Sandwich structured carbon fiber composites with enhanced EMI shielding performance

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Abstract. The development of EMI shielding material has been increased due to the increased market request, especially on the electrical car industry. This paper introduced one new designed carbon fiber composites, the composites with sufficient thermal conductivity and enhanced electromagnetic shielding can be used for many of practical applications (e.g. boxes for electrical batteries in electric cars). Aim of this paper is design and evaluation of the multilayer composite structures reinforced by carbon web and conductive cuprous particles covered central layer. From the test result, after integrate the Meftex30 layer into the composites material, the EMI shielding performance is significantly improved more than 30%, but the bulk density of the composites still shows good superiority compared with metal material. The thermal property test shows the composites material has good heat preservation property which can be suitable for the application for the battery case of the electrical car.

Keywords: Carbon Web, Multilayer Composites, Electrical Conductivity, EMI Shielding.

M. Petr et al. (eds.), *62nd International Conference of Machine Design Departments (ICMD 2022)*,
Atlantis Highlights in Engineering 28,
https://doi.org/10.2991/978-94-6463-423-5_34

1 Introduction

With the continuous increase in the production and ownership of communication industry in the global market, the problems of electromagnetic interference (EMI) and extra EMI shielding become increasingly prominent [1][2]. In order to build an safe and anti-EMI environment for people and sensitive equipment, researchers around the world have been actively promulgating increasingly new materials in recent years [3], [4]. Another remarkable application for electromagnetic shielding materials is as battery casings for electric vehicles [5]. While ensuring certain mechanical properties, it also has electromagnetic shielding characteristics to protect electric vehicle drivers from excessive electromagnetic wave radiation [6].
Polymeric EMI shielding materials have been widely used in many fields in the last few years. In many studies the researchers compared to conventional EMI shielding material made from metallic materials owing to their ease of processing, lightweight, remarkable corrosion resistance, economical fabrication methods, etc. [7]. The conventional method of making an electrically conductive composite for EMI shielding applications is to mix conductive fillers such as metallic fibers[8], metal coating[9], carbon black[10], graphite[11], graphene [12], and carbon nanotubes [13] into the polymeric matrix. Along with polymer-based EMI shields, the research has also shifted to materials such as biodegradable EMI shields, EMI shields based on textile materials, cement-based EMI shields, EMI shields that can be used at high temperatures, metallic alloys-based EMI shields, ceramic EMI shields, etc. [14].
Considering about the application in the battery pack of electrical, only the static and dynamic stability of the box body can ensure that the power battery does not have abusive conditions and make the power system run smoothly. The conventional EMI shielding materials can't fulfill these requests due to the poor mechanical performance and balance of the shielding effectiveness. Regarding to the mechanism of EMI shielding, when the electromagnetic wave is absorbed by the material, the energy will be converted into heat, in this case, this will not be suitable for the battery heat dissipation. This paper systematically investigates a new type of EMI shielding textile composite material that meets the new energy vehicle battery pack box, including the material's lightweight, electromagnetic shielding effect and excellent thermal insulation performance. By using the sandwich structure one reflection layer is integrated into the carbon fabrics layer, the EMI shielding effectiveness is improved significantly.

2 Method

2.1 Materials

The twill carbon fabric with gsm 245 g/m^2 is supplied from the Havel composite company, Czech Republic. The central layer is polyester nonwovens with gsm 30 g/m^2 plated with copper particles, which is supplied from Bochemie company, Czech Republic, under the name Meftex 30. The epoxy resin ChS Epoxy 200 and other resins used in the composites processing are from Havel composite company, Czech Republic.

The hybrid composites fabrication is manufactured by hot press molding procedure. Regarding to the sample with the matrix of epoxy resin(C/Cu/Epx), all layers is applied the epoxy resin individually in the form of a dispersion of epoxy resin and dried at an elevated temperature. Then arrange the layers in a sandwich structure and press in a heated hand presser at a temperature of 180 °C for 30 minutes. The other sample(C/Cu/MePh) is manufactured by using different matrix, which is a copolymer of melamine formaldehyde and phenoxy resin. The individual layers are impregnated in a dispersion mixture of the mentioned resins, dried at an elevated temperature. Then arrange the layers in a sandwich structure and press in a heated hand presser at a temperature of 120 °C for 30 minutes.

2.2 Characterization

Density

Density is one of the most important factors in determining the properties of polymer composites material and is defined as mass of the material per unit volume, measured as per standard ASTM D1895[15].

EMI shielding

The EMI shielding effectiveness test was processed by the coaxial transmission line method according to ASTM 4935-10 [16] to evaluate flat materials. This method presumes a plane wave impact on a shielding material in the frequency band from 30 MHz to 1.5 GHz. This measuring equipment consists of a coaxial specimen holder (supplied by Electro-Metrics, Inc., EM-2107A). The input and output signals were transferred to a vector network analyzer from A Rhode & Schwarz ZNC3. The analyzer was designed to generate and receive an electromagnetic signal. The power ratio can calculate the SE (forward transmission coefficient S21) without and with shielding material. The calculation equation is as following Eq. (1):

$$SE(S21) = -10log\frac{P_1}{P_2} = 10log\frac{P_2}{P_1} \quad (1)$$

P1 is the received power without the shielding material, and P2 is the received power with the shielding material present. The electromagnetic wave reflection coefficient SER (S11) interpreted that the electromagnetic wave signal from the transmitting antenna was reflected by the shielding material and received by port 1. The ratio of the receiving reflected electromagnetic wave power P3 and P1 calculate the input reflection coefficient by Eq. (2),

$$SE_R(S11) = 10log\frac{P_3}{P_1} \quad (2)$$

According to the transmission line theory, the total SE can be interpreted by the following in Eq.(3)(4) :

$$SE = SE_A + SE_R + SE_M \quad (3)$$
$$1 = T_{EM} + A_{EM} + R_{EM} \quad (4)$$

In Eq.(3), SE is shielding effectiveness, SE_R is reflection loss, SE_A is absorption loss, and SEM is multi-reflection loss. Usually, the factor SE_M can be mathematically positive or negative (in practice, it is always negative) and can be ignored when the SEA > 6 dB. It is usually only significant when the shielding material is thin and at low frequencies (i.e., below approximately 20 kHz) [17].

In Eq.(4), the coefficient of the transmittance (TEM) and reflectance (REM) can be calculated by Eq.(5), Eq.(6):

$$SE = -10\, log_{10}\, T_{EM} \quad (5)$$
$$SE_R = -10\, log_{10}(1 - R_{EM}) \quad (6)$$

Thermal properties

According to the standard ISO 11092, Alambeta as the thermal properties measuring equipment used in this work and thermal conductivity and thermal resistance were selected. Thermal resistance is the value obtained by dividing the temperature difference between any two parts by the heat flux flowing between the two points. The sample is set on the measuring bottom plate during the test, the head plate will go down and touch the sample with a 200 Pa pressure. Then the heat flow value of the sample will be analyzed and calculated, and the final thermal resistance and conductivity value will be displayed. The measurement ambient temperature was 24°C and the relative humidity. Every sample is tested 5 times at different points and the average value was calculated.

3 Results and discussion

3.1 Morphology and density

The morphology of the sample is shown in Fig. 1.

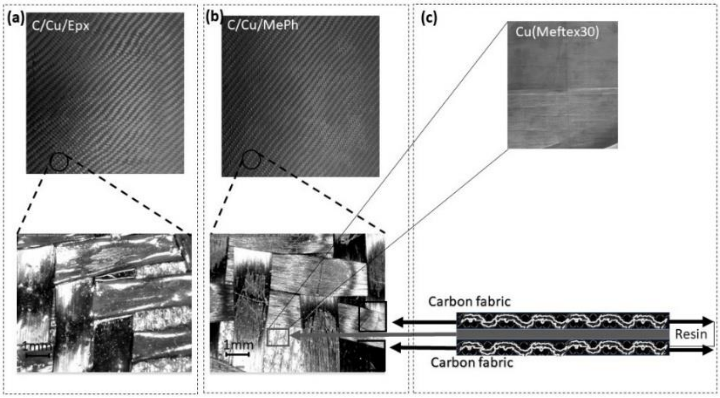

Fig. 1. Morphology of carbon fiber composites EMI shielding material (a) C/Cu/Epx (b) C/Cu/MePh (c) Cu(Meftex 30) and the sandwich structure of the carbon fabric composites

From the microscopic image we can clearly identify the Cu(Meftex 30) layer from the gap between the carbon filaments. The surface of the sample is relatively flat. Three layers after the heat press processing combined intensively.

The density of all samples (including the reference samples) are listed in the tab 1.

Table 1. Density of materials

Sample	Density (g/cm^3)
C/Cu/Epx	0.57
C/Cu/MePh	1.09
Cu(Meftex 30)	0.25
Carbon fabric	0.53
Carbon + Epoxy	0.99

The density of both composited samples shows good potential to use it in the battery cover of electro-car. Considering factors such as cost and processing, the battery pack casings of entry-level and economical electric vehicles mostly use steel casings, and some new energy vehicle battery packs use metal casing materials. Aluminum is the common used material whose density is $2.7 g/cm^3$, it's obviously higher than the carbon composites material. On the other side, the thickness of both samples are relatively thin compare to traditional metal materials.

3.2 EMI shielding effectiveness

One of the main purpose to insert the Cu (Meftex 30) layer into the carbon composites material is to enhance the EMI shielding performance. Figure 2 present the test result.

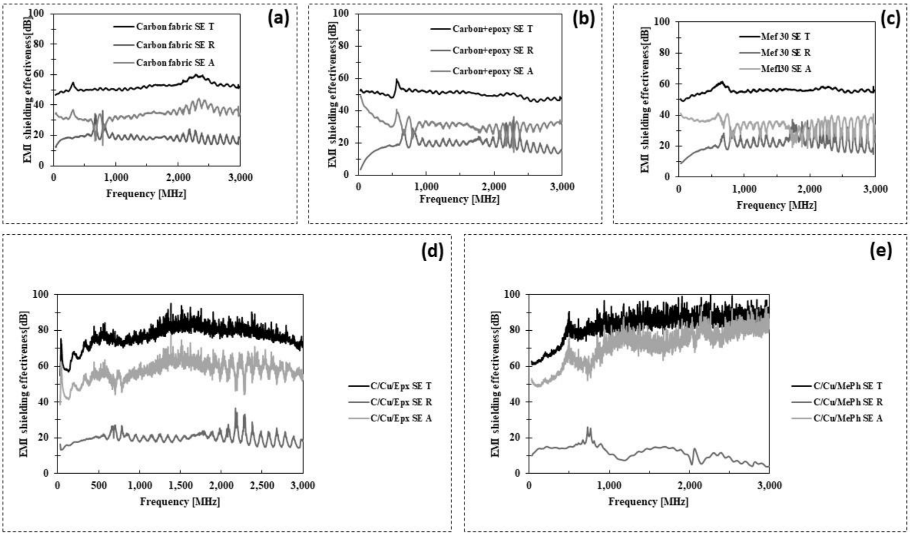

Fig. 2. EMI shielding test results (a) Carbon fabric (b) Carbon epoxy (c) Cu (Meftex 30) (d) C/Cu/Epx (e) C/Cu/MePh

From Figure 2(a)(b) it can be clearly distinguished that no matter adds the epoxy or not, the EMI shielding effectiveness (SE) has no significantly different for the carbon fabrics. The reason is epoxy is non-conductive polymer, which has no impact to the SE of the whole material. The carbon fabric performs around 50dB SE in the frequency band 30MHz to 3GHz, and the pure Meftex 30 also presented good SE around 58dB in the same frequency band (Figure 2c).

After putting the Cu covered layer into the structure, the SE of the sandwich material has significantly increased compare to the material individually measured value. The average SE of C/Cu/Epx is 76.5 dB in the frequency band 30MHz to 1.5GHz and the SE of C/Cu/MePh is 84.6 dB in the same frequency band. For this value, according to the reference[18], these material can be listed as the AAAAA grade for professional use, which is sufficient to protect the passenger in the electro-car away from the extra electromagnetic radiation.

The values of SE_R and SE_A reflected the main attenuation of the EMI happened on which interface and how strong it is. When the value of $SE_R > SE_A$ we suppose the main attenuation of the electromagnetic wave is happened on the surface layer, and if $SE_R < SE_A$ we suppose the main attenuation is happened inside the material. From the Figure 2(d) 2(e) it can be clearly identified that the $SE_R < SE_A$ for all samples, which is reasonable. Because carbon fiber itself is one kind of good EMI absorption material, after integrate the reflection layer in the middle, the main attenuation of electromagnetic wave is still inside the material.

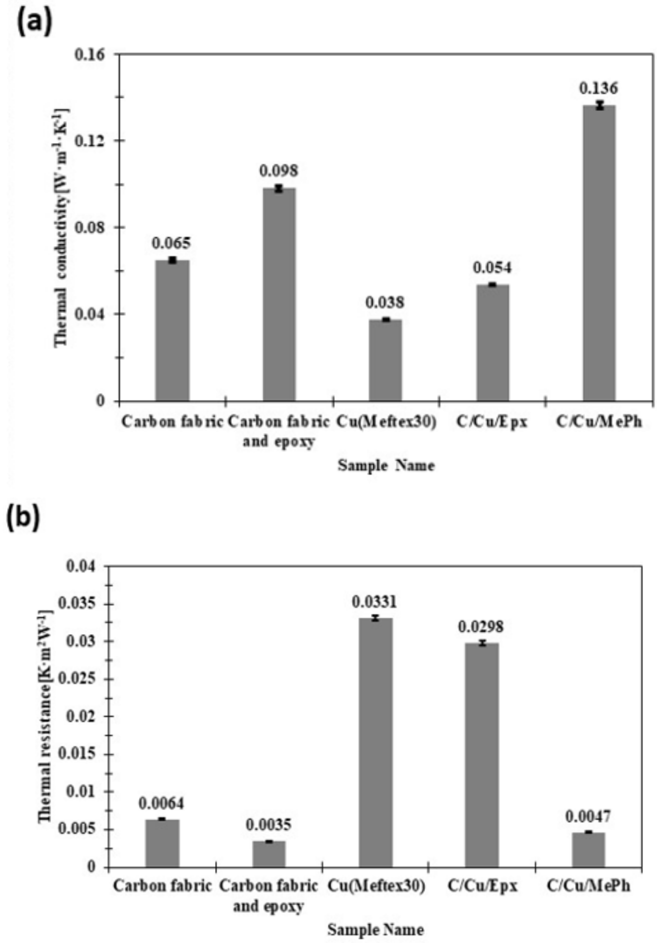

Fig. 3. Thermal properties test result (a) Thermal conductivity (b) Thermal resistance

3.3 Thermal conductivity and thermal resistivity

The thermal properties of the sandwich composites material also been studied in this paper. The results are shown in Fig. 4a and b.

The C/Cu/EPX consists of two layers of carbon fabric and one layer of Meftex30. In this case comparing with single layer carbon fabric, the thermal conductivity is slightly lower. However, the C/Cu/MePh perform better thermal conductivity, this is caused by the different thermal property of resin for the sample. Considering about the influence of the material thickness, thermal resistance can evaluate the heat preservation property of the sample. The C/Cu/Epx performs significantly higher thermal resistance than the sample C/Cu/MePh.

Considering about the application of this material as the battery pack for electro-car. The working performance of the power battery is greatly affected by the temperature. The suitable working temperature is 20℃～40℃. Too high or too low temperature will affect its performance and even cause damage. In order to enable the power battery pack to work within a suitable temperature range, the power battery pack is usually equipped with a thermal management system. The thermal management system of the battery pack includes three functions: cooling, heating and heat preservation. Compare to metal material, the thermal conductivity of the carbon composites material is extremely lower. In this case, the thermal insolation property of carbon composites material is more suitable for the heat preservation.

4 Conclusion

This paper introduced on kind of new EMI shielding material fabricated via sandwich structure integrating the reflection layer into carbon fabric composite structure. The sandwich composites is light weight and thin, which is the advantage for many application filed. After integrate the reflection layer, the EMI shielding effectiveness is improved significantly. The thermal property test shows the material is good for heat preservation. Considering about the application for battery pack of the electrical car, with suitable cooling system, the sandwich structured carbon composites material shows good potential for this application.

Acknowledgments: This study was supported by the project “Modular platform for autonomous chassis of specified electric vehicles for freight and equipment transportation”, Reg. No. CZ.02.1.01/0.0/0.0/16_025/0007293

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