Research of glass fibre used in the electromagnetic wave shielding and absorption composite material

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Abstract. Electromagnetic shielding and absorption composite material plays an important role in the defence and economic field. Comparing with other filler, Glass fibre and its processed product—metal-coated glass fibre can greatly reduce the material's weight and costs, while it still remains the high strength and the electromagnetic shielding effectiveness. In this paper, the electromagnetic absorption mechanism and the reflection mechanism have been investigated as a whole, and the shielding effectiveness of the double-layer glass fibre composite material is mainly focused. The relationship between the shielding effectiveness and the filled glass fibre as well as its metal-coated product's parameters has also been studied. From the subsequent coaxial flange and anechoic chamber analysis, it can be confirmed that the peak electromagnetic shielding effectiveness of this double-layer material can reach -78dB while the bandwidth is from 2GHz to 18GHz.

1. Introduction

With the development of modern science and technology, electric equipment is widely used and the electromagnetic environment becomes much more complex. So it is pressing to reduce the electromagnetic interference between equipments and to make them work properly. Moreover, the widely used electric equipment has been presenting a great challenge to national economy and defense. The electromagnetic shielding (EMS) technology has been used to prevent important information from leaking out, and research of the basic material used for EMS becomes much more important [1]. At present, electromagnetic shielding composite materials are always filled with metal fibers and conductive powders, which make them heavy and highly conductive. Unlike this kind of EMS composite materials, glass fiber and its metal-coated product composed with resin, would have higher shielding effectiveness and strength with less mass density, which has been regarded as the potential replacement of them [2, 3]. In this work, the relationship between fiber parameters and shielding effectiveness of material were discussed; the relationship between absorbing properties and fiber filling volume were analyzed; and the declination between metrical result and calculated result were explained. In the end, it can be pointed out that glass fiber and its processed product could play an important role in material's electromagnetic shielding effect, and it also had significant meaning in achieving the integration of function and structure of material.

2. Experiment

In the experiment, phenolic resin and metal-coated glass fiber were used as raw materials, and the composite material was prepared by a hot-pressing method. The process mainly contains three parts as follows.
2.1. Raw Materials
Metal-coated glass fiber: Aluminum was coated on the E-glass fiber. The thickness of the Aluminized layer: 2.5 μm; the diameter of the fiber: 20 μm. Common E-glass fiber: the diameter was 17 μm, insulated. Electromagnetic absorber: W-type ferrite and alloy powder, the particle size were 30 μm and 8 μm. Resin: Magnesium-Phenolic resin, trademark 2122.

2.2. Preparation of the Material
The material was made up of two different kinds of layers: the electromagnetic shielding layer and the microwave absorbing layer. All the raw materials should be mixed in the solution. Experimental process was: Firstly, cut Aluminized glass fiber into different kinds of length: 1.5mm, 10mm and 16mm, and the E-glass fiber were cut into 4mm. Then the Aluminized fiber and the resin were mixed together using acetone as thinner—which was the shielding layer; in the same way, E-glass fiber, absorber and resin were mixed together—which was the microwave absorbing layer. Both layers should be preheated in a mold at 110ºC in 120 seconds, to form a plate shape. Secondly, previous two kinds of plates were pressed with a mold at 180ºC, and the final sample was obtained with a thickness of 3 mm (electromagnetic shielding layer was 2mm and absorbing layer was 1mm). In this experiment, the viscosity of the system can be adjusted.

2.3. Shielding Effectiveness test of Material
Electromagnetic absorbing effectiveness of the material were obtained from methods for measuring the reflectivity of radar absorbing materials with anechoic chamber, while vertical polarization and shielding effectiveness were obtained from the coaxial guide method, which is a near field experiment, with the effectiveness represented by dB. Conductivity was analyzed by means of a 4 probe resistivity measuring instrument. The inner structure of the material was observed by a scanning electron microscope.

3. Result and Discussion
In the Aluminized glass fiber layer, fiber's filling volume and its size is crucial to the conductivity and shielding effectiveness of material. In addition to this, the filling volume of E-glass fiber in the absorbing layer has something to do with the microwave absorbing effectiveness. Through the research, we find that glass fiber and its processed product play an important role in the control of electromagnetic parameters.

3.1. The Relationship between Conductivity, Electromagnetic Reflection Properties and Aluminized Glass Fiber of Material

![Figure 1](image.png)
An important parameter of the composite material is the percolation threshold [4], which will occur when the conductivity ($\sigma$) of the material changes suddenly with the increase of a fiber content. However, this is relative to aluminized fiber's length and diameter. In this experiment, the fiber's diameter was constant, while the relationship between the aluminized fiber's length and its electrical as well as electromagnetic properties were mainly investigated. The 1.5mm, 8mm and 16mm length aluminized fibers were used as the research object, as shown in figure 1(a).

When the fiber length is 1.5mm, its percolation threshold is about 12% (wt), so if the fiber content is higher than this demarcation point, the material will suddenly become a conductor. However, this demarcation point is changeable depending on the fiber length. If a longer fiber length was used instead, for example: 10mm or 16mm, the percolation threshold will decrease to 11% (wt) correspondingly. So elongating the fiber length can possibly decrease the fiber content which is necessarily needed. However, when fibers of longer length were used as the research object, it has been found that the above conclusion doesn't work, shown in figure 1(b). From figure 1, it can be seen that, if the fiber length was continually elongated, the percolation threshold will increase instead. It may be caused by technological factors in mixing and dispersing process. While the fiber length continually become longer, the fiber is hard to be dispersed. Some fiber will cluster as one, and make large insulating area, which was confirmed from the SEM photograph, as shown in figure 2.

Material may acquire its highest shielding effectiveness when its fiber length is in the appropriate range [5]. In this experiment, the best fiber length range for the percolation threshold is from 7mm to 16mm. Besides, the shielding effectiveness of material (fiber content 60wt %) at above fiber length range when the frequency is 2GHz to 18GHz, was also tested, as shown in figure 3.
From figure 3, it can be concluded that the material with a longer length can possibly gain a higher shielding effectiveness comparing to that with shorter fiber length. It can also be observed that in higher frequency areas, 10mm length sample is even better than the 16mm sample. The half-wave resonance may be the reason for this, for 10mm fiber length just meeting the requirement of 2cm electromagnetic wave's resonance—the frequency of 15GHz, which conforms to the tendency in figure 3.

3.2. The Relationship between Electromagnetic Absorbing Properties and E-glass Fibre of Material

Single electromagnetic shielding layer of material could cause some new problems such as second clutter pollution. In order to solve this problem effectively, an electromagnetic absorbing layer which composed of E-glass fiber and absorbent was attached on the surface of reflection layer. Here, the usage of conventional reinforcing E-glass fiber in the electromagnetic absorbing material as well as the correlation between E-glass fiber content and material's absorbing and shielding effectiveness, were mainly studied, with the result shown in figure 4.

From figure 4, it can be concluded that: conventional E-glass fibre can change electromagnetic parameters of material, thereby causing the different absorbing rate, like in figure 4(a). The relationship between fibre content and absorbing rate were studied, and it can be found that when the fibre content is 5wt%, the absorbing rate of material is close to the intrinsic absorption rate of 21.3dB. When the fibre content was continually increased to 12wt%, the maximum absorbing rate would rise to 24.2dB, and the peak of curve would move to the left. However, too much glass fibre will result in the reducing of absorbing rate. When fibre content was increased to 25wt%, there was an evident decrease of the peak with only 17dB. It may be caused by the E-glass fibre’s multiple interface structure and the changing of electromagnetic parameters because appropriate fibre’s multiple interfaces would cause electromagnetic wave's strongly scattering and attenuation, while at the same time which would also change the dielectric factors [6] and cause the peak to move to the left. However, too much fibre will lead to both decrease of permittivity and permeability and increase of the match thickness, so fibre content is important to material's absorbing ability. In this experiment, it has been found that the fibre content of 10wt% to 12wt% is the right amount.

The total shielding effectiveness when reflection layer and absorbing layer being superimposed was investigated in figure 4(b). It can be found that not only the total SE is higher than single layer, but also the clutter is perfectly suppressed. When the frequency is in the range of 11GHz to 18GHz, the clutter suppression ratio can reach up to about 90%, and the total SE can still maintain -70dB.

4. Conclusions

Conventional glass fibre and its processed product were used in the electromagnetic shielding material. Compared with other electromagnetic shielding materials, this material has a lower density and a
higher shielding effectiveness; more important, it could perfectly suppress the clutter and maintain FRP's mechanical strength.

- The percolation threshold of material would decline with increase of the aluminized glass fibre length; besides, it would also be controlled by the technology factors, and the percolation threshold would increase when fibre length is longer than 16mm;
- Longer fibre length could possibly gain a higher shielding effectiveness, however, resonance should also be taken into account, especially in the high frequency area;
- Conventional glass fibre could efficiently adjust the absorbing curve's intensity and peak position, but excessive glass fibre would result in the decline of absorbing, and the content of 10wt% to 12wt% is found to be appropriate;

Reflection-absorbing superimposed material could efficiently shield electromagnetic wave, and it would be helpful to the electromagnetic compatibility of the composite material. Compared with conventional shielding material, the prepared material could finally attenuate 90% microwave's energy when the frequency range is from 11GHz to 18GHz.

References
[1] Yang S Y Electromagnetic Shielding Theory and Practice National Defense Industry Press, Beijing, China, 2006 pp. 96.
[2] Tan S T and Zhang M Q 1999 Conductivity and electromagnetic shielding properties of metal fiber filled polymer composite Mater. Eng. 12 3.
[3] Xia Y, 2002 Research of carbon black filled polyethylene composites Plastic 31 48.
[4] He D, Ekere N N 2004 Effect of particle size ratio on the conducting percolation threshold of granular conductive-insulating composites J. Phys. D: Appl. Phys. 37 1848-152.
[5] Hochberg A and Versieck J 2001 Shielding for EMI and antistatic plastic resins with stainless steel fibres Plastics Additives 3 24
[6] Sun J, Jiang T 2005 Research of nano-ferromagnetic thin films plating on glass fiber technology. Journal of Yunnan University S1 38