INVESTIGATION OF ELECTROMAGNETIC SHIELDING PROPERTIES OF BORON AND CARBON FIBRE WOVEN FABRICS AND THEIR POLYMER COMPOSITES

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Abstract

Using of electronic devices increased by the development of the technology. Electronic circuits of these electronic devices diffuse electromagnetic energy and this energy effects human in negative way. Recently, the prevention of electromagnetic waves is an important subject. Prevention of electromagnetic waves is also important for defence and telecommunication sectors.

In this study electromagnetic shielding(EMSE) properties of boron and carbon fibre plain woven fabrics and their polymer composites were investigated. Shielding properties were performed between 15MHz and 3000MHz by coaxial transmission-line method according to ASTM-D 4935-10. Boron and carbon fibre fabrics and their polymer composites show different shielding properties in different frequency band.

Keywords: Electromagnetic shielding, boron fibre, carbon fibre, composite.

1. Introduction

The growth of the electronic industry and the widespread use of electronic equipment in communications, computations, automations, biomedicine, space, and other purposes have led to many electromagnetic interference (EMI) problems as systems operate in close proximity. It is likely to become more severe in the future, unless proper EMI control methodology and techniques are used to meet the electromagnetic compatibility requirements.

With the rapid growth of the electrical and electronic devices and accessories, which emit electromagnetic energy in the different frequency bands used in the markets, it becomes essential to limit and shield electronic equipment against all sources of interference due to all these electromagnetic energies[1]. Among the various solutions offered, textile products and textile-based composite materials have caught the attention of researchers for the versatility and conformability these textile structures provide. Increased awareness of EMI has led to the formulation of new regulations around the globe for the manufacturers of electrical and electronic equipment to comply with the electromagnetic compatibility requirements [2]. If an electromagnetic wave gets into an organism, it vibrates molecules to give out heat. In the same way, when an electromagnetic wave enters the human body, it will obstruct a cell's regeneration of DNA and RNA. Furthermore, it brings an abnormal chemical activities to produce cancer cells, and increases the possibility of leukemia and other cancers. Injuries by electromagnetic waves to the human body are the top priority of professionals and scholars, and we are most concerned with solving this problem [3,4].

Electromagnetic wave consists of an electrical component and magnetic component perpendicular to each other and propagates at right angles to the plane. The waves are produced by the motion of electrically charged particles. These waves are also called "electromagnetic radiation" because they radiate from the electrically charged particles. They travel through empty space as well as through air and other substances. This is difficult to visualize, however the waveform has similar characteristics of other types of waves.

Although they seem different, radio waves, microwaves, x-rays, and even visible light are all electromagnetic waves. They are part of the electromagnetic spectrum, and each has a different range of wavelengths. The range of wavelengths for electromagnetic waves from the very long to the very short is called the Electromagnetic Spectrum[5].

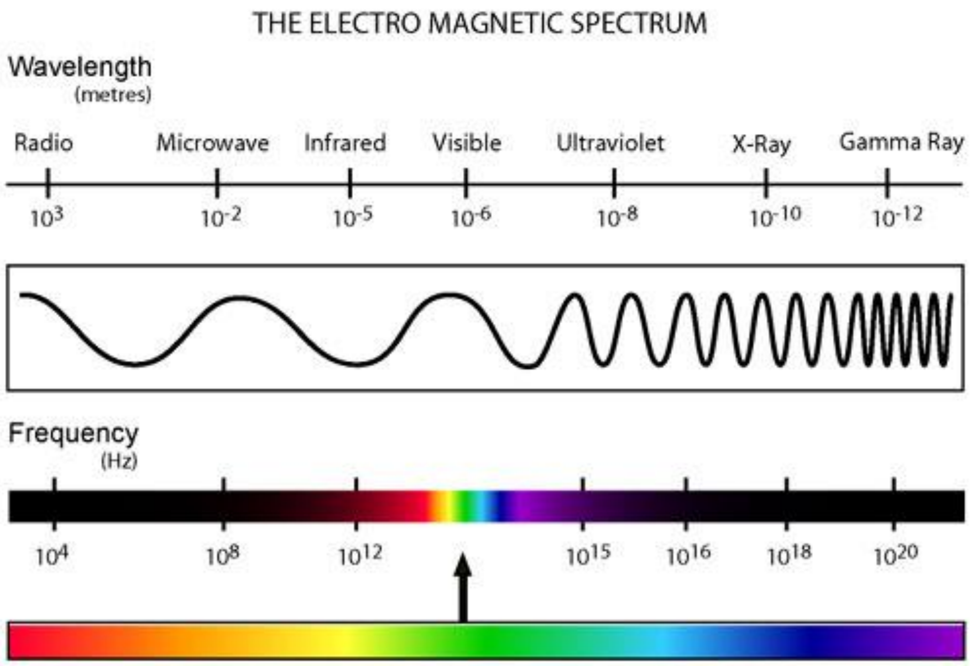


Figure 1: *Electromagnetic Spectrum*

Several methods are available for shielding the electromagnetic radiations such as ionic plating, electroless plating, cathode sputtering, conductive paints, vacuum metallization, zinc paints, zinc flame spraying, zinc arc spraying, and conductive fillers such as copper, stainless steel, and aluminum. The above methods can be categorized under two headings, such as surface treatments and fillers. Surface treatments are often time consuming, labor intensive, and costly. Conductive fillers in the form of particulates, filament, and woven fabrics are increasingly being used for shielding electromagnetic radiations. Attempts by researchers using woven fabric indicate that the shielding effectiveness of the fabrics depends on the conductive filler content. Various conductive fillers are selected based on their electromagnetic shielding effectiveness (EMSE) values at different electromagnetic frequencies [6].

In this study electromagnetic shielding(EMSE) properties of boron and carbon fibre plain woven fabrics and their polymer composites were investigated. Shielding properties were performed between 15MHz and 3000MHz by coaxial transmission-line method according to ASTM-D 4935-10. Boron and carbon fibre fabrics and their polymer composites show different shielding properties in different frequency band.

1.1. Shielding Effectiveness

Shielding can be specified in the terms of reduction in magnetic (and electric) field or plane-wave strength caused by shielding. The effectiveness of a shield and its resulting EMI attenuation are based on the frequency, the distance of the shield from the source, the thickness of the shield, and the shield material. Shielding effectiveness (SE) is normally expressed in decibels (dB) as a function of the logarithm of the ratio of the incident and exit electric (E), magnetic (H), or plane-wave field intensities SE(dB)=20log(E0/E1), SE(dB)=20log(H0/H1), and SE(dB)=20log(F0/F1) respectively [7].

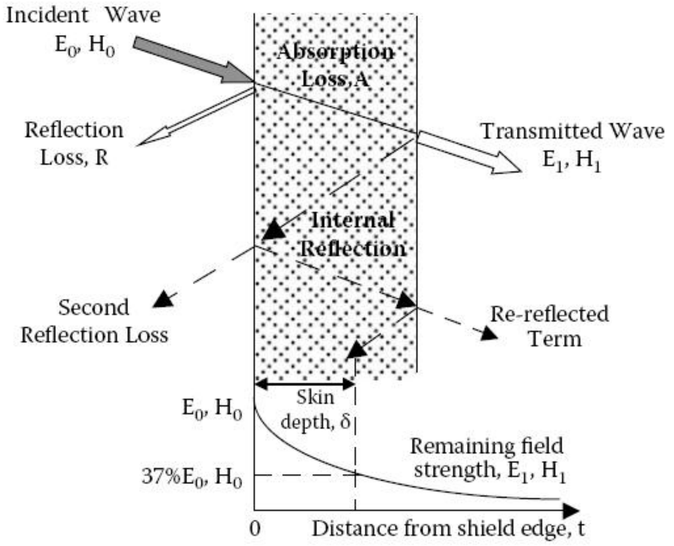


Figure 2: *Graphical representation of EMI shielding.*

With any kind of electromagnetic interference, there are three mechanisms contributing to the effectiveness of a shield. Part of the incident radiation is reflected from the front surface of the shield, part is absorbed within the shield material, and part is reflected from the shield rear surface to the front where it can aid or hinder the effectiveness of the shield depending on its phase relationship with the incident wave, as shown in Figure 1. Therefore, the total shielding effectiveness of a shielding material (SE) equals the sum of the absorption factor (A), the reflection factor (R), and the correction factor to account for multiple reflections in thin shields:

$$SE= R+A+B \qquad (1)$$

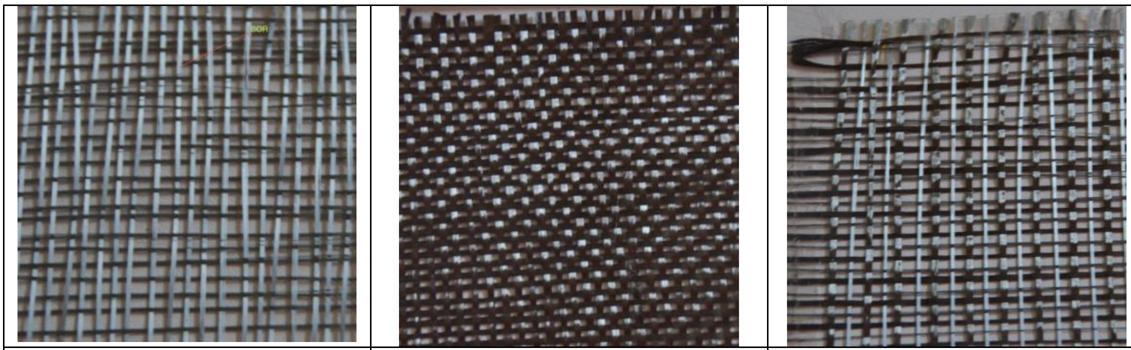
All the terms in Equation 1 are expressed in dB. The multiple reflection factor B can be neglected if the absorption loss A is greater than 10 dB. In practical calculation, B can also be neglected for electric fields and plane waves.

2. Materials and Methods

2.1. Materials

2.1.1. Fabrication of Fabrics

The yarns were formed into handloom machine. Kind of weave structures are namely plain. The woven fabrics are produced by considering similar weft and warp density. Picture of weaving fabrics are shown in figure 3.



Boron Fabric	Carbon Fabric	Boron-Carbon Fabric

Figure 3: *Picture of Weaved fabrics*

2.1.2. Fabrication of Composite Structure

In this study, boron, boron-carbon and carbon fibers are used to produce plain weaving fabrics and polyester resin was used as matrix. Thermosetting polyester was applied as a resin. Composite structures were fabricated by hand lay up method. First, polyester resin was sprayed onto a laboratory tissue and smeared evenly onto the surface of the mould. Finally, the composites were post-cured at 20 ^{0}C for 24 hours.

2.1.3. EM Shielding Effectiveness (EMSE) Measurements

The electromagnetic shielding effectiveness of the produced needle punched nonwoven fabrics were determined with based on ASTM D 4935-10 the coaxial transmission line method for planar materials standard. A shielding effectiveness test fixture (Electro-Metrics, Inc., model EM-2107A) was used to hold the sample with a network analyzer generating and receiving the EM signals. This standard determined the shielding effectiveness of the textile structures using the insertion-loss method. The technique involved irradiating a flat, thin sample of the base material with an EM wave over the frequency range of interest, utilizing a coaxial and a flanged outer conductor. [8-10] Figure 4 shows the EMSE testing apparatus.

Figure 4: *Set up of EMSE Testing Apparatus*

A reference measurement for the empty cell was required for the shielding-effectiveness assessment (Figure 5a). The reference sample was placed between the flanges in the middle of the cell, covering only the flanges and the inner conductors. A load measurement was performed on a solid disk shape which had a diameter the same as that of the flange (Figure 5b). The size of the cross section of reference sample (Figure 5c) and load sample (Figure 5d) are also shown in Figure 5. The reference and load measurement were preformed on the same material.

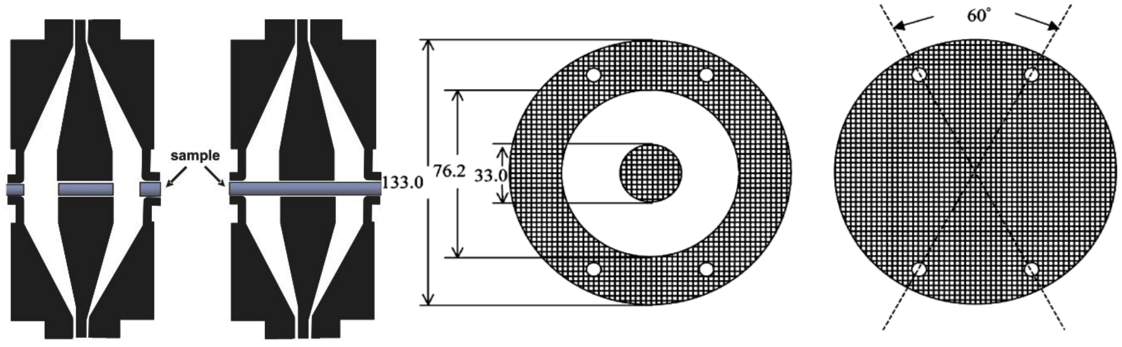


Figure 5: *A cross-section of the shielding effectiveness test fixture (a) reference sample in the jig and (b) load sample in the jig. Specific dimensions of the specimens for shielding effectiveness measurement (unit: mm), (c) Reference sample (d) Load sample*

The shielding effectiveness was determined from (Formula 2), which is the ratio of the incident field to that which passes through the material.

$$\mathrm{EMSE} = 10\log\left(\frac{P_1}{P_2}\right) \qquad (2)$$

Where P1 (watts) is received power with the fabric present and P2 (watts) is received power without the fabric present. The input power used was 0 dBm, corresponding to 1 mW.

The shielding effectiveness measurements were carried out between 15MHz to 3000MHz. The measurement device consists of a network analyzer, which is capable of measuring incident, transmitted and reflected powers, and a sample holder. The shielding effectiveness is determined by comparing the difference in attenuation of a reference sample to the test sample, taking into account the incident and transmitted power.

Table1: *Evaluation of Electromagnetic Shielding Effectiveness for General Use [12]*

Grade	5 Excellent	4 Very Good	3 Good	2 Moderate	1 Fair
Percentage of Electromagnetic Shielding	ES＞99.9%	99.9%≧ES 99.0%	99.0%≧ES＞90%	90.%≧ES＞80.%	80%≧ES＞70%
Shielding Effectiveness	SE＞30dB	30dB≧SE＞20dB	20dB≧SE＞10dB	10dB≧SE＞7dB	7dB≧SE＞5dB

SE: Shielding Effectiveness (dB)
ES: Percentage of Electromagnetic Shielding (%)

Table 2: *Evaluation of Electromagnetic Shielding Effectiveness for Professional Use*

Grade	5 Excellent	4 Very Good	3 Good	2 Moderate	1 fair
Percentage of Electromagnetic Shielding	ES > 99.99999%	99.9999% ≥ ES > 99.999%	99.999% ≥ ES > 99.99%	99.99% ≥ ES > 99.9%	99.9% ≥ ES > 99.0%
Shielding Effectiveness	SE ≥ 60dB	60dB ≥ SE>50dB	50dB ≥SE>40dB	40dB ≥SE>30dB	30dB ≥SE>20dB

SE: Shielding Effectiveness (dB)
ES: Percentage of Electromagnetic Shielding (%)

3. Results

The results obtained from the measurements were commented by considering woven fabrics with boron, boron-carbon and carbon. Three different frequence groups 15-600 MHz low frequnce, 600-1200 MHz medium frequence and 1200-3000 MHz high frequence were formed. Obtained graphics were given one by one.

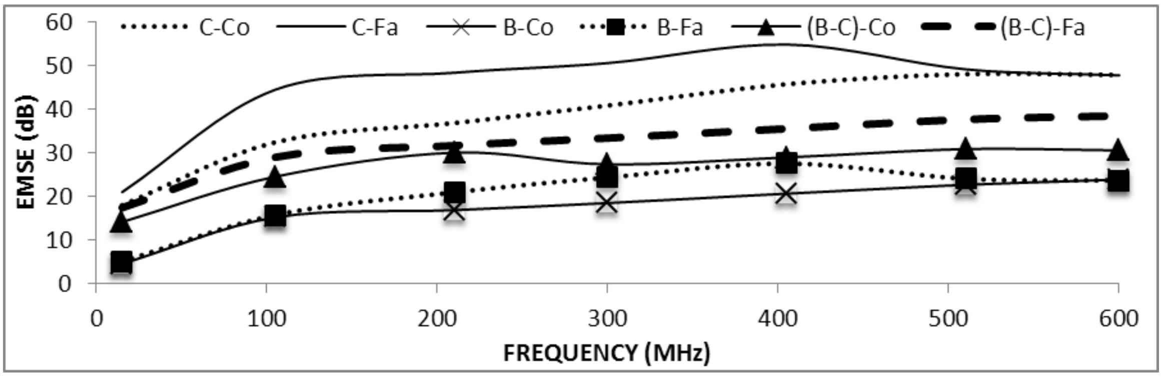


Figure 6: *Electromagnetic Shielding (EMSE) of woven fabrics with Boron, Carbon and (Boron-Carbon) and Reinforced composite with Boron, Carbon and (Boron-Carbon) fabrics between 15-600MHz*

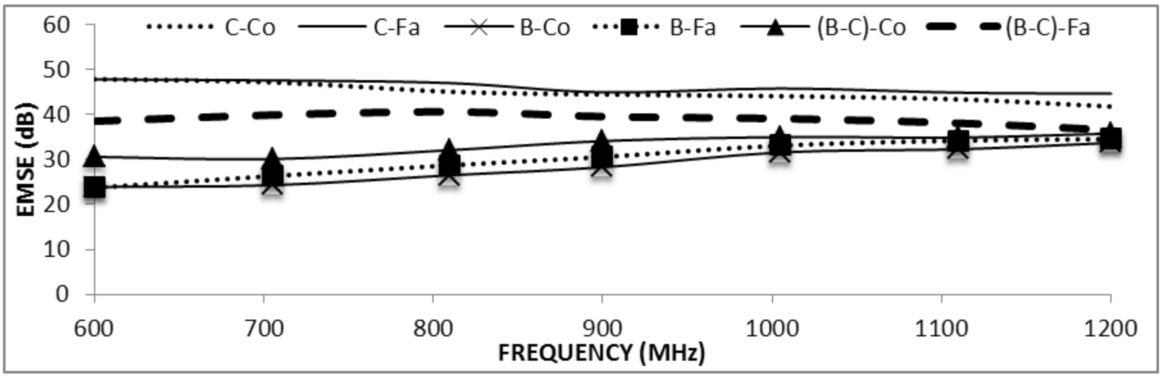


Figure 7: *Electromagnetic Shielding (EMSE) of woven fabrics with Boron, Carbon and (Boron-Carbon) and Reinforced composite with Boron, Carbon and (Boron-Carbon) fabrics between 600-1200MHz*

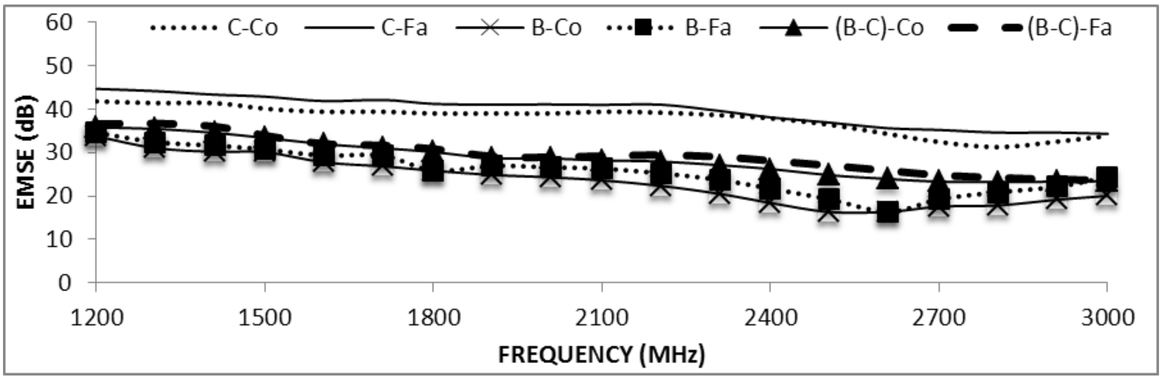


Figure 8: *Electromagnetic Shielding (EMSE) of woven fabrics with Boron, Carbon and (Boron-Carbon) and Reinforced composite with Boron, Carbon and (Boron-Carbon) fabrics between 1200-3000MHz*

The Effect of Different Materials on Electromagnetic Shielding Effectiveness

Figure 6 shows EMSE values of the woven fabrics and their composites at the low frequency range of 15-600MHz. It was seen that EMSE values of all the woven fabrics and their composites increase slightly up to 300MHz. Among all the three fabrics and their composites, the carbon fabric and its composite displayed the highest EMSE whereas the boron fabric and its composite displayed lowest EMSE. All fabrics and their composites exhibit Electromagnetic Shielding Effectiveness over 15 dB at the low frequency range of 15-600MHz.

Figure 7 shows EMSE values of the woven fabrics and their composites at the medium frequency range of 600-1200MHz. All fabrics and their composites exhibit Electromagnetic Shielding Effectiveness over 20 dB at the medium frequency range of 600-1200MHz. All fabrics and their composites display higher Electromagnetic Shielding Effectiveness at the medium frequency range than at the low frequency range. The EMSE increase with increasing of frequency at the medium frequency range.

Figure 8 shows EMSE values of the woven fabrics and their composites at the high frequency range of 1200-3000MHz. All fabrics and their composites exhibit Electromagnetic Shielding Effectiveness over 10 dB at the high frequency range of 1200-3000MHz. All fabrics and their composites display lower Electromagnetic Shielding Effectiveness at the medium frequency range than at the medium frequency range. The EMSE decrease with increasing of frequency at the medium frequency range.

Comparing of Electromagnetic Shielding Effectiveness of Composites and Fabrics

As you can see from figure 6-8, all woven fabrics exhibit better Electromagnetic Shielding Effectiveness than their composites. This can be explain with covered matrix materials surface of fabrics. Because, Matrix materials that is polyester resin behaves as an isolator. As a result, EMSE decrease.

4. CONCLUSIONS

In this study, Electromagnetic Shielding Effectiveness of the woven fabrics produced with different conductive were tested and results were commented. The results obtained from electromagnetic shielding test were listed in the below.

- ✓ The best Electromagnetic Shielding Effectiveness obtain with carbon fabric and its composite between 15 and 3000 MHz. The boron fabric and its composite exhibit lowest EMSE between 15 and 3000 MHz.

- ✓ 1000-2400 MHz frequency range is used for mobile phone, wireless technology and 3G technology and the frequency range describe high shielding.

- ✓ All woven fabrics exhibit better Electromagnetic Shielding Effectiveness than their composites.

ACKNOWLEDGEMENTS

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