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Development and investigation of electromagnetic shielding fabrics with different electrically conductive additives

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ABSTRACT

To obtain the protection against electromagnetic radiation (EMR) emitted by operating electrical and electronic devices, the shielding materials based on woven fabrics coated with the highly conductive layers were designed and investigated. The electrostatic charge dissipation properties and EMR shielding properties within certain frequency bands were investigated and compared with such properties of textile fabrics with incorporated conductive metal fibres. Also the influence of washing on electrical properties of developed fabrics was examined.

This study presents technological guidelines for designing coated textile fabrics, which are able to safeguard high electrostatic charge dissipation properties and to provide effective protection against EMR, using two types of electrically conductive coatings. The results of EMR shielding measurements, especially within the range of 2 GHz–20 GHz, showed that fabrics with conductive coatings exhibit certain advantages over fabrics with incorporated metalized yarns. Whereas shielding properties at the low frequency range of 20 kHz–50 kHz for all investigated conductive fabrics are similar despite the type of conductive additive. Methods for measurement of electrostatic properties, reflection and transmission as well as the assessment of EMR shielding effectiveness (SE) are also presented.

Introduction

The reduction of EMR impact is very important protection for the survivability of the people frequently using electrical equipment, which exposes humans to different frequencies of electromagnetic waves. The electrical and electronic devices, usable in modern society at an ever increasing rate, are capable of emitting electromagnetic waves with frequencies that are potential hazards to health [1,2].

Unwanted reception of EM radiation may lead to electromagnetic interference (EMI). The most common type of EMI occurs in the radio frequency of EM spectrum, from 10^4 to 10^{12} Hz. This energy can be radiated by computer circuits, radio transmitters, fluorescent lamps, electric motors, over-head power lines, lightning and many other sources [1]. The most utilized range is the microwave range, which can be defined as 1 GHz–40 GHz. Most of modern point to point, wireless, and satellite communications occupy this range [3]. Conductive woven or knitted fabrics with particular EM shielding properties, because of their structural order and ability to flex, offer an opportunity to counter theses threats.

Electrical conductivity or reciprocal value of it–surface resistivity, is a key parameter of conductive textiles, which often determines the scope for application of a given material.

Applications involving the transport of electrical data, EMI shielding and heating textiles call relatively low resistivity levels–less than 10^3 Ω/sq [3,4], while the materials for electrostatic dissipative protective clothing should have the performance of around 10^9 Ω/sq [5].

There are various techniques to improve the conductivity of textiles:

- introduction of electrically conductive yarns (carbon fibres, metal fibre) [6,7];
- metallization of fabrics or yarns (voltaic, vacuum vaporisation) [1,8];

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- lamination or coating of conductive layers onto the fabric surface with: metal particles, transparent organic metal oxides, carbon, inherently conducting polymers (ICP) [9–13].

The shielding efficiency of metalized textile fabrics mainly derives from energy reflection, but not from its absorption [14–16]. Conductive polymers may be used as alternatives to some commonly used metallic shielding materials. In contrast to metallic shielding materials, conducting polymers not only reflect but also absorb electromagnetic radiation in the microwave frequency range [13,15].

Inherently conducting polymers (ICP) are innovative materials, and are good materials to obtain conductive coating systems for fabrics. Mainly for these purposes such polymers as polyaniline (PANI), polypyrrole (PPy) and their composites are used [17].

There are some papers in the literature, where it is stated that conductive polymers, have a significant advantage over the shielding textile materials with metalized yarns [10,17,18], but also occur studies which claim higher EMR shielding effectiveness of metalized fabrics compared with ICP coatings. That could be explained that in different studies the fabrics with different quantity of conductive additives, types of coatings and structural homogeneity are investigated.

The conjugated polymer system, used in this study—poly(3,4-ethylenedioxythiophene)-polystyrene sulfonate (PEDOT-PSS) is today most promising and widely used in research and development of conductive coatings. The literature contains few papers [11,19] regarding the electrically conductive textile coatings by the addition of a dispersion of PEDOT-PSS to a coating formulation. In both studies the influence of PEDOT-PSS concentration in coating formulation on the surface resistivity was investigated. In the study [11] also the effect on the surface resistivity of the addition of a conductivity enhancer, such as ethylene glycol, as well as the influence of drying procedure during the coating have been investigated But the evaluation of EMR shielding properties of such coated fabrics were not included in either of the papers. Also in these studies the influence of washing on electrical properties of PEDOT-PSS coated fabrics as not examined.

Another interesting way of obtaining the materials with greater capability of absorbing EMR radiation is application of coatings with absorbers of EM fields, such as carbon particles, ferrite substances [1,4,14]. So in our work we used not only the coating formulations with PEDOT-PSS, but also ones with a carbon as conductive filler.

In purpose properly to evaluate the shielding properties of developed fabrics it is very important to select a relevant parameters and methods of their measurement, to obtain the reliable results.

A parameter that characterises any shield is the effectiveness of shielding (SE) and is defined as the ratio of the electromagnetic field strength measured without and with the tested material when it separates the field source and the receptor [10,16,20]. The same relationships is valid in relation to the conjugated field (far field—where the distance from EM radiation source is higher than $\lambda/2\pi$) or electric component (near field) [20].

There are several methods used for evaluating the SE of flat shielding structures [9,16,21,22]. There are developed particular methods of electromagnetic shielding investigation for far-field and near-field measurements [23,24]. Currently known methods differ in frequency range, sample dimensions, measurement conditions, the geometry of the test setup. Therefore it is not possible to compare the results of shielding effectiveness obtained by so diverse test methods. There is also a lack of generally accepted standardised methods for measuring shielding effectiveness [9].

At the developing stage of new textile materials intended to have EMR shielding properties it is more importantly to have a reliable measurement method to afford ground for comparisons of small samples of designed fabrics. It is important to use the same testing conditions—test setup geometry, the size of the test samples, and atmosphere for testing, parameters of the source of EMR radiation. The description of measuring methods used in this study for determination of EMR shielding effectiveness in the particular frequency ranges is presented in the paper.

The aim of the research was to design and characterize textile materials with two different electrically conductive coatings, intended to safeguard high electrostatic charge dissipation properties and to provide effective protection against EMR, and to compare their effectiveness in this aspect with conductive textile fabrics developed by us, earlier [26,28] where as conductive additive metalized yarns were inserted into the fabrics by in-weaving.

Experimental

Materials

Samples of polyester/cotton plain weave woven fabrics were coated with two different formulations described in Table 1.

The first conductive coating used contains conjugated polymer system—poly(3,4-ethylenedioxythiophene)-polystyrene sulfonate (PEDOT-PSS). In this system the PEDOT is a stable conjugated polymer which remains oxidized, highly conductive and water dispersible in a complex with PSS [4]. PEDOT-PSS water dispersions are coating formulations which have been suggested by manufactures mostly for substrates such as glass, plastics, and ceramics. We have adjusted this technology for the formulation of conductive coating on textile fabrics using screen printing method. The specially prepared paste containing PEDOT-PSS polymer system—Clevios SV3 (see Table 1), produced by Heraeus (Germany) was applied. The second conductive coating applied—contains conductive filler carbon black as an absorber of EM waves. In this case the paste Tubiscreen EL700 (see Table 1), produced by CHT-Bezema (Germany, Switzerland) was used. The amount of carbon in the paste—24.12%, was determined using analyzer CS-2000 (ELTRA).

The coating was performed manually, using screen printing method. The samples of fabrics were printed with particular paste coating their full surface (50 cm $\times$ 50 cm), or using the squared printing pattern, with square dimensions of 1 by 1 cm and the width of lines of 2 mm. In order to bond and fix the conductive layer on the fabric, the samples were dried in laboratory oven and steamer TFOS IM 350 (Roaches International, England) at condensation temperature of 150 °C for 4 min. For the investigations materials of the same thickness were used and the coating deposit was evaluated through calculation of amount of conductive paste on the fabric surface (Table 2).

Also two types of PES/Cotton plain weave woven fabrics with conductive yarns (20 tex), with different distances between conductive yarns, inwrought in the fabrics were manufactured for this research work. The description of fabrics developed is presented in Table 2.

Methods

All fabrics, manufactured for this research work, were characterized by electrostatic properties and shielding effectiveness, evaluated using two methods: one for measurements from 20 kHz to 50 kHz, another from 2 GHz to 20 GHz.

Methods for measuring electrostatic properties

In order to evaluate the electrical conductivity of samples the reverse value—surface resistance was measured according to EN