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A Review on the Production Methods and Testing of Textiles for Electro Magnetic Interference (EMI) shielding

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ABSTRACT
The need of the present generation to protect themselves from electromagnetic radiation due the various technological developments has paved way to the birth of EMI shielding of textiles. The shielding effectiveness of the developed fabric will vary depending upon the fabric or the coating constituents. The shielding requirements for different applications vary widely which has resulted in the development of wide variety of shielding mechanisms and materials which can be used in the production of shielding equipment and work wear. In addition to their production, testing of shielding gears involves various methods to be adopted depending on the application.

Keywords - EMI shielding, Shielding testing, shielding materials, ICP

I. Introduction

Due to increasing growth in the electronic and communication industry, the use of EMI shielding in various fields like biomedical, space, automations have increased[1].The intensity of electromagnetic interference (EMI) in the past few decades have increased due to the development of electronic equipment and wireless system[2]. A design-in approach, which requires all the down-stream process to be addressed in the early conceptual and design stages of product development, is usually followed to avoid EMI problems which are identified during the stages at which it is difficult to include in. The selection of right material for EMI shielding depending upon end use is a major concern. The EMI shielding material can be an enclosure or barrier or cover, ventilation panels and windows, conductive gaskets etc. depending on the product [1].

The complexity of shielding requirement is expanding and has resulted in complex design requirement based on the size, the complexity of the communications and information processing system, and the frequency range. The main purpose of EMI shielding in defence is to prevent external EMI from penetrating sensitive environment such as electronic equipments, personnel, etc., and to prevent electromagnetic signals to be transmitted or conducted outside the controlled area.

In this paper, we review the materials widely used in the manufacture of textiles with EMI shielding ability through conductivity, and the test methods adopted to study the properties of these speciality fabrics.

II. Materials for EMI shielding

Clothing with EMI shielding, in defence, is subjected to provide protection from the electromagnetic fields emitted from various electrical devices and communication appliances. The radiation produced from these devices is dangerous and invisible, and hence to ensure safety, conductive layers with shielding properties are worn to cover every portion of the body. The shielding effectiveness of the material is dependent upon the operating frequency range of the radiation, intrinsic electrical properties of the chosen shielding material, the number and configuration of discontinuities in the shielding material, etc. [3].

Low cost copper, aluminium or tinned copper foil tape backed with a highly conductive pressure-sensitive adhesive (PSA) has been used in military shielding applications. Although metals are the most common EMI shielding material, due to its disadvantages such as high density, processing difficulty, poor handle, etc., alternatives are sought after. Conductive polymers offer a solution to this problem [4].

Conductive polymers used for shielding have some advantages over their metallic counterparts in terms of flexibility, access to wide range of structures, reduced weight and cost [5]. Moreover in the present age, the EMI shielding by absorption is of major interest rather than reflection. Metal could not be used as an absorbent since their shallow skin depth results in shielding through reflection mechanism [6]. The significant quality of Intrinsic Conductive Polymer (ICP) is to selectively absorb the radiation instead of merely reflecting it from the surface. Higher levels of uniformity in conductivity of ICP and ICP thermoplastic blends lead to superior shielding characteristics [7].The necessity to reduce costs and higher performance of shielding materials has led to the development of innovative absorbing materials such as conducting polymer which operates in a wide frequency range [8].

III. Shielding characteristics of innate textile structures

The shielding effectiveness was found to be dependent on the angle between the yarns in contact and the density of yarns in the model. The yarns at right angle conducted the best in contrast to the yarns arranged parallel [9]. Individual yarns and fibers can be treated with polymers and then formed into fabric which is proved to have good shielding effectiveness [10]. The aperture size and contact resistance of yarns in fabrics are critical parameters in determining shielding effectiveness [11]. The electrical resistance of EMI fabric changes according to yarn to yarn or fiber to fiber contact [12]. The surface resistance of knitted fabric is dependent on the exposure of conductive material(core conductive yarn) [13]. The conductivity of stretchable fabrics increased upto an extension of 60% above which the conductivity decreased [14]. Polypyrrole coated glass fiber fabrics have been used as Salisbury screen absorbers [15].

IV. EMI shielding with conductive fillers

In 1992, Rodrigeuz invented a protection material which is an improvement of the apron invented earlier (US patent 3,996,620) which is made up of lead. This protection material is a copper-based coating to a fabric or a fabric insert which is very flexible and is capable of being removed and washed. The garment is protective against electromagnetic radiation, radio frequency and microwave radiation but offers no protection against X-ray radiation [16].

In 1999, Hardy developed a brassiere which provides electromagnetic shielding of radiation at efficiency of 18.5 dB to 39 dB at frequencies of 200MHz-10 GHz which is claimed to protect women from cancer. Homemakers and women in other business are constantly near appliances which have the potential of inducing breast cancer through bombardment of body cells by electromagnetic radiation. The brassiere is a cotton fabric interwoven with stainless steel thread [17]. Khalilabad *et al* [18] prepared electro-conductive fabrics by loading graphene oxide through a number of coatings for increasing the electrical conductivity. Ni-Co alloy coated composites have fluctuating curve of absorption with respect to coating time [19]. Seignetto magnet-materials combining dielectric and magnetic properties are the absorbing coating of smallest thickness [20].

V. EMI shielding with ICPs

Highly doped poly-pyrrole (PPy) films are suitable for shielding application with shielding levels above 40 dB in the 300 MHz-2 GHz frequency range, in contrast to lightly doped PPy film which is characterized by little deflection/absorption at a conductivity of 0.01S/cm [21]. Ar,O_2,N_2 plasma treatments on poly-ethylene terephthalate (PET) thin film resulted in better interfacial bonding between the PET and PPy surface; better coating fastness is obtained [22]. Polyester soaked in 50% aqueous pyrrole solution showed higher conductivity which is used in composites prepared for EMI shielding. Pyrrole and aniline could be used to induce conductivity in a fabric used for EMI shielding [23].The loss of conductivity in EMI shielding-fabric coated with ICP is attributed to chlorine content of the film [24]. In situ polymerization of pyrrole has been carried out in jigger machine which can be scaled up for large scale production in industry [25]. 50 μm thick PPy film provides 30 dB attenuation is sufficient for practical EMI applications [26]. PPy coated cotton fabric in addition to EMI shielding were found to exhibit antimicrobial properties. EMI shielding fabric coated with PPy shows no significant relationship between thermal and conductivity characteristics of the coated fabric [27]. Polypyrrole coatings require high stability and reproducible formulation to be used in shielding application [28]. Absorption dominant shielding characteristic of ICPs render them more useful in stealth technology [29]. Synthesis temperature plays a major role in the characteristic of the ICP coating involved [30]. PPy fabrics have relatively high absorbance and low reflectance, and hence have excellent radio frequency (RF) and microwave absorbance characteristics [31]. Fabrics coated with ICP have good UV protection properties [32]. Increase in diffusion time during dispersion of the monomer increases EMI shielding efficiency [33]. When the surface resistivity decreases, the reflection levels increase and the temperature increase with the decrease in irradiation [34]. Polyaniline doped conducting fabrics lead to the development of absorbing structural materials [35]. Composites with low conductivity showed absorption dominant characteristics [36].

VI. EMI shielding with nanomaterials

Electromagnetic wave absorption is related to dielectric and magnetic losses. Soft metallic magnetic nanomaterials have the capability of absorbing EMI waves at high frequencies. T.W.Shyr *et al* [37] reported the presence of stainless steel fibre in a fabric increased the EMI shielding dominated by absorption related characteristics. Deposition of PPy, Multiwall Carbon

Nanotubes(MWCNT) over viscose non-woven fabric exhibit higher conductivity than PPy coated fabric which is due to the higher interaction between the π-π bonds of MWCNT and PPy [38]. PPy nanoparticles which are less than 50 nm in size show higher rubbing fastness at dry and wet conditions [39]. Hollow Poly(aniline-co-pyrrole)-Iron oxide nanoparticles (HPAP-Fe3O4) exhibits best microwave absorbing property between 0.5 and 10 GHz [40]. In the frequency range of 6-14 GHz, the fabric coated with Polyaniline (PAni) showed absorption of 48% [41].

VII. Shielding Effectiveness (SE) measurement methods for textile substrates

Measuring a thin conductive film for shielding characteristic under plane wave condition involves the test material to be placed in between the source of a plane wave and a detector. The accuracy of measurement is of a major concern owing to several errors arising due to contact resistance, air gaps, calibration error, etc. [42]. Various measurement methods used for textile have been listed in Table 1. Table 2 gives a summary of the important variables pertaining to these test methods.

Table 1: Various SE measurement techniques for textile substrates

Shield Test technique	**Conductive fabric**
ASTM D-4935-10	Most appropriate
Time domain	
Complex permittivity approach	Appropriate
TEM-cell	
Dual TEM cell	

Table 2: A summary of important variables in various test methods

Test methods	**Basic variables of interest**	
	Operating frequency	**Simulation of incident field type**
ASTM D-4935-10	30 MHz-1.5 GHz	Far-field
Complex permittivity approach	100 MHz-3.5 GHz	Far-field
TEM-cell	1 MHz-1 GHz(E-field) 1 MHz-400 MHz (H-field)	Far-field
Dual TEM cell	100 MHz-2 GHz	Far-field
Time domain	200 MHz-3.5 GHz	Far-field

7.1 ASTM D-4935-10-test method

This test method is the most suitable method for measuring electromagnetic shielding effectiveness (SE) of a planar material (textile) due to a plane wave, far-field EM wave operating at a frequency range of 30 MHz to 1.5 GHz. The net SE caused by reflection and absorption are measured for far-field. Near field values may be calculated for both electrical (E) and magnetic (H) sources from the measured far-field values. The apparatus (shown in Fig. 1) includes a specimen holder(enlarged, coaxial transmission line with special taper sections and notched matching grooves to maintain a characteristic impedance of 50 V throughout the entire length of the holder), a signal generator(capable of generating a sinusoidal signal over the desired portion of the frequency range), a receiver (capable of measuring signals over the same frequency range as the signal generator), coaxial cable connectors (connecting power between specific components without causing interference with other components) and attenuators (devices used to isolate the specimen holder from the signal generator and the receiver). The sources of errors in the measurement are due to operator errors, specimen-caused errors, and measurement system errors [43].

Figure 1: General test setup in ASTM 4935

An innovative test method has been proposed by Sarto *et al* [44] which overcomes the limitations of ASTM D4935 test method concerning the upper operating frequency and the required minimum specimen dimensions. The measurement is performed in the frequency range from 30 MHz up to 8 GHz, using an FCSH (Flanged Coaxial Sample Holder) below cut-off. ASTM D-4935-99 method was used as standard for measuring permittivity (relative complex permittivity), magnetic permeability (relative complex magnetic permeability) and EMI shielding efficiency. The instruments used by J.S.Im *et al* [45] while following the above mentioned standard are vector network analyzer with an amplifier and a scattering parameter test set. He also used annular disks for holding the sample to be inserted into the test tool.

7.2 Complex permittivity measurement-free space approach

Although there are a lot of microwave methods suggested for measuring complex permittivity, free-space approach is more suitable in sub-mm range since the sample size has reasonable dimensions in order to avoid undesirable edge diffraction effect.

The complex permittivity (ε_r), as in equation (1), is related to electric field consists of two parts: a real part ($\varepsilon_{r'}$) associated with the energy storing capacity of the material and an imaginary part($\varepsilon_{r''}$) related to the electrically dissipative nature of the material [46]:

$$\varepsilon_r = \varepsilon_r' + i\varepsilon_r'' \qquad (1)$$

The values of relative permittivity (ε”), given by equation (2), is directly proportional to total (ac+dc) conductivity of the material expressed as:

$$\varepsilon'' = i\sigma_{tot}/\omega \qquad (2)$$

where σ_{tot} is the total conductivity of the material and ω is the angular frequency [47].

The complex permittivity of textiles and leathers were measured at 330□ GHz using the absolute THz power meter with thin-film sensor operating near the Brewster angle in order to provide a minimum multiple-reflection effect [48].The experimental set up for complex permittivity measurement is shown in Fig. 2.

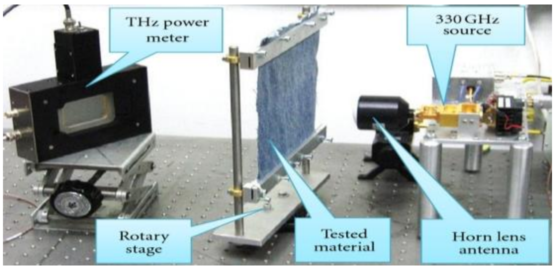

Figure 2: Experimental set up for complex permittivity measurement

The measurement procedure includes the two steps: (i) calibration-measurement of the transmitted signal without material under test (P0), (ii) measurements of the transmitted signal as a function of incident angle in a presence of material under test (P1), and (iii) the ratio P1/P0 is the power transmittance needed to extract the complex permittivity.

7.3 TEM cell and Dual TEM cell

A Transverse Electromagnetic cell (TEM cell), (shown in Fig. 3) a rectangular coaxial line with a flanged outer conductor were put-together to adapt to the co-axial line fixture. The inner conductor of TEM cell is depressed by 1mm to avoid contact impedance problem in the cells. A full two port measurement calibration was carried out for each section before the tests were conducted to minimize the errors. To avoid air gaps between the cells, the outer flanges of the test cell are tightly clamped together. Shielding effectiveness was found by connecting the two port system to a vector network analyzer.

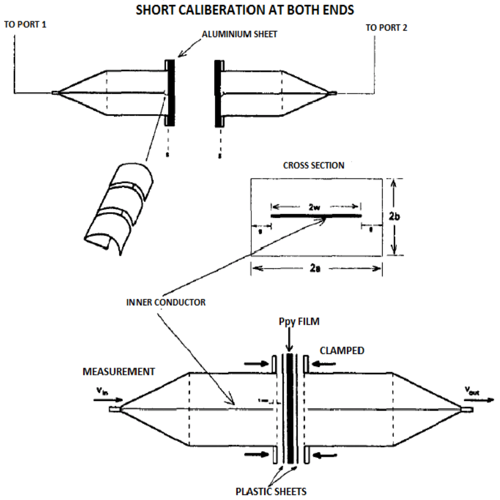

Figure 3: TEM cell sample holder unit for SE measurement

The dual TEM cell (shown in Fig. 4) allows simultaneous measurements of electric and magnetic polarizabilities of test material fixed in a small aperture, which is not possible with a single TEM cell. The dual TEM cell consists of two TEM cells one of which is coupled via a small aperture in the shared conducting wall. The aperture transfers power from the driving cell to the receiving cell. The dual cell simulates both high and low impedance near field simultaneously. The effect of dual cell during SE measurement could be removed by measuring insertion loss in an empty cell and subtracting it from the insertion loss measured with the cell loaded with sample. Insertion loss was found through dual TEM cell for the polypyrrole coated nonwoven fabric in the work by J.Avloni *et al* [49]. SE at low frequency (SE_{LF}) is given by equation (3):

$$SE_{LF} = 20\,log\left(1 + \frac{Zo/_{Zs}}{2}\right) \qquad (3)$$

where Zs is the surface impedance of the conductive material and Zo is the vacuum impedance, and at SE at high frequency SE_{HF} is given by equation (4):

$$SE_{HF}=10\log\left(\frac{\sigma}{16\omega\varepsilon}\right)+20\frac{t}{\delta}\log(e) \qquad (4)$$

Here, σ is the surface conductivity, ω-angular frequency, ε-relative permittivity, t-thickness and δ -skin depth of the sample are known.

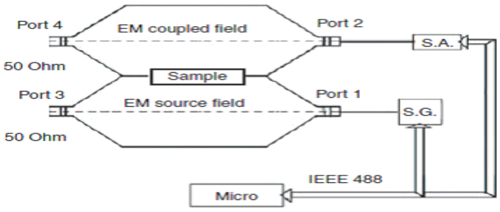

Figure 4: Dual TEM cell measurement set up

7.4 Time domain approach

Pulsed or time domain (TD) signals made to pass through the test sample can be used for SE measurements. Use of a TD source makes it possible to differentiate the direct path (through the test sample) and indirect path (diffracted).The signal is recorded at the receiving end. An impulse generator is used to generate an impulse of a few hundreds of Pico-second width to be radiated through a TEM horn antenna (because TEM horns have rear amplitude and phase response for a wide frequency range. At the receiving end the pulse is detected by a similar antenna connected to a waveform recorder (sampling oscilloscope). Insertion loss measurements were found by measuring the difference of power recorded at the transmitting and receiving ends. The measurement system is shown in Fig. 5.

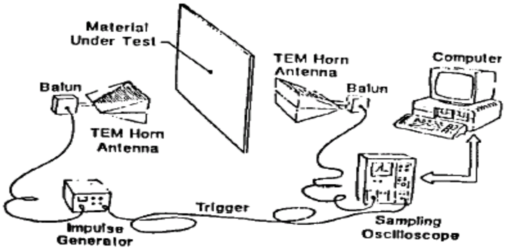

Figure 5. Time domain shielding effectiveness measurement system

VIII. Conclusion

Fabrics with EMI shielding are materials which require unique range of properties. They are necessary not only in the field of defense but also in various fields of science. New developments are carried out at a wider range and pace in the aspect of material and quality concern. Studies have been carried out in the aspect of developing well defined system while in the production of EMI shielding gears for potential application is concerned to backlogs in the fulfillment of several properties. Continuous research in this field will lead to desired shielding in diverse applications.

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