The measurement of electromagnetic shielding effectiveness of the composite carbon fibers/nickel thin film

Ho Chang[1], Yun-Min Yeh[1], Ching-Song Jwo[2], Sih-Li Chen[3]

[1] Department of Mechanical Engineering, National Taipei University of Technology
[2] Department of Energy and Refrigerating Air-Conditioning Engineering, National Taipei University of Technology
[3] Department of Mechanical Engineering, National Taiwan University
[1,2] No. 1, Sec.3, Chung Hsiao E. Rd. Taipei 10608, Taiwan
Tel: +886-2-27712171 ext.2063 Fax: +886-2-27317191 E-mail: f10381@ntut.edu.tw

Abstract

This paper studied the development of a conductive composite film and the measurement technique of electromagnetic (EM) shielding effectiveness (SE) of the prepared film. A coaxial transmission-line technique based on ASTM D4935-99 Standard was applied to measure the electromagnetic shielding effectiveness. Through the self-developed nanofluid synthesis system, the nickel nanofluid with an average particle size of 50 nm was prepared. By using polymer blending method, carbon fiber and carbon fiber/nickel nanoparticles are blended with waterborne polyurethane (WPU) to prepare conductive composite films with thickness of 0.25mm. Experimental results show that the electromagnetic shielding effectiveness value of the prepared conductive composite material can reach 26 dB within the range of 50 MHz ~ 1.5GHz.

Keywords: Electromagnetic shielding effectiveness, carbon fiber, waterborne polyurethane

1. Introduction

In recent years, people have been pursuing digitalized and electronized high technology life. Although the successively developed electronic products have brought convenience to people, they also have produced more and more serious electromagnetic radiation pollution to the environment. Taking cell phone and computer for example, they release electromagnetic wave to disturb other electronic products and disable them from operating normally [1]. Highly conductive metallic material is the best shielding material for reflecting and absorbing electromagnetic wave. However, it is rather heavy, not easy to fabricate and high tendency to corrode. As the research and development of electronic and digital products gradually incline to the new design concepts of lightness, slimness, shortness and smallness, it is very suitable for high polymer material, which has high degree of freedom in design, and is light and anti-corrosion, to be applied to electric equipments. Hence, it is required to add conductive filler to polymer material in order to improve the charge transfer ability achieve conductive effect. Furthermore, the shielding ability against disturbance of electromagnetic wave can be enhanced [2-3]. In fact, metal is the most commonly seen conductive filler, such as silver, copper or nickel particles or flakes. All of them have good conductivity, and can enhance the electromagnetic shielding effect [4]. And carbon material also has good conductivity, such as carbon black, graphite and carbon fiber. Although their conductivity is not as good as metal, it is light, stale and cheap in price [5], so it is suitable for serving as conductive filler.

Employing polymer blending method, the paper blend the self-made nickel nanoparticles and carbon fiber with waterborne polyurethane (WPU), forming a composite material with electromagnetic shielding.

2. Experimental

The polymer used in this experiment was waterborne polyurethane (WPU, with a trade name HUD-810, which was made by Headway Advanced Materials Inc., Taiwan).

A PAN-based carbon fiber yarn (Toray T700SC, Japan) consisting of 12000 monofilaments (diameter 7 μm, density 1.8 g/cm^3) was used as a conductive filler as well as a reinforcing agent.

This research used a novel processing technology to produce a nanofluid. The equipments used in this experiment were the same as references [6]. The arc discharge nanofluid synthesis system, which was mainly composed of cooling system, arc discharge generator system, vacuum system, ultrasonic vibration system, nanofluid collector and pressure balanced system, was employed to produce a nanofluid.

First of all, appropriate volume of filler and deionized water were blended with WPU and stirred well. The fluid was adjusted at a suitable viscosity, making the thickness of film uniform. After that, slurry was pasted on the release paper, which was then dried under normal temperature for 12 hours, and then baked in an oven at 60^{o}C for 90 minutes until the water content was evaporated. Then, the composite film could be torn from the release paper, forming a composite film with thickness of 0.25mm.

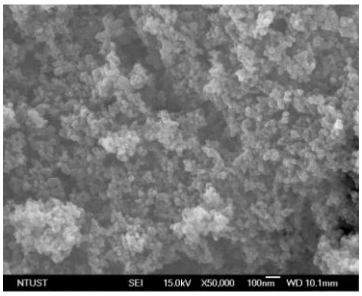

Fig. 1. FESEM image of the fabricated Ni nanoparticles.

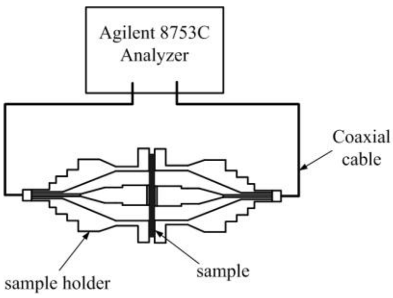

Fig. 2. Coaxial transmission-line holder for measuring electromagnetic shielding effectiveness.

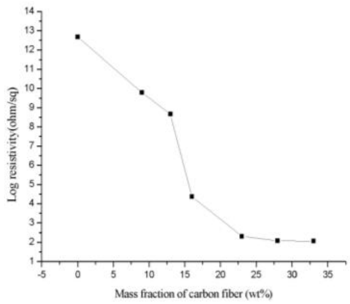

Fig. 3. Relationship between carbon fiber filling volume and surface resistivity.

As the conductive property of electromagnetic shielding material would affect its shielding effectiveness, measuring the conductive property of shielding material could indirectly evaluate its electromagnetic shielding effectiveness. The way of indirect evaluation could measure the surface resistivity of material. The four-point probe resistivity measuring instrument for measuring electrical resistivity was a four-point probe conductive meter with model No. LASEST-GP MCP-T600, which was a product of Japan Mitsubishi Chemical Corporation. And another instrument for measuring concentric electrical resistivity was a product of the American Monroe Electronics Inc. with model No. 272A.

The SE of the composites was analyzed by the method using coaxial cable. Designed according to ASTM D4935-99 Standard, coaxial method was applicable to far-field measurement. The measuring instrument was composed of two parts: network analyzer (Agilent8753C) and sample holder (Fig. 2). Signals were transmitted by coaxial cable line. The frequency was scanned within the range of 50MHz~1.5 GHz with 30 data points both in reflection and transmission. The SE was defined as the ratio of transmitted power (Pt) to incident power (Pi). It was measured in decibel (dB) as follows:

$$\text{SE}=10\log\left(\frac{p_t}{p_i}(dB)\right) \tag{1}$$

3. Results and discussion

The process parameters were vacuum pressure 30 torrs, peak current 3A, pulse-on and pulse-off time 6 μs, and breakdown voltage 220V. Figure 1 shows the FE-SEM image of the fabricated Ni nanoparticles by using the abovementioned working parameters. As seen from the FE-SEM image in Fig. 1, the produced Ni nanoparticles had a mean particle size of around 50 nm. By using a single-crystal XRD meter. Comparing the XRD pattern after examination of the standard spectrum of a JCPD card, the crystal structure of the fabricated particles was anatasa Ni as shown in Fig. 2 (JCPD no. 70-0989).

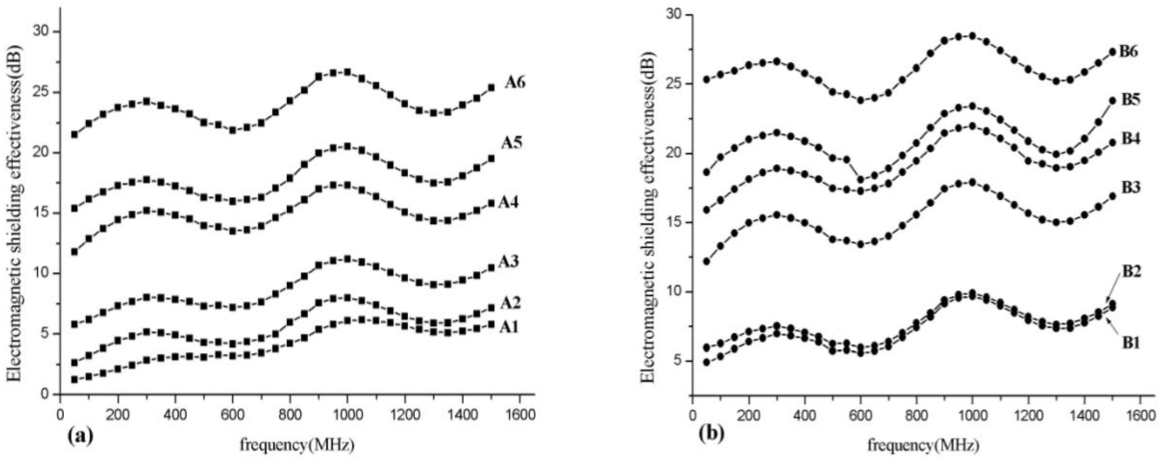

Fig. 4. Electromagnetic shielding effectiveness of composite materials filled with different contents: (a) carbon fiber; and (b) carbon fiber/Ni nanoparticles.

As known from the changing relationship between the measurement of surface resistivity volume of composite material and the filling of carbon fiber in the present work (Fig. 3), carbon fiber was filled at the percolation threshold of WPU. From Fig. 3, it was known that when carbon fiber had a very high electrical resistivity value (6.26×10^9 Ω/cm^2) at a low filling of 9wt%, since the filling volume was very low, it could not contact with each other to form conductive network. When the filling volume of carbon fiber was 13wt%, the electrical resistivity (4.69×10^8 Ω/cm^2) fell to one lower level. And the increase of filling volume was gradually followed by the formation of a conductive network. When the filling volume of carbon fiber was 16wt%, the electrical resistivity value fell rapidly to 2.35×10^4 Ω/cm^2. Since the filled carbon fiber formed a conductive network inside the WPU, the conductivity of WPU rose drastically. As the filling volume was 23wt%, the electrical resistivity fell even more to $208\Omega/cm^2$. When the filling volume continued to increase to 28wt%, the electrical resistivity was $122\Omega/cm^2$. The rise of conductivity was gradually alleviated, and a complete conductive network was formed inside the material. Therefore, percolation threshold happened when the filling volume of carbon fiber exceeded by around 13wt%, making the composite material transformed from insulator to be conductor.

Table 1. Volume of pure carbon fiber and carbon fiber/Ni nanoparticles filled in composite materials and their average shielding effectiveness values.

	Sample no.	Mass fraction of pure carbon fiber(wt%)	SE(dB)
Pure carbon fiber	A1	9	4.1
	A2	13	5.6
	A3	16.6	8.6
	A 4	23	14.9
	A 5	28.5	17.8
	A 6	33.3	23.9
carbon fiber add Ni nanopnarticle (13wt%)	B1	9	7.2
	B2	13	7.6
	B3	16.6	15.3
	B4	23	19
	B5	28.5	20.9
	B6	33.3	26

Figure 4 and Table 1 show the electromagnetic shielding effectiveness of composite materials filled with different volumes of carbon fiber at 50MHz~1.5GHz. The average shielding values of the composite materials A1 and A2 were 4.1dB and 5.6dB respectively. The low filling volume almost had no shielding effectiveness. Such a low filling volume resulted in a small degree of connectivity between filler and filler in the composite material. Hence, the average shielding values of the composite materials B1 and B2 added with Ni nanoparticles were also 7.2dB and 7.6dB only respectively. The average shielding value of the composite material A3 was 8.6dB. The increase of filling volume makes the conductive network constructed gradually, thus enhancing the shielding effectiveness. As to the composite material B3 added with Ni nanoparticles, since Ni nanoparticles were distributed in the composite material, its conductive paths were increased, thus enhancing its conductivity and increasing the average shielding value to be 15.3dB. When the carbon fiber content exceeded 16.6wt%, the average shielding values of the composite materials B4, B5 and B6 added with Ni nanoparticles were higher than those of the composite materials A4, A5 and A6 by around 20%. By then, the conductivity had reached the marginal value. Even though the conductive filler was increasing, the rise of its conductivity became very slow. Just because of the addition of Ni nanoparticles which increased the loss of absorption, the shielding effectiveness was increased.

4. Conclusion

According to the above research results and discussion, it is known that after surface resistivity and shielding tests were made by the study for the WPU polymer material mixed with different proportions of conductive fillers. By using polymer blending method, carbon fiber and Ni nanoparticles were blended with waterborne polyurethane, thus successfully preparing a composite film with electromagnetic shielding effect.Compared with pure carbon fiber composite film, the electromagnetic shielding effectiveness of the composite film added with nickel nanoparticles after exceeding the percolation threshold can be increased by 20%.The percolation threshold of the composite film added with pure carbon fiber may happen when the filling volume of carbon fiber exceeds 13wt%.

References

1. K. Lozano. *Vapor-grown carbon-fiber composites: Processing and electrostatic dissipative applications.* JOM. 2000, 52, pp. 34-36.
2. N.C. Das, S. Yamazaki, M. Hikosaka, T.K. Chaki, D. Khastgir, A. Chakraborty. *Electrical conductivity and electromagnetic interference shielding effectiveness of polyaniline-ethylene vinyl acetate composites*. Polymer International. 2005, 54, pp. 256-259.
3. L.X. Liu, Y.A. Huang, R.S. Huang, T. Tang, Z. Xu, X. Ge, J.Y. Shen. *Preparation and characterization of the nano-particles composites of ni-fe alloys dispersed on expanded graphite for the shielding of electromagnetic radiations*. Chinese Journal of Inorganic Chemistry. 2007, 23, pp. 1667-1670.
4. R.M. Bagwell, J.M. McManaman, R.C. Wetherhold. *Short shaped copper fibers in an epoxy matrix: Their role in a multifunctional composite*. Composites Science and Technology. 2006, 66, pp. 522-530.
5. D.D.L. Chung. *Electromagnetic interference shielding effectiveness of carbon materials*. Carbon. 2001, 39, pp. 279-285.
6. H. Chang, T.T. Tsung and C.H. Lo. *A study of nanoparticle manufacturing process using vacuum submerged arc machining with aid of enhanced ultrasonic vibration*. Journal of Materials Science. 2005, 40, pp. 1005-1010.