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Electromagnetic interfering shielding of aluminum alloy–cenospheres composite

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Abstract Fly-ash cenosphere particles were used as mixture in aluminum matrix composite by squeeze casting method [1]. The electromagnetic interfering shielding effectiveness (EMISE) was investigated in the frequency range from 0.03 MHz to 1.5 GHz. It showed the SE value of Al2024/cenospheres composite (ACC) is higher than that of aluminum alloy, and comparative to traditional material 1J50. Unlike 1J50, the mechanism of EMI shielding for ACC is reflection and multiple reflections. Analyzed by XRD and SEM, chemical reactions may occur between the matrix and cenosphere particles during the casting procedure, but it affects the shielding effectiveness little.

Introduction

Nowadays, the electromagnetic radiation is becoming the fourth public pollution after the noise, water and air pollution. And as we know, electromagnetic interference shielding is in critical demand due to the increasing sensitivity and the interference between digital devices. Human being not only for the healthy electromagnetic environments, but also for daily works and proper communications particularly needs it. It is also needed for prohibiting electromagnetic forms of spying.

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Cenospheres, an industrial by-product, is conventionally used as mixture due to its stability, low density and thermal conductivity [2]. Recently, cenosphere particles with surface modification have been paid great attention to be exploited as conductive fillers in polymer matrix or cement matrix composites on EMI shielding [3–5]. This article provides a new application for cenospheres to be used as mixture in aluminum alloy matrix to enhance the EMISE. Traditional EMI shielding materials like permalloy, nickel and steel are still in use for most structural applications. However, the SE of permalloy always reduces in the process of machining and as a result of which, increase the cost and the energy waste. But, this type of composites avoids the disadvantage of traditional materials, such as high cost, high density. Its density is adjustable, and only about 1.4–2.0 g/cm^3 for our composites.

Experiment

The ACC of 40 vol% were fabricated by squeeze casting method. Fly-ash cenosphere particles were supplied in batches by Harbin thermo-electric plant, and its particle size distribution was measured on Mastersizer 2000 in advance (see Fig. 1). In the present investigation, the particle size we used was concentrated on 100 μm. And we also demonstrated the microstructure, chemical reaction with the help of X-ray diffraction (XRD) and S-570 scanning electron microscopy (SEM). The DC electrical resistivity on Keithley Model 2400 by four-probe method was also measured. The shielding effectiveness (SE) was tested using coaxial cable method, and the set up is illustrated

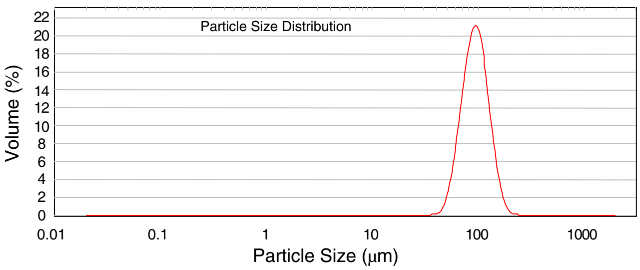

Fig. 1 The particle distribution of cenospheres used in ACC

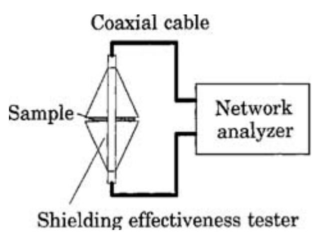

Fig. 2 The equipment of electromagnetic shielding effectiveness measurement

in Fig. 2. All samples used in SE measurement were performed with 115 mm in diameter and 2 mm in height.

Results and discussion

Shielding effectiveness measurement

The mechanism of EMI shielding can be described as follows:

$$SE = R + A + B \tag{1}$$

where SE is shielding effectiveness, it usually depends on three aspects, namely reflection, absorption and multiple reflections. The losses, whether due to reflection, absorption or multiple reflections, are commonly expressed in dB [6]. Figure 3 shows the SE in the frequency range from 0.03 MHz to 1.5 GHz for aluminum alloy (line 1) and ACC (line 2), respectively. The SE value of ACC is higher than that of aluminum alloy. In Fig. 4, the SE value of ACC is comparative to the traditional material 1J50. As known from Eq. 1, the SE value is mainly from three aspects: reflection, absorption and multiple reflections. Then, what's the mechanism of EMI shielding for our composites in this paper?

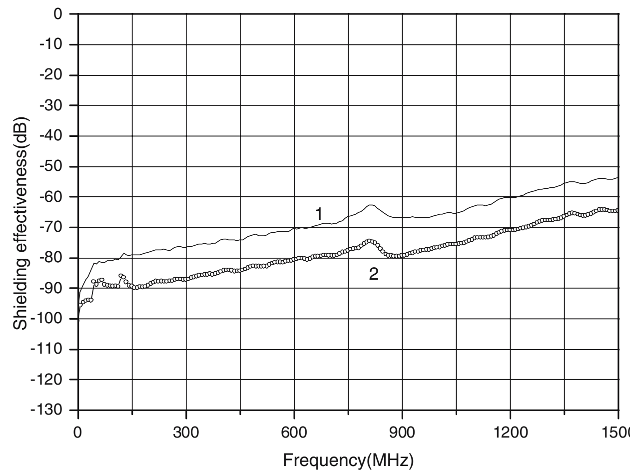

Fig. 3 Shielding effectiveness of aluminum alloy (line1) and ACC (line 2)

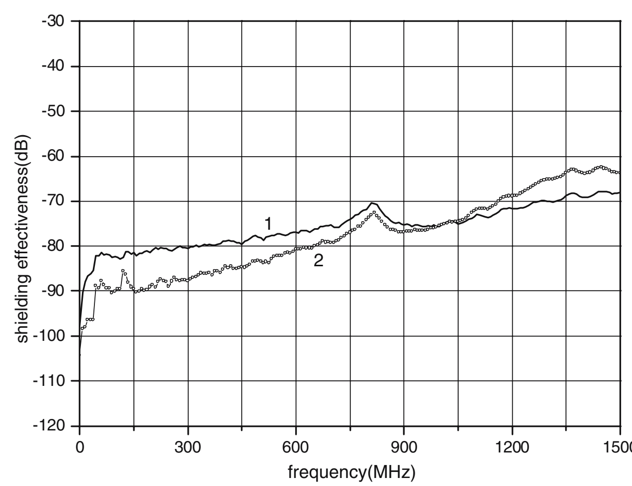

Fig. 4 The shielding effectiveness of 1J50 (line1) and ACC (line 2)

DC resistant measurement

The DC electrical resistivity of ACC with sample-shape of $3 \times 4 \times 70\ \mathrm{mm}^3$ was tested by four-probe method at room temperature. The electronic conductivity was then consequently calculated:

$$\sigma = L/RS = 0.76 \times 10^7\ \Omega\,\mathrm{m}^{-1} \tag{2}$$

According to the equation followed, the SE value for ACC from reflection is lower than that of aluminum alloy. Thus, we can say, the increase in value of SE for the composites is not induced by the enhancement in reflection.

$$R = 168 - 10\lg(f\mu_r/\sigma_r) \tag{3}$$

Chemical reactions

The XRD pattern of cenospheres and ACC are showed in Fig. 5. There are new components formed in composites besides the raw materials. Thermodynamic analysis indicates that there is the possibility of chemical reactions between aluminum melt and cenospheres during solidification processing at temperatures above the melting temperature of aluminum [7]. A stable system must be in a state of the lowest Gibbs free energy. The reaction from Al to Al_2O_3 is a course of transformation from the higher Gibbs free energy to the lower [8]. But, even though, the resultants Si and Al_2O_3, seen in XRD pattern, were no use in EMI shielding. There may be other reactions between the matrix and cenospheres in the course of preparation, but cannot be seen in XRD pattern and could not affect SE value much due to its small quantity.

The loss for absorption is due to the high magnetic permeability. In ACC, the value of magnetic permeability for aluminum alloy, silicon, and alumina is the same to the vacuum. It is accepted that the presence of iron oxide in cenospheres enhances the loss for absorption, but in frequency range investigated, the SE value of cenospheres is obviously near zero when the frequency f is greater than 150 MHz, as shown in Fig. 6. That is, the loss for absorption from iron oxide in composites on SE value increase can be neglect at the frequency range at 150 MHz and higher.

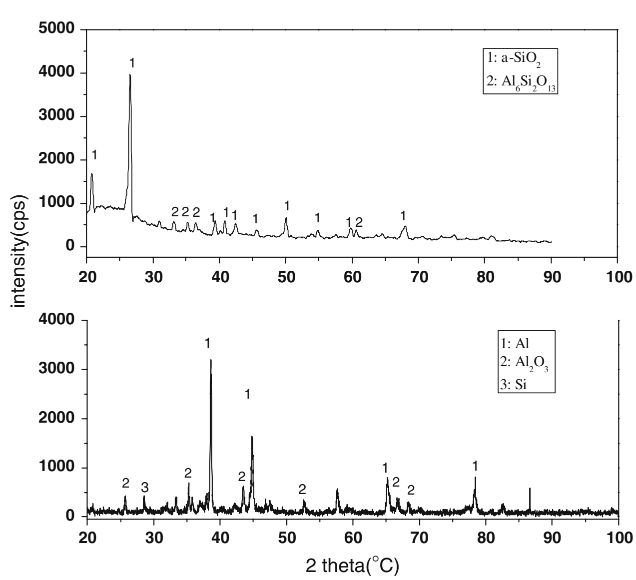

Fig. 5 XRD spectra of hollow cenospheres (above) and aluminum-fly ash particulate matrix composites (below)

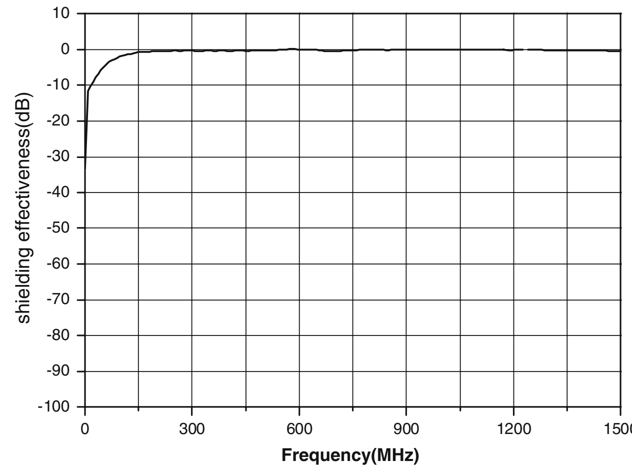

Fig. 6 The shielding effectiveness of hollow cenospheres

Microstructure

Multiple reflections, which refer to the reflections at various surfaces or interfaces in the shield, require the presence of a large surface area or interface area in the shield. An example of a shield with a large surface area is a porous or foam material. Material of ACC is an example of a shield with a large interface area and surface area. Figure 7 displays the OM photograph for ACC. Cenospheres are mostly integrated, hollow and well proportioned in aluminum matrix. The porous structure provides large interfaces between the matrix and the cenospheres (see Fig. 8A). In Fig 8, there are also many holes existed between cenospheres in composites (see Fig 8B). These closed structure in aluminum matrix made the electromagnetic wave reflect time after time. Like foam materials but better than foam materials, such as better strength, adjustable density and the diameter of the foam, the composites

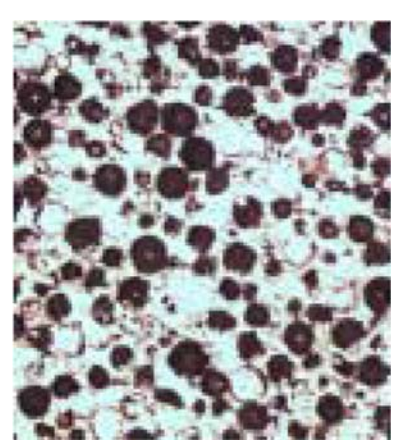

Fig. 7 OM of ACC

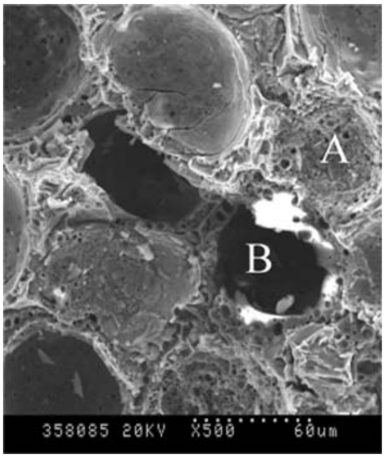

Fig. 8 SEM of ACC

thus contribute about 10–20 dB to SE value in the frequency range from 150 MHz to 1.5 GHz.

Conclusion

A new application for hollow cenosphere particles as an admixture in aluminum matrix composites for electromagnetic interference shielding is provided in this paper. The dominant mechanism of EMI shielding for aluminum matrix composites is reflection and multiple reflection. The composites also have potential applications in covers, shrouds, casings, manifolds, valve covers, garden furniture, and engine blocks in the automotive.

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