' interest in the use of textiles with an electroconductive coating as screens of non-ionizing electromagnetic fields. The technologies of obtaining thin metallic layers on textile substrates are promising from the point of view of applications in textronics [3]. This approach include the application of conductive materials on the surface of the fabric itself using processes such as lamination, coating, spraying, ionic plating, electroless plating, vacuum metallization, cathode sputtering, and chemical vapor deposition [4].

The rapid technological progress that we observe around us means that people are exposed to the ever increasing exposure to the electromagnetic field from the entire spectrum of wavelengths. There are many artificial sources of high-frequency electromagnetic radiation in the human environment. The increase in the number of devices based on Wi-Fi, GSM and LTE technologies results in an increased emission of electromagnetic radiation.

Many electronic devices, electrical switchboards and control cabinets contain interference-sensitive components from an external electromagnetic field. Additionally, such devices can emit a disturbing field themselves work of other nearby electronic circuits and measuring systems. Also, in everyday human surroundings there are more and more sources of high frequency electromagnetic radiation.

The health hazard associated with the artificial electromagnetic field is the subject of research in both medical and physical sciences. Recently, the problem of electrosensitivity has aroused a lot of interest and especially much controversy. This term appears more and more often in social consciousness and is associated with ailments reported by an increasing number of people and related to the impact of various types of electrical, electronic and, in particular, telecommunications devices. [5]. Although the harmful effects of this type of radiation on living organisms have not been demonstrated, this causes a growing interest in effective and economical methods of protection against the influence of electromagnetic fields [6,7].

Electromagnetic shielding

Electromagnetic shielding is the process of reducing the electromagnetic field by blocking the field with barriers made of conductive or magnetic materials. The amount of reduction depends upon the material used, its thickness, the size of the shielded volume and the frequency of the fields.

In order to limit the influence of magnetic radiation, various types of materials can be used for shielding [8]:

- Metal shields
- Composite shields
- Paints and other coatings
- Woven and knitted fabrics

Shielding effectiveness (*SE*), a measurement of the attenuation of an EM signal through a shielding material is commonly used to examine the electrical shielding performance. Shielding effectiveness of the material (*SE*) is defined as the ratio of the field strength E_{out} to the E_{in} field in front and behind of the screen and is expressed by the relationship (1):

$$SE = -20\log_{10}\left(\frac{E_{out}}{E_{in}}\right) \tag{1}$$

The total *SE* (2) level depends of three mechanisms: reflections loss *R* (dB), absorption loss *A* (dB) and multiple reflection loss *M* (dB) inside material.

$$SE(dB) = R(dB) + A(dB) + M(dB) \quad (2)$$

Schematic diagram of electromagnetic shielding is present in the figure 1. The shielding happens due to reflection, absorption, or multiple reflections of the incident radiation by the barrier. When the indicated wave reaches the surface of shield materials, it will be reflected, absorbed, and refracted.

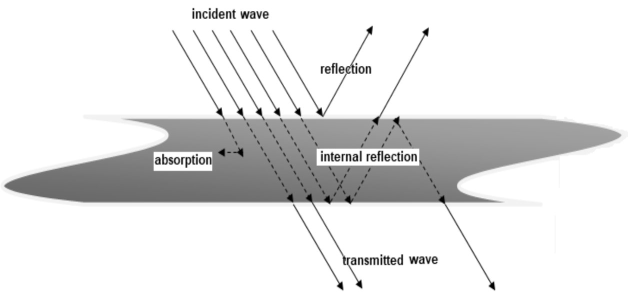

Fig.1. Schematic diagram of electromagnetic shielding

The materials used to build EMS barriers must have good electrical conductivity and magnetic permeability parameters. For this purpose apply metal screens (aluminum, copper, etc.), through laminates containing conductive reinforcement (metal or graphite), structures sputtered with conductive layers, alloys with very high magnetic permeability (mu -metal), or composites based on electrically conductive polymers, as well as honeycomb structures (eg MaxAir™) [9-13]. However, metal covers have some limitations, first of all it is their high weight. The use of textiles with a conductive coating can successfully replace metal covers. The emerging role of textiles as shielding is mainly due to their desirable properties in terms of flexibility, versatility, low mass, and low cost.

Metallization

The broadly understood metallization occurs, inter alia, in the form of vacuum metallization. Vacuum metallization consists in applying a layer of metal to a selected surface, most often plastic, using the gaseous state of the metal.

A vacuum metallizer as a machine consists of many elements. The vacuum chamber is the main base of the entire installation, it is secured and sealed. Due to the mechanics of rotation of the sprayed elements, horizontal chambers have been distinguished, in which the drum rotates along the horizontal axis, the details are mounted on hangers located horizontally on the rotating drum leaving the chamber on rollers. In the center of the drum there are current rails, and the basket's rotational drive is transferred through the engine to the basket, where the chain mechanism ensures, apart from the rotation of the entire basket, the rotation of the hangers containing details around its axis. This method is practical due to the capacity of the horizontal chamber, it is able to fit many more hangers on the rotary basket, which also, depending on the size of the machine, may be longer, and thus, during one cycle, more details can be metallized.

The metallization cycle consists of the following steps:

- Ionization
- Evaporation
- Embedding

The first is ionization, a step in which details are disturbed by ions in combination with air molecules to ensure better adhesion. For this purpose, the machine evacuates the pressure in the chamber to approximately $9{\cdot}10^{-3}$ mBar. Then, the turned on transformer generates a voltage on the electrode from 2000 V to 3000 V. The anode, i.e. the metal rod, during the reduced pressure creates an electric field with the cathode, i.e. the chamber, which is necessary for the current to occur, but the electric current cannot arise until the charged particles are introduced into the chamber, therefore the into the argon particle chamber whereby the generated electric charges on the way from the anode to the cathode bombard the workpieces to form an adhesion coating for the later aluminum step. Ionization takes between 200 and 300 seconds.

The next step is evaporation, after ionization is followed by the so-called defrosting of the diffusion pump. Although the pump works from the moment the machine is switched on, a special valve with a pneumatic actuator covers the pump housing tightly. Only defrosting, i.e. lifting the actuator and opening the valve between the diffusion pump, the chamber, and the rest of the pumps, causes high vacuum pumping to start. The pressure in the chamber is gradually lowered until reaching the threshold predicted by the technological process, depending on the efficiency and tightness of the pump set, the threshold for starting evaporation is a pressure of about 5·10-4 r, it takes about 500 seconds to reach such a pressure. After reaching the target, the analog vacuum sensor reads by the controller allows the pairing to begin. The activated autotransformer generates a current of 1000 - 1300 A, which is transferred to the current rails located under the ceiling of the chamber and passing through it.

To create pairs, you need filaments and rods, in our case aluminum. The number of bars in aluminum depends on what we want to obtain the aluminum coating layer on the detail, it is determined in the technological process, most often 1 or 2 bars per filament. During the flow of such a high electric current at a pressure within the range of $5{\cdot}10^{-5}$ mBar, the filaments heat up to a temperature that allows the aluminum to change from a solid to a gaseous state, the melting point of aluminum is about 660°C. The chamber it fills up with aluminum steam, and the rotating basket collects its particles on the details. In this way, the final product is ready, after the spraying is finished, the diffusion pump is closed again with the actuator with a flap, and its output is cut off from the other pumps with a solenoid valve, the pumps are also cut off from the machine body, i.e. the chamber, as a result, the chamber can be safely vented with air valve. After air entrainment, the door catch rises and the chamber opens by itself to the designated point.

Materials

For the purposes of the work, samples of knitted fabrics with different fiber structure and weave density were prepared, which were then coated with aluminum layers in the vacuum metallization process. Among the different materials, five of them were chosen: denim due to the dense and strong weave, and commonly associated strength, glass fiber due to the textile construction and durable fibers, silk due to the density of the weave and the delicacy and softness of the fibers, and two types textile meshes, one soft and the other rigid, due to the common use of materials of this type (Fig.2).

Fig. 2. Samples of knitted fabrics: denim, glass fiber, silk, two different non-woven fabric

Material samples used for the test were placed in specially designed stiffening holders (Fig.3), which were intended to stress the samples during the metallization process.

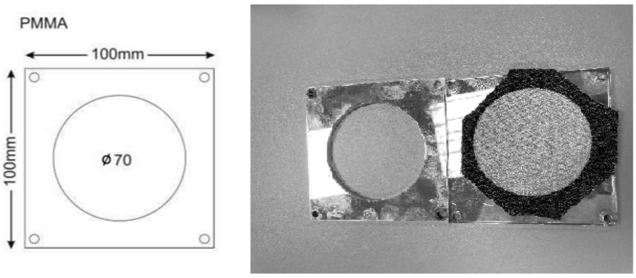

Fig.3. The stiffening holders

The table 1 shows the markings of the samples and the measured thickness of the samples.

Table 1. The markings of the samples and the measured thickness of the samples

Material	**Sample markings**	**Thickness of the sample**
Denim	A	0,6 mm
Glass fiber	B	0,12 mm
Silk	C	0,34 mm
Technical Knitted Fabric A (dense)	D	0,51 mm
Technical Knitted Fabric B (sparse)	E	0,26 mm

Fig. 4. Assembly of samples in the metallizer chamber

In addition to the main samples, samples for testing the thickness of the aluminum coating for subsequent layers were prepared. The prepared samples were placed in the metallizer chamber on separate rotating hangers (Fig.4).

Five runs were run in a row, each cycle taking one series of samples. The same number of aluminum bars was used for each cycle.

Results

After metallization process, comparative photos were taken using a computer microscope for all textiles. Pictures were taken of textiles without aluminum coating, with one coating layer, and with five coating layers (Fig. 5).

Then, measurements of the volume and surface resistance were started. For this purpose, the KEITHLEY 6514 electrometer was used, the measuring range of which for resistance reaches up to 200T Ω, and the system itself can perform up to 1200 readings per second (Fig. 6).

Figures 7 and 8 show successively the values of volume resistance and surface resistance of individual materials for successive sputtering layers of aluminum. When measuring the surface resistance of textile meshes, both of the first and second type, the measuring range of the device, i.e. $1 \cdot 10^{15}$ Ω, was exceeded, therefore the values were not identified.

Fig.5. Textiles without aluminum coating, with one coating layer, and with five coating layers

Fig.6. Laboratory stand for resistance measurement

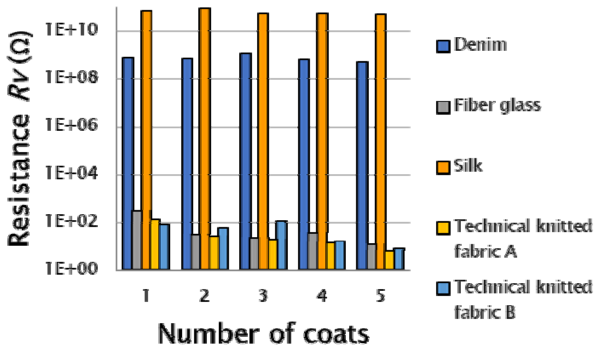

Fig. 7. The values of volume resistance of individual materials for successive sputtering layers of aluminum

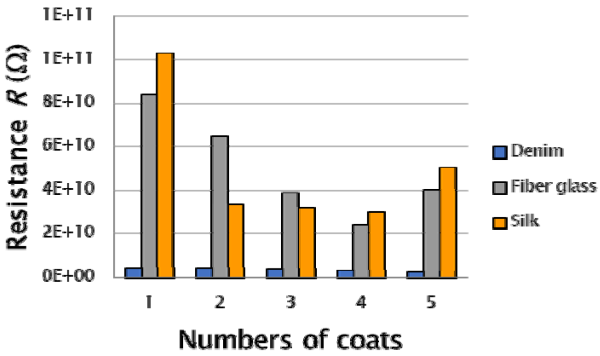

Fig.8. The values of surface resistance of individual materials for successive sputtering layers of aluminum

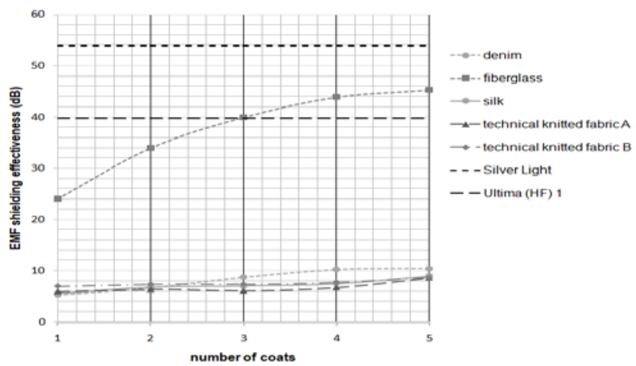

Fig.9. The shielding effectiveness of individual materials for the sputtering layers of aluminum

The diagram in Figure 9 shows the shielding effectiveness of individual materials for the successive layers. Additionally, the graph shows the reference levels of the commercially used materials with dashed lines: Silver Elastic [14] and Ultima [15].

Conclusion

The research showed significant differences in both the volume and surface resistance as well as the effectiveness of the electromagnetic field shielding.

The electromagnetic shielding depends on the overall fabric structure and thickness. The dense weave of fibers (denim, silk) caused a significant increase in the volume resistance. The loose weave (technical knitted fabric) caused a significant increase in the surface resistance.

The surface structure has a significant impact on the shielding effectiveness of electromagnetic field.

Satisfactory values were obtained only for glass fiber material (SE > 40 dB).

The shielding effectiveness increases with the number of aluminum layers. The optimal number of layers is 4-5. Metallized glass fiber is suitable for making structural reinforcements and laminates, giving the products new properties.

The research was supported by the National Centre for Research and Development of Poland, grant, No. LIDER/11/0049/L-10/18/NCBR/2019

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