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Characterization of electromagnetic shielding fabrics obtained from carbon nanotube composite coatings

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ABSTRACT

The present paper reports novel electromagnetic shielding (EM) fabrics produced by knife-over-roll coating and using combinations of carbon nanotube (CNT), conductive polymer and metal nanoparticles. The materials are analyzed by EM shielding and surface resistivity methodologies, scanning electron microscopy and BET surface area. The synergy among the conductive materials, percolation threshold, EM shielding behaviors and theoretical predictions are also investigated. The coating thickness obtained was 100–200 μm, and the EM range tested was 200–1000 MHz. EM shielding fabrics of 95–99.99% (15–40 dB) were obtained, and CNT was found to be the most effective material. The reported methodology and materials are suitable for the production of customized, flexible, lightweight and porous conductive fabrics for either EM shielding or functional electronic applications, including high specific surface area conductive materials.

1. Introduction

Electromagnetic (EM) shielding is important to block electromagnetic radiation that could be harmful to electronic devices, environment and humans. Textiles have been highly considered for EM shielding applications in the electrical & electronic industries as well as for the production of protective garments due to the increasing concern about health issues caused by human exposure to radiation. The emerging role of textiles as EM shielding is mainly due to their desirable properties in terms of flexibility, versatility, low mass and low cost.

Textiles are intrinsically non EMI shielding materials and are rather insulating materials; however, they can successfully turn to be EMI shielding after raw-material changes, new production process or process adaptations that make them electrically conductive [1]. Some of the methods to obtain conductive fabrics are the use of metallic fibers and yarns, such as stainless steel, aluminum or copper yarns; however, these types of yarns tend to have low flexibility due to their large diameter, which produces a heavier, stiffer and uncomfortable fabric. To reduce this problem, researchers have been studying the influence of yarn density, fabric constructions, different patterns, yarn diameter, quantity of conductive yarns in the structure, layers and yarn direction [2–14].

Conductive fabrics can also be produced by conductive yarns with the use of conductive fillers or coatings incorporated in the yarn production. These processes are based on mixing the fiber polymer with fillers during their production processes such as melt or wet spinning; or by twisting and wrapping a synthetic fiber with metallic yarns using mechanical spinning processes. The yarn coating approaches are mainly in situ polymerization or plating techniques [15–19]. By using conductive fillers or coating during yarn production, yarns of small diameter can be obtained, and therefore, very flexible and light weight fabrics. These coating technologies are less often used due to their inherent complexities.

In general, the above techniques are time-consuming, complex and require the utilization and know-how of the whole textile supply-chain. Moreover, the resulting fabrics normally do not possess isotropic EM shielding behavior, due to the yarn direction obtained by weaving and knitting processes [20].

Other approaches to develop conductive fabrics include the application of conductive materials on the surface of the fabric itself using plating techniques [21–35]. Coating usually does not change the flexibility of the fabrics and is applied in very thin layer, low mass and closed fabric structures. Most of the commercially available EM shielding fabrics are produced by coating technologies and have very homogeneous and closed structures thus exhibiting extremely high EM shielding capabilities and isotropic behavior. In the present study, knife-over-roll coating was used instead of plating techniques. This approach had not been previously investigated with the use of CNT.

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Table 1
Conductive materials used.

Silver nanoparticles (Ag)
Nickel coated carbon fiber filler (Ni/CF)
Multi-Wall carbon nanotubes (CNT)
Polypyrrole nanoparticles (Ppy)

Metals and carbon products are the most frequently used materials for EM shielding applications. Carbon nanotubes have been intensively tested for EM shielding applications; however, mainly for the fabrication of composite films for higher frequency applications (X-Band and Ku-Band) and not for producing EM shielding fabrics [36–52]. In the present study the standard ASTM method (ASTM D4935-10) was used, which utilizes frequency in the range of 200 MHz–1 GHz for assessing EM shielding fabrics.

Nanoscale materials are reported to have the ability to fill up the vacancy of the conductive network formed by conductive materials of different shapes, resulting in a denser and more complete conductive network. In addition, nanoscale materials have high specific surface area and low density. CNTs also have outstanding structural, mechanical and electrical properties, and very high aspect ratio, which enhances the formation of conductive networks.

Conductive polymers such as polypyrrole and polyaniline have been used for the development of conductive fabrics and yarns, mostly via in situ polymerization [35]. In the present study, nanoparticles of polypyrrole were used instead of in situ polymerization.

2. Experimental

Conductive fillers were applied on nonwoven and knitted fabrics using knife-over-roll coating technique. The coating formulations were developed using aqueous dispersions of polyacrylate binders and thickeners, non-ionic surfactants and polyvinylpyrrolidone (PVP). Homogenous and well dispersed recipes were obtained with the use of stirrer and ultrasonication. The formulations were developed using low concentration of conductive fillers in order to obtain an optimal dispersion and appropriate viscosity for the knife coating applications. A multi-layer approach was adopted to gradually achieve the percolation threshold and maximum conductivity; as well as to maintain a good dispersion and homogeneity of the application.

The coating generates a thin layer of high density material on the surface of the fabric; thus, it is represented by surface density (g/m^2) instead of weight percentage of the composite [wt%]. The surface density (S) relates to the actual amount of the filler used in the application, calculated by: mass of coated fabric (C_m) minus mass of pristine fabric (P_m) and minus solid mass of binders, thickeners and surfactants (S). Represented by the equation: S [g/m^2] = C_m [g/m^2] – P_m [g/m^2] – S [g/m^2].

2.1. Materials

The conductive materials used in the experiments are listed in Table 1; they were tested individually and in combinations to explore their synergy.

The CNT was purchased from Nanostructured & Amorphous Materials Inc., and it has purity: 95%, outside diameter: 50–100 nm, inside diameter: 5–10 nm, and length: 5–10 μm. This type of CNTs was chosen because they are supplied by the manufacturer as being a "highly conductive" type, due to their structural characteristics and purity. Furthermore, the MWCNTs used have considerably lower cost than their single-walled alternatives (SWCNTs) and would result in a commercially viable process for the production of EM shielding fabrics. The properties of MWCNTs used were analyzed via Raman spectroscopy, before and after the application, and no structural alterations were observed, suggesting that the CNTs' highly conductive properties were retained after the application onto the fabrics.

Table 2
Recipe preparation for knife coating.

Quantity	CNT 3 wt%	Ag 5 wt%	Ni/CF 5 wt%	Ppy 3 wt%
Binder (g/L)	40	–	30	30
Thickener (g/L)	1	5	5	5
PVP (g/L)	3	2	–	–
Surfactant (g/L)	2	–	1.5	–

The nano Ag was purchased from Mknano, it has 99.9% purity, and particle size <90 nm. The Ni/CF was obtained from Sulzer Metco (E-Fill 2901), it has density: 3.8 g/cm^3 and composition: 67Ni/33C wt%. The polypyrrole (Ppy), a conductive polymer, was obtained from Eeonyx Corporation, under the name Eeonomer® 200 F (particle size avg. 40 nm, apparent density 0.03 g/cm^3, and surface area 570 m^2/g) and Eeonomer WPpy (polypyrrole dispersed in water, 6% solids).

The fabrics used in the experiments were knitted (single jersey, cotton, 154 g/m^2) and nonwoven (polyester, 75 g/m^2) fabrics. The chemical auxiliaries used and their quantities are summarized in the Table 2. The binders used in these experiments have the purpose to adhere and bind the conductive fillers to the fabric, instead of being used to form composites; therefore, small quantities were used.

2.2. Coating methodology

A laboratory coating machine (Mathis Type SV) was used for the application of the developed recipes. This process allows a very thin layer to be applied on one side of the fabric. In this process, a knife (blade) carries the coating paste along the fabric, and its height and velocity determine the quantity and thickness applied on the fabric. A multi-layer approach was used, that is, the coating was applied up to five consecutive layers, with increasing knife height, allowing a thicker layer to be obtained in every step. After the application of each layer, the fabric was dried in a stenter frame.

2.3. EM shielding and surface resistivity methodologies

EM shielding is the process of limiting the flow of EM fields between two locations by a barrier. The shielding barrier needs to have high conductivity/dielectric constant or high magnetic permeability. The shielding takes place through a combination of reflection, absorption and multiple reflections of the radiation by the material (Fig. 1).

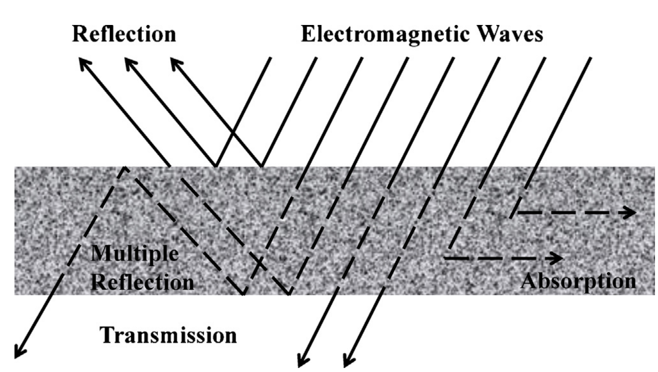

Fig. 1. Mechanisms of EM shielding.