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EFFECTS OF CARBON FIBER ORIENTATION ON ELECTROMAGNETIC INTERFERENCE SHIELDING PERFORMANCES

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ABSTRACT

The high thermal-conductive carbon fiber is a promising electromagnetic interference (EMI) shielding material. This material is gaining popularity in building construction as it is corrosion resistant, has high tensile strength, is light weight and low in cost as compared to commonly used metal shielding which is heavy weighted and prone to EMI leakage at joints of building structures. This paper presents the investigations of EMI shielding effectiveness on multilayer carbon fiber composite with different orientations. Three concrete samples are considered in different orientations and are experimentally tested via shielding effectiveness (SE). The SE experiment set-up consists of a planar sample with its input and output connected to a vector network analyzer (VNA) in the frequency range of 3.0 GHz to 4.2 GHz. Based on the conductivity measurements of different orientations, the shielding effectiveness is obtained as a function of frequency as the plane wave analysis correlates the conductivity and shielding effectiveness measurements. It is proven that the carbon orientation contributes to changes in conductivity due to the positioning of the electric field of the incident wave and thus, produces different shielding performances.

Keywords: Electromagnetic Shielding; Carbon Fiber; Shielding effectiveness (SE)

INTRODUCTION

EMI problems become the main issue towards electrical and electronic devices as it can interfere, interrupt, degrade and obstruct electrical system performance of certain devices or equipment such as radar system used in military or computer control room. This unwanted EM radiation is basically electrical in nature and is either radiated or conducted. Normally, EMI caused by electrical/electronic devices such as computer circuits, radio transmitters, mobile electronics or power transmission lines can be any form of disturbance which may lead to the disruption of TV signals, interruption in mobile phone communication, corruption of data in computer systems, and cause jamming or sensitivity to medical, military and aircraft systems [1,2].

The increase of EM pollution to a level never attained before is due to the rapid development of electronic systems and telecommunication technology [3]. This EM pollution can also harm human bodies by causing diseases such as leukemia, tumor and cancer [4,5]. In July 1967, one serious case of EMI occurred on the USS Forestall and a reported number of 134 people were killed and caused a damage of $ 72M. Thus, EMI shielding has attracted wide attention and the demand has increased it has become a potential solution to all EMI incidents [6].

Various types of materials have been investigated as their electrical properties promise high shielding value in many applications. Traditionally, high conducting materials such as metals were used as shielding material, preventing electromagnetic radiation by reflection. However, carbon based materials such as carbon fiber, carbon nanotubes (CNTs) and carbon black which act as absorbers have gained particular interest for EMI shielding applications due to their lightness, low cost, resistance to corrosion and design flexibility [7,8,9,10].

In 2006, the global demand for carbon fiber (CF) was estimated to be about 27,000 tons per year, and the price lay between €15 and €19 per kg. The valuable commodity of CF is expected to raise demands to about 15% per year in the future [11]. Carbon fiber is found to be a fascinating material for numerous commercial and domestic applications including electrical equipment, automotive parts and heavy duty aircraft which promising absorbers owing to its high modulus, high strength, low density and low coefficient of thermal expansion [12,13]

Much research has been carried out regarding the microwave-absorption and related mechanisms of CFs. It has been observed that addition of both the cement matrix and polymer matrix composites with CFs enhance the shielding effectiveness (SE) over a wide frequency range [12]. Basically, the SE depends on the thickness of the material, its electrical characteristics and the nature of the incident radiation. Thus, increasing the thickness of the material would provide high number of fibers intercepting with the incident EMI waves (N.C Das, October 2000). An SE of 20 dB indicates that 99% of the EM energy is reflected or absorbed by the material. It is a typical value needed for EMI/RFI shielding applications. However, according to electromagnetic compatibility (EMC) regulations, an adequate level of shielding for many commercial applications of EMI SE is at least 30 dB, which indicates that 99.9% of the EM energy is reflected or absorbed by the material [14,15].

EXPERIMENTAL

The properties of carbon fiber are presented in Table 1. The permittivity value is an important characteristic of shielding materials which relates to the ability of EMI shielding. Ameli, A. et.al have investigated that EMI SE can be improved up to 65% when the dielectric permittivity is increased [16]. From the table, the permittivity of the used carbon fiber is 3.4. Epoxy resin and hardener are added into the CF composites (CFCs) with a ratio of 1:2, respectively.

Table 1: Properties of the carbon fiber

	Carbon fiber
Fiber	High Strength
Density (g/m2)	300
Relative Permittivity	3.4
Design Thickness (mm)	0.167
Tensile Strength for Design (N/mm2)	3550
Tensile Modulus for Design (N/mm2)	2.35x10^5

Specimen of block concretes is casted with carbon fiber sheets in mold concrete within the cube size of 150mm x 150mm x 150mm. Carbon fiber composites layer organization as presented in figure 1. The first sample is casted without carbon fiber and the other sample is casted with 5 layers of carbon fiber with different orientation. Samples S0, S1, S2 and S3 respectively indicate the samples without CF, samples with 5 layers of parallel CF (0^0 orientation), samples with 5 layers of perpendicular CF or(0^0/90^0/ 0^0/ 90^0/ 0^0), and samples with 5 layers of CF (0^0/45^0/ 90^0/ -45^0/ 0^0). These samples are prepared according to the standard concrete building of grade 30. The concrete must undergo some tests such as slump test and strength test after curing for 28 days.

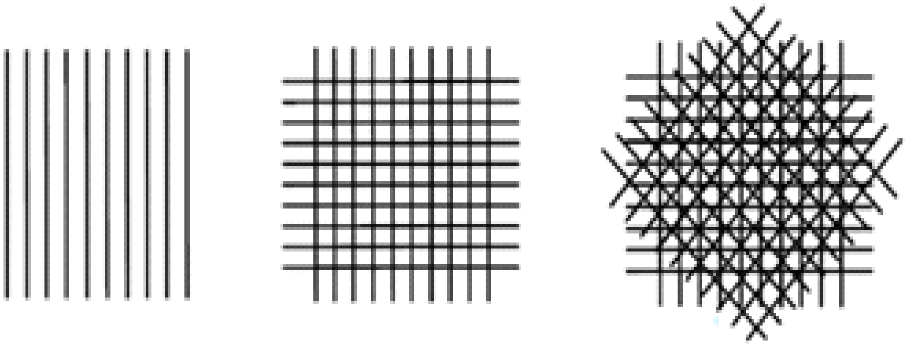
(a) (b) (c)

Figure 1: Carbon fiber composites layer organization: (a) sample S1, (b) sample S2 and (c) sample S3

EMI SE was measured in the frequency range (2.6–4.2 GHz) using a two-port Anritsu Vector Network Analyzer (VNA) Master 2026B, two standard coaxial cables, a set of waveguides and a holder in accordance to the American Society of Testing Materials (ASTM) D4935-99 [17]. The block diagram of VNA is as shown in figure 1. The incident EM wave had a power of 0 dBm which corresponds to 1 mW. After calibration of the set-up, the reflection and transmission measurements are directly measured by the VNA and used to calculate the EMI SE. The measurement of VNA are defined in terms of scattering parameters (S-parameters) [18]. For a 2-port network, four fundamental S parameters can be measured, and they are defined as S_{XY}. For a 2-port VNA, measurements of signals leaving Port 1 are called forward measurements, and those leaving Port 2 are called reverse measurements.

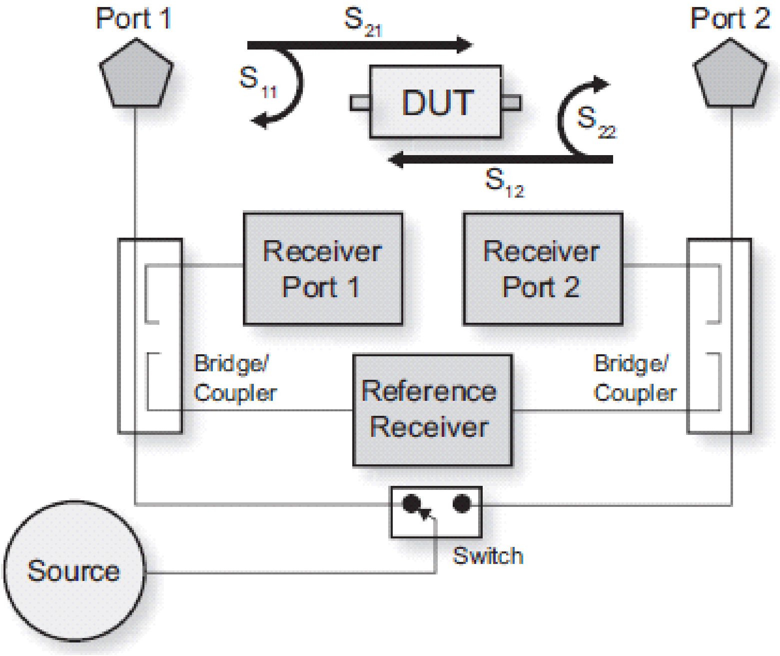

Figure 2: A simplified block diagram of VNA Master's architecture(Master)

Based on Figure 2, S_{11} is called Forward Reflection and it represents the measurement of the signal that leaves port 1 and is reflected back to Port 1. S_{11} is defined as the ratio of power of the reflected wave over the incident wave. Meanwhile, S_{21} is called Forward Transmission and it represents the measurement of the signal that leaves port 1 and transmitted to Port 2. S_{21} can be defined as the ratio of power of transmitted wave over the incident wave [19,20] The other parameters, the S_{22} and S_{21} are the reversed situation of these S_{11} and S_{21}, respectively. In order to measure return loss at Port 1 (or Port 2), the Log Mag display with S11 (or S22) is used. On the other hand, the Log Mag display with S21 or S12 is used to measure the gain or loss in a DUT that is connected between Port 1 and Port 2 [21].

$$\text{Log Magnitude (dB)} = 20\text{Log}10\,|Sxy| \tag{1}$$

RESULT AND ANALYSIS

The EMI SE of CF samples were measured in the high frequency range of 3.0 to 4.2 GHz using a Vector Network Analyzer (VNA) in Anechoic Chamber in STRIDE. Samples S0, S1, S2 and S3 respectively indicates the samples without CF, samples with 5 layers of parallel CF (0^0 orientation), samples with 5 layers of perpendicular CF ($0^0/90^0/ 0^0/ 90^0/ 0^0$), and samples with 5 layers of CF oriented ($0^0/45^0/ 90^0/ -45^0/ 0^0$).

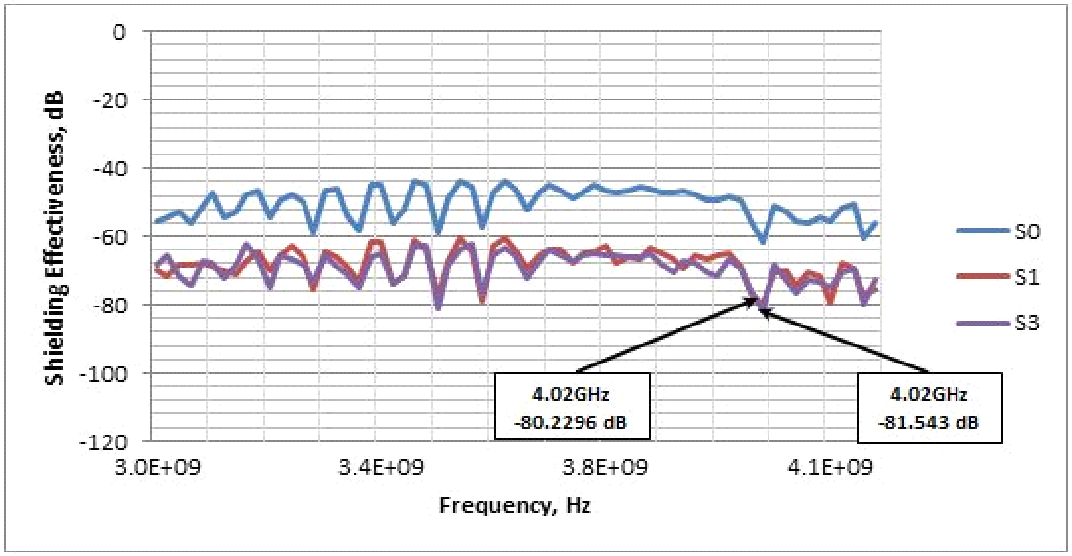

Figure 3: Graph SE analysis of sample S1 and S3

Figure 3 shows the graph of SE obtained for sample S1 and S3 of carbon fiber samples in the high frequency range. The average SE gained by both samples is -71.7122 dB and -73.3861 dB for S1 and S3 respectively. From the graph, S1 presents the maximum SE which is -80.2296 dB at 4.02 GHz with improvement of 44.65% compares to S0. Meanwhile, the SE attained by S3 increased slightly at frequency of 4.0 GHz with maximum SE of -81.543 dB also at frequency 4.02 GHz. At this maximum SE, the percent improvement of SE is 46.90% compare with the S0. The results showed that the SE response of S3 seems to be slightly better and effective compare to SE response generated by S1. However, both samples show an approximately effective SE performance along the frequency ranges and provide improvement greater than 40 % compared to S0. Different orientation of materials placed in a concrete provide different levels of shielding performances and a suitable orientation gives the best result in preventing signal penetration.

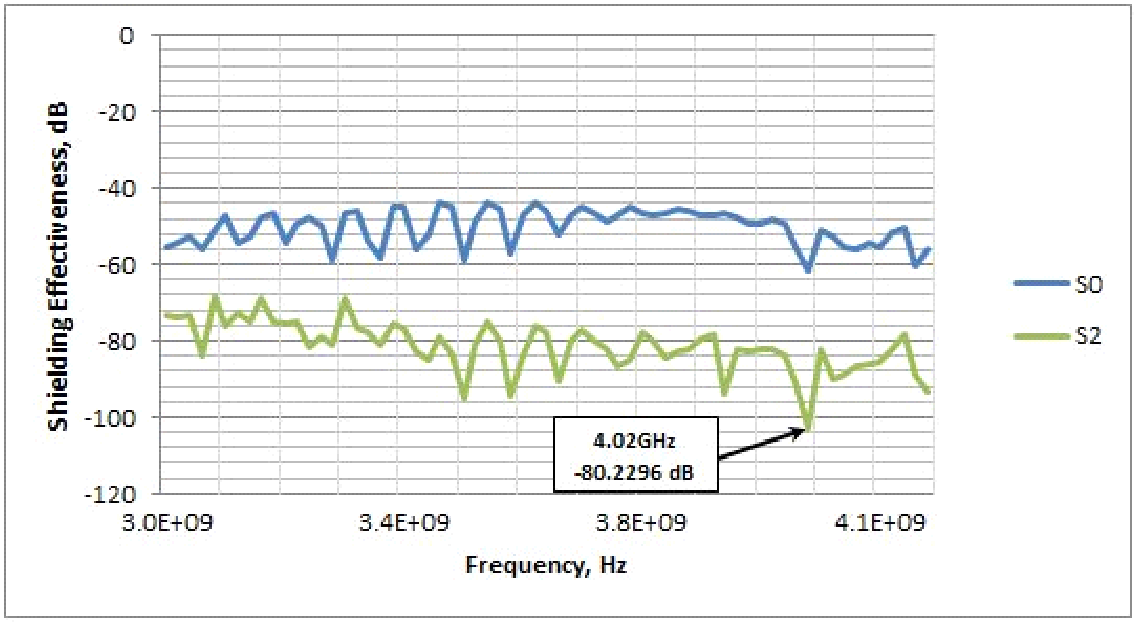

Figure 4: Graph SE analysis of sample S2

Figure 4 shows the graph of SE obtained for sample S2 of carbon fiber. From the graph, the SE seems to be very effective in the frequency range of 3.0 GHz to 4.2 GHz. From the graph, the average SE obtained by the sample is -81.2615 dB. Besides, the maximum SE achieved by S2 is -102.983 dB at frequency 4.02GHz with the SE percent improvement 85.52 % compared to reference sample, S0. The graph states that the SE value gives an excellent performance at range 3.40 GHz to 4.05 GHz. Basically the thickness of the material is the main factor of SE obtained where the increment of thickness of the material Increasing the specimen thickness would increase the number of fibers intercepting with the incident and enhance the SE ability of the material [2]. It has been verified that the thickness of the material improves the EMI SE. Five layers of CF, s5 placed in block concretes provide better shielding performance instead of one layer, s1 and three layers, s3 of CF material. The result shows that the SE of s5 seems to be constantly effective in the range of frequency 1.5GHz to 2GHz, gives shielding performance of 49% at 1.75 GHz [22].

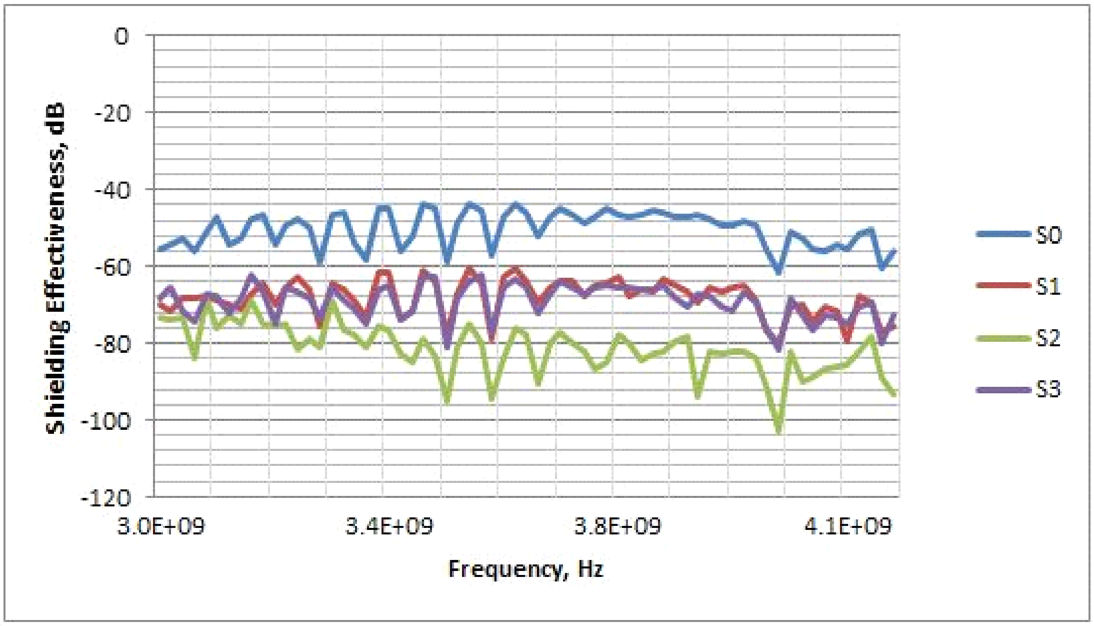

Figure 5: Graph SE comparisons of all carbon fiber samples

Figure 5 shows the graph comparisons of SE attained by all samples in the range of frequency 3.0 GHz to 4.2 GHz. From the graph, it is clearly shown that S2 provides the best performance of SE compared to the other samples at this range of frequency. The SE response obtained by S2 clearly shows that the samples provide a great improvement in SE with twice the improvement of percentage compared to the other samples. This shows that the sample S2 has a good SE to reduce the signal penetration since the SE attained have constant at great performance. However, for samples S1 and S3, both samples shows constantly operative at the same frequency ranges although both SE performance is slightly difference. The result shows that S3 is much better than S1 by having 2.25% improvement. Christopher J. et.al found that the electrical properties of composite materials such as unidirectional carbon laminates are highly dependent on their fiber orientation. Therefore, a good position and orientation of CF layer in concrete sample will also provide an excellent SE in the frequency up to 4.0 GHz [18].

CONCLUSION

EMI SE of multilayer CFCs with different orientations have been measured and discussed. It has been investigated that sample S2 provides better EMI SE compared to S1 and S3. Sample S2 has attained a better performance with an average SE of 81.2615 dB and a maximum SE value of -102.983 dB at a frequency of 4.02GHz with an SE percent improvement of 85.52 % which is suitable for many applications especially for military and security purposes. However, the SE attained by S1 and S3 is also excellent since both shielding performance exceed 40%. The average SE gained by both samples is -71.7122 dB and -73.3861 dB for S1 and S3 respectively at a frequency of 4.02. An excellent mechanical and electrical properties of material promising high shielding performance. The electrical properties of composite materials such as unidirectional carbon laminates are highly dependent on their fiber orientation. Thus, the result shows that the orientation of shielding materials will also improve the SE performance.

REFERENCES

[1]. Das, N.C., Khastgir, D., Chaki, T.K., & Chakraborty, A. *Composites Part A,* **31** 1069-1081 (2000)
[2]. Yang, S., Lozano, K., Lomeli, A., et al. *Composites Part A-Applied Science and Manufacturing,* **36** 691-697 (2005)
[3]. Thomassin, J. M., Jerome, C., Pardoen, T., et al. *Materials Science and Engineering R,* **74** 211-232 (2013)
[4]. Im, J. S., Kim, J. G., Bae, T. S., et al. *Journal of Physics and Chemistry of Solids,* **72** 1175-1179 (2011)
[5]. Nam, I. W., Kim, H. K., & Lee, H. K. *Construction and Building Materials,* **30** 480-487 (2012)
[6]. Morgan, D., & Peregrinus, P. A handbook of EMC testing and measurement. Institution of Electrical Engineers (IEE), London, 1995.
[7]. Chung, D. D. L. *Carbon,* **50** 3342-3353 (2012)
[8]. Crespo, M., Mendez, N., Gonzalez, M., et al. *Carbon,* **74** 63-72 (2014)
[9]. Gnidakouong, J. R. N., Kim, M., Park, H. W., et al. *Composites: Part A,* **50 73-80 (2013)**
[10]. Singh, A. P., Gupta, B.P., et al. *Carbon* **56** 86-96 (2013)
[11]. Aircraft demand prompts Toray to boost carbon fibre capacity. *Reinforced Plastics,* **51**(9) 1-43 (2007)
[12]. Cao, M. S., Song, W. L., Hou, Z. L., et al. *Carbon,* **48** 788-796 (2010)
[13]. Wang, R., He, F., Wan, Y., et al. *Journal of Alloys And Compounds,* **514** 35-39 (2012)
[14]. Arjmand, M., Apperley, T., et al. *Carbon,* **50** 5126-5134 (2012)
[15]. Jason, M. K., Nicholas, B. J. &, Julia A. K. *Polymer Composites*. **26** (5) 671–678 (2005)
[16]. Ameli, A., Jung, P. U., & Park, C. B. *Carbon,* **60** 379-391 (2013)
[17]. ASTM. Standard Test Method for Measuring the Electromagnetic Shielding Effectiveness of Planar Materials. *ASTM* D 4935-99, 1999.6.
[18]. Christopher, J. V. K., & Denver, M. *Composite Structures,* **91** 467-472 (2009)
[19]. Nam, I. W., Lee, H. K., & Jang, J. H. *Composites Part A-Applied Science and Manufacturing,* **42** 1110-1118 (2011)
[20]. Theilmann, P., Yun, D.J., Asbeck, P., & Park, S.H. *Organic Electronics,* **14** 1531-1537 (2013)
[21]. Master, VNA. Model MS2026B Data Sheet, Vector Network Analyzer 5 kHz to 6 GHz FieldFox handheld RF cable and antenna analyzer.
[22]. Ruslan, M. S., & Chew, S. P. *Advanced Materials Research,* **748** 309-313, **(**2009)