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Effect of silver plating time on the properties of conductive silicone rubber filled with silver-coated carbonyl nickel powder

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ABSTRACT

This article investigates the effect of the silver plating time on the microwave shielding and mechanical properties of the conductive silicone rubber filled with silver-coated carbonyl nickel powder. The results show that the electromagnetic shielding effectiveness (SE) of the rubber with the silver-coated carbonyl nickel powder rises up to about twice that of the rubber with the carbonyl nickel powder and the elongation of the rubbers at break increases when the plating time reaches 40 min. The property improvement is related to the strengthening effects of the silver coating layer on the carbonyl nickel powder in the rubber. The silver coating layer builds a silver-silver conductive channel and a cooperative mechanism of the electromagnetic wave reflection and absorption. That is beneficial to increasing the SE of the rubber. In addition, the silver coating layer on the surface of the carbonyl nickel powder has a better combining ability with the rubber than the powder itself, which may play an important part in the increase of the elongation.

1. Introduction

As a novel conductive and electromagnetic interference shielding material, conductive silicone rubbers play an important role in electrical connection and electromagnetic protection of sensitive electronic components. To improve the conductive and electromagnetic performance, a number of materials have been researched in the recent years, such as conductive silicone rubbers filled with nickel-coated carbon fiber, nickel-coated graphite, and silver-coated cenospheres [1–3].

It is well known that the fillers have a significant influence on the application of the rubbers. Common fillers include metals (e.g. copper powder), carbon materials (e.g. carbon fibers) and core-shell particles (e.g. silver-coated cenosphere), which possess relatively high conductivity and are beneficial to enhancement of electromagnetic wave reflection of the rubbers [3–7]. Another fillers include the particles of dielectric or magnetic dipoles (e.g. Co/SiO_2 nanosphere core-shell composites and carbonyl iron/nickel powder), which can absorb and attenuate the incident electromagnetic wave, then crunch the electromagnetic energy into heat energy, or weaken the electromagnetic waves' interference [8–10].

Carbonyl iron powders and carbonyl nickel powders have been widely applied in the electronic industry as a kind of magnetic absorber and filler due to high saturation magnetization, superior stability, and enhanced dispersion [11–14]. Recently, it has been proved that the silver coating on the carbonyl iron powder can improve the electromagnetic shielding effectiveness (SE) of the carbonyl iron powder. In addition, the SE of the conductive silicone rubbers filled with the silver-coated carbonyl iron powder increases obviously compared with those filled with the carbonyl iron powder. That is related to the reflection of silver coating and the absorption of carbonyl iron powder [15,16].

However, little work has been carried out to understand the effects of the conductive silicone rubbers filled with the silver-coated carbonyl nickel powder on the conductive and electromagnetic wave shielding properties. Although the carbonyl nickel and carbonyl iron powders possess good magnetic performances, the microstructures and properties of the two powders are different [14,15]. When the silver-coated carbonyl nickel powder is applied in the silicone rubber, the conductive and electromagnetic of the rubber may be distinctive from the one with silver-coated carbonyl iron powder. Considering the excellent magnetic property and well-defined structure of the carbonyl nickel as well as the good conductivity of the silver, the silver-coated carbonyl nickel

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powder may provide another good choice for the conductive and electromagnetic property improvement of the rubbers. Therefore, the development of the conductive silicone rubbers filled with the conductive-magnetic composite materials is necessary for excellent conductive and electromagnetic wave shielding capabilities.

Primary work has been performed on the conductive and electromagnetic wave shielding properties of conductive silicone rubbers or silver-coated powders. Li [17] found that the silver coating enhanced the infrared absorption and reflectance of the powder at the appropriate plating time. Wang [18] indicated that volume resistivity of the conductive silicone rubbers decreased four orders of magnitude when the proper curing temperature was provided.

In this paper, the effect of silver coating on the conductive and electromagnetic wave shielding properties of the conductive silicone rubbers filled with silver-coated carbonyl nickel powder are discussed and their microstructures are analyzed. In addition, the mechanism of the silver coating on the conductive and electromagnetic wave shielding properties is investigated.

2. Experimental procedure

2.1. Material and preparation

The pure carbonyl nickel powder (99.5 wt. %) was used as a raw material. The powder particle size range was 2–8 μm with an average particle size of 6 μm. After was cleaned, the carbonyl nickel powder was transferred into the chemical plating solution keeping the temperature of 25 °C. The chemical plating formula as well as the experimental conditions was listed in Table 1. The silver-coated carbonyl nickel powder samples were obtained by washing with a certain amount of ethanol, and then dried at room temperature for 1 h. To analyze the mechanism of the silver coating on conductive and electromagnetic properties of the materials, the silver-coated carbonyl nickel powder samples were prepared at the chemical plating time of 20min and 40min respectively.

The conductive silicone rubber filled with the silver-coated carbonyl nickel powder was prepared by mixing the pure silicone rubber, vulcanizing agent and silver-coated carbonyl nickel powder at 15 °C for 2 h in the double planetary mixing equipment. The mixture was poured into a 200 × 200 mm stainless picture-frame mold with a thickness of 2 mm. The mold was placed in a plate vulcanizing instrument at 165 °C curing temperature with inert-gas protection. Pressure of 10 MPa was applied and held for 5 min to get a group of the conductive silicone rubber sheets. The sheets were kept at room temperature (20 ± 5 °C) for 24 h before testing. The conductive silicone rubber filled with the carbonyl nickel powder was prepared by the same method above. The mass ratio of the silver-coated carbonyl nickel powders to pure silicone rubber was 350:100 and that of the carbonyl nickel powders to pure silicone rubber was the same.

2.2. Mechanical test

Tensile properties were measured according to the standard of ASTM: D412-06ae2 using a tensile testing machine (LLYOD, Lloyd Instruments Ltd., UK) at a crosshead speed of 500 mm/min. Shore A hardness was measured based on ASTM: D2240-05(2010) standard by a Shore A durometer.

Table 1
Silver plating solution composition.

Composition	Content
$AgNO_3$	30 g/L
NH_4OH	100 g/L
glucose	30 g/L
Kalio-natrimn tartaricum	10 g/L
NaOH	25 g/L

2.3. Measurements of SE

The SE of the sample for plane-wave conditions was measured by means of the flange coaxial method. The setup consisted of a DN15115 SE tester which was connected to an Agilent 4396B RF network spectrum impedance analyzer. The scanning frequency ranged from 100 MHz to 1.5 GHz. The thickness of the rubber layers were 2 mm.

2.4. Morphology observation

Scanning electron microscopy (SEM) (ZEISS EVO18, ZEISS Ltd., Germany) was used to observe the distribution of fillers of the composites and the tensile fracture morphology. The elemental distribution was evaluated by energy-dispersive x-ray analysis (EDX).

3. Results and discussion

Fig. 1 shows the variation in the electromagnetic shielding effectiveness (SE) of the conductive silicone rubber filled with the silver-coated carbonyl nickel powders at different plating time. It is found that the increase of the plating time can remarkably improve the electromagnetic shielding properties of the conductive silicone rubber in the frequency range of 100–1500 MHz. When the plating time reaches 40min, the SE of the rubber with the silver-coated carbonyl nickel powder rises up to about twice that of the one with the carbonyl nickel powder.

Table 2 indicates the mechanical properties of the conductive silicone rubbers filled with the silver-coated carbonyl nickel powders at different plating time. From the table, it is seen that the elongation of the rubbers at break increases with the plating time while the tensile strengths are roughly identical.

The improvement in the electromagnetic and mechanical property is related to the strengthening effects of the silver coating layer on the carbonyl nickel powder in the rubber. Fig. 2 shows the microstructures of the silver-coated carbonyl nickel powders with different plating time. It is found the increase of the plating time

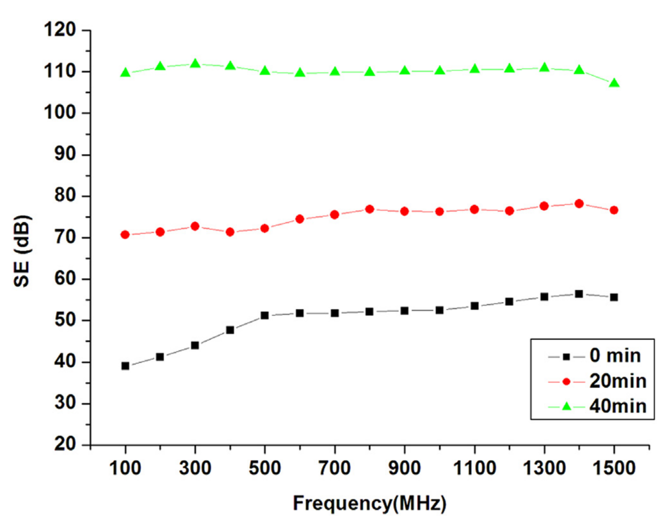

Fig. 1. Electromagnetic shielding effectiveness of the conductive silicone rubber filled with the silver-coated carbonyl nickel powders at different plating time: (a) 0 min (the carbonyl nickel powder), (b) 20 min and (c) 40 min.