Original Article

Characterization of electromagnetic interference shielding composed of carbon fibers reinforced plastics and metal wire mesh based composites

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ABSTRACT

The efficiency of many electronic devices and energy sources are negatively affected by the electromagnetic radiation emitted by the external sources. In order to enhance the efficiency and the security of those devices, materials having effective electromagnetic interference shielding property are employed as protectors. In this paper, stainless steel, copper or nickel wire mesh (wraps) were woven into carbon fiber reinforced plastics (wets) to develop materials with the electromagnetic shielding ability. The shielding effectiveness, reflection and absorption losses are investigated for different combinations of metal wire mesh into the composites. It was observed that, the samples showed different behavior to attenuate the electromagnetic interferences depending on the side on which the input was applied. Average shielding effectiveness was found to be more than 94 dB for all samples, while the lowest value was around 82 dB. The combination of nickel and copper showed the highest shielding performance. The average absorption loss was found to be 79.8%, 80%, 84% for the combinations copper/stainless steel, copper/nickel and stainless steel/nickel respectively.

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1. Introduction

The electronic devices that are working in an environment surrounded by external sources of electromagnetic radiation waves are usually disturbed by electromagnetic interferences (EMI) from those sources. Those interferences are the main cause of the reduction of performance and life of devices. Therefore, EMI shielding of those devices is required [1–5]. Due to the wide use of electronic and wireless devices, the demand for EMI shielding materials has recently increased, and different materials are being developed to fulfill the requirements. EMI shielding materials are characterized by their good electrical conductivity, magnetic permeability, and good dielectric permittivity [6]. The capacity of a material to act as a shield for electromagnetic interference is measured by its shielding effectiveness (SE). Shielding materials absorb or reflect the electromagnetic waves that reach them [1], and sometimes

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they can allow few waves to pass through them without being absorbed. The lesser the waves pass through the material, the better is its shielding effectiveness. Usually, materials with high electrical conductivity such as carbon nanotubes and graphene [6], and good electromagnetic shielding such as Mg alloys [7,8] are used for EMI shielding. Recently, carbon-based materials and intrinsically conducting polymers are attracting attention in EMI shielding applications and related fields [6,9–13]. The EMI shielding increases with the increase of carbon nanotube in the graphene nanoplatelets:carbon nanotube (CNP:CNT) hybrid nanofiller [13]. The increase of the silicon carbide (SiC) content in carbon fiber reinforced silicon carbide matrix composites is found to reduce EMI shielding effectiveness of the composites [14]. The incorporation of graphene decorated with graphene quantum dots (G-D-GQDs) and G-D-GQDs decorated with silver in polyvinylidene fluoride (PVDF) matrix produces a PVDF/G-D-GQDsAg nanocomposite that can shield up to 99.9% of electromagnetic interferences in X-band range [15]. The integration of multiwalled carbon nanotube into cement enhances the EMI shielding effectiveness of the cement composites in the microwave range with high ratio of absorption [1]. The carbon fibers, which are known to have good mechanical properties and good electrical conductivity, can be used as reinforcement into the polymer matrix and provide EMI shielding properties at certain frequencies. The combination of carbon fiber reinforced plastics with conducting metal can enhance the shielding effectiveness of the materials.

In this study, copper, nickel and stainless steel (ferritic stainless steel 430) wire mesh, together with carbon fiber reinforced plastics (CFRP) were used to make CFRP-metal plain woven laminates. The experiments were conducted to examine the electromagnetic shielding properties of textile composites made up of lamination of those plain weaves and prepreg carbon fibers plies.

2. Experimental procedures

The sheets of 200 × 200 metal wire mesh, having 0.03 mm diameter filaments and CFRP prepregs were purchased and used to fabricate the test specimens. Three kinds of metal wire mesh were used in this study, which includes nickel (Ni), stainless steel (SUS) and copper (Cu) meshes. The sheets of wire mesh and CFRP were cut into yarns of width 15 mm. The wire mesh yarns were wrapped into the CFRP yarns to make plain weaves manually, as shown in Fig. 1. The width dimension was chosen for simplicity and reducing weaving time.

Two woven layers of different metals were laminated together and coated with two layers of carbon fiber reinforced plastics as illustrated in Fig. 2, which shows the schematics of the samples. Three combinations of metal-based woven were considered for laminations, such as; Cu-Ni, Cu-SUS and Ni-SUS as presented in Table 1. The laminated layers were placed into the press, shown in Fig. 3, and molded using the autoclave method. The molding pressure was set up to 70 MPa. The temperature was increased up to 150 °C and maintained for 90 min during the molding process after which the cooling step was

![Fig. 1 – 200 × 200 metal wire mesh/CFRP plain weave fabrics.](image1)

![Fig. 2 – The lamination technique of the samples.](image2)

| Table 1 – Combination of plain weave fabrics in the lamination of the samples. |
|------------------|------------------|------------------|
| Samples          | Plain weave 1    | Plain weave 2    |
| Sample-1         | Copper/CFRP      | Stainless steel/CFRP |
| Sample-2         | Nickel/CFRP      | Copper/CFRP      |
| Sample-3         | Nickel/CFRP      | Stainless steel/CFRP |

![Fig. 3 – Autoclave molding press, JCTECH.](image3)
initiated. The obtained samples after molding had a thickness of 1 mm.

The measurement of electromagnetic shielding effectiveness was conducted with a coaxial transmission line described in ASTM D4935-99. This procedure was used to investigate the EMI shielding properties of the composite material. The setup of this test measurement requires two specimens; one for the reference and another for the load. These specimens were prepared for each composite material, as shown in Fig. 4. According to ASTM D 4935-99, the load specimen should have an outer-ring of diameter 133 mm. The flange coaxial transmission line was used as the specimen holder and as a waveguide. The test parameters were set in the ENA Network Analyzer E5080A. The scattering parameters (or S-parameters (i.e. S11 and S21)) were recorded in the frequency range from 500 MHz to 1.5 GHz.

3. Results and discussions

Figs. 5–8 show the experimental results of shielding effectiveness for the developed samples. Since in each sample there were two plain weave fabrics with different metals, where one kind of metal was present on one side and the another on the other side, the test was conducted for both sides. After recording the data, when the input was on one side, the test was repeated with the input on the other side of the sample.

Fig. 5 shows the shielding effectiveness of sample-1, which combined the plain weave of SUS/CFRP and plain weave of Cu/CFRP. The shielding effectiveness varied from 84 dB to 125 dB when the power source was applied to the stainless steel side. Otherwise, it was between 83 dB and 126 dB. These results showed that sample-1 exhibited a wider range of electromagnetic interference shielding effectiveness when the...
incident waves were supplied to the Cu side than to the SUS side. The wider range of SE from the copper side can be related to the higher magnetic reflection loss [16] and its high electrical conductivity when compared to stainless steel.

The range of the shielding effectiveness of the sample-2, as shown in Fig. 6, was 83–126 dB when the nickel side of the sample was exposed to the incident waves. When the sample was reversed, a shielding effectiveness varying between 84 and 124 dB was obtained. However, at high frequency range, sample-2 showed good shielding properties when the copper side received the incident waves from the source. In Fig. 7, sample-3 showed almost the same lowest shielding effectiveness of about 82 dB regardless of which side the incident waves were applied. But the highest shielding effectiveness of 118 and 125 dB were obtained when the wave radiations from the sources were received by the side with stainless steel and nickel, respectively. It was observed, for the sample-2 and sample-3, that supplying the incident electromagnetic radiations to the side of the sample that contained the Ni/CFRP weave would lead to higher shielding effectiveness with wide range of shielding properties. This might be due to the fact that nickel wire mesh has better magnetic properties than the copper and stainless steel wire mesh.

The typical values of shielding effectiveness are plotted in Fig. 8. In this figure, for example, S1_SUS means that sample-1 had the stainless steel side facing the sources of waves during the test. Although all samples presented an average shielding effectiveness of about 94 dB in the frequency range (0.5–1.5 GHz), it was found that the combination of Ni/CFRP weave and Cu/CFRP weave can provide the best properties of EMI shielding.

The effect of absorption and reflection losses on shielding effectiveness was also studied and the results are plotted in Figs. 9–12. As shown in Fig. 9, when the incident radiation was applied on the side of sample-1 with the Cu/CFRP weave, the reflection loss tended to increase then decreased at the high frequency range. In the frequency bandwidth of 1–2 GHz, sample-1 produced lower reflection losses and lower absorption losses when the side with stainless steel was taken as the receiver of the electromagnetic incident waves.

It can be seen in Fig. 9 that both the reflection and absorption of sample-1 increased when the first internal reflection occurred at the interface of CFPR sheet and Cu/CFRP woven. It is then reduced when that reflection occurred at the interface of the CFRP with SUS/CFRP weave in the frequencies range of 1–1.2 GHz. Placing the SUS/CFRP weave on the side of the wave sources produced the reflection up to 67 dB and the absorption up to 105 dB. But when the sample was reversed the maxi-
maximum reflection loss was reduced by 30% and the maximum absorption loss increased by 3.7%.

Fig. 10 shows the absorption and reflection properties of sample-2 as a function of the frequency. Similar to sample-1, sample-2 had better absorption properties and poor reflection when the weave with copper metal was placed in front of the electromagnetic waves than the woven with nickel metal. Absorption and reflection losses were up to 106 dB and 51 dB, respectively, when the incident waves hit the copper side. Otherwise, they were up to 100 dB and 53 dB respectively. According to the results of sample-1 and sample-2, Figs. 9 and 10, respectively, it can be seen that placing the Cu/CFRP woven on the side of the incident wave improved the absorption properties of materials.

The absorption and reflection properties of bimetal composites that contained stainless steel and nickel are presented in Fig. 11. The results showed that when the side of sample-3 with nickel based woven was placed between the waves sources and SUS/CFRP woven, the sample produced lower absorption and higher reflection properties than the side with stainless steel. The nickel side produced an average reflection of 19 dB and an average absorption of 75 dB. On the other hand, the average reflection and absorption were 15 dB and 80 dB respectively for SUS side. The properties of sample-3 were in good agreement with the properties, which compare the reflection and absorption behavior of different metallic material; including nickel, copper, and stainless steel; at 150 kHz and 400 MHz, reported elsewhere [16].

Fig. 12 describes a summary of the typical absorption and reflection properties. The bimetal composite materials (S1, S2, S3) presented an average reflection loss between 15 dB and 20 dB, and the average absorption between 74 dB and 80 dB.

4. Conclusion

Samples made by the lamination of CFRP ply and the metal mesh/CFRP plain woven were investigated for electromagnetic shielding applications. Each sample contained a combination of two conducting metals including; nickel, stainless steel, and copper. The lamination was made in such way that the two sides of the sample have different metals. Depending on the side where the input wave was applied, the samples showed different behavior to attenuate the electromagnetic interferences. An average shielding effectiveness of more than 94 dB was obtained for all samples, while the lowest shielding effectiveness was over 82 dB. The combination of nickel and copper seemed to give good shielding properties when compared to others. Whereas, the combination of nickel and stainless steel had the highest absorption loss and the lowest reflection loss. It was found that, the developed bimetal/CFRP composites materials are great absorber of electromagnetic waves. The absorption properties of those materials can be improved by increasing their thickness.

Conflicts of interest

The authors declare no conflicts of interest.

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