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Short communication: material properties

The electromagnetic interference shielding of silicone rubber filled with nickel coated carbon fiber

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ABSTRACT

In this paper, nickel coated carbon fiber (Ni-CF) was obtained by an electroplating method. The Ni-CF was used as conductive filler in silicone rubber for electromagnetic interference (EMI) shielding applications. The effect of Ni-CF content on the volume resistivity and shielding effectiveness (SE) of the silicone rubber composites was investigated. The results indicated that the nickel coated carbon fibers mixed in the silicone rubber were randomly oriented and cross-linked with each other to form a three-dimensional conductive pathway network. The volume resistivity of the composite decreased and SE was enhanced with increase of the Ni-CF content. When the Ni-CF content reached 80 phr, the volume resistivity reached 0.042 Ω cm, while the SE values of the silicone rubber composite were typically about 80 dB across the tested frequency range from 30 MHz to 1200 MHz.

1. Introduction

Silicone rubber is applied today in a large variety of applications due to its low density, good chemical resistance, weather resistance and convenient fabrication [1]. However, silicone rubber is electrically insulating and transparent to electromagnetic radiation. With the development of electronic information technology and widespread use of electronic devices, electromagnetic interference (EMI) has become a serious problem in recent years. EMI shielding materials are attracting more and more attention for the purpose of protecting the workspace and the environment from the radiation emitted by electronic devices [2–4]. An effective way to the preparation of electromagnetic shielding rubber is to add conductive fillers into a silicone rubber matrix [5,6].

Traditional conductive fillers can be divided into carbon based materials (carbon black, graphite, carbon nanotubes) and metal powder materials (silver powder, copper powder, nickel powder). Carbon system conductive fillers with low conductivity are used for the preparation of conductive rubber with volume resistivity more than 1 Ω cm. Metal powder exhibits excellent conductivity, but its limitation is high density and high cost [7,8]. With the development of metallization technology, core-shell particles such as silver plated nickel powders, silver plated cenosphere particles and nickel plated graphite particles have been developed in these fields [9–12]. Among them, nickel plated graphite shares advantages of both carbon and metal powder materials. It possesses light weight, good conductivity and low cost. Hence, it has attracted extensive attention and has been applied in the conductive composites industry [13–15]. However, powder type conductive fillers do not easily form conductive paths in the matrix material. The amount of conductive filler needs to be more than 200 phr to meet the conductivity requirement, which certainly will increase the cost of conductive rubber and decrease the mechanical properties.

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Carbon fiber, one of the most advanced and important reinforcements, possesses high modulus, high strength, low density and low coefficient of thermal expansion [16]. Coating a metallic layer onto the surface of carbon fiber can enhance its conductivity. Compared with metal plated graphite powder, metal plated carbon fiber can develop conductive pathways more easily and achieve higher conductivity with less addition due to its high aspect ratio. Therefore, metal plated carbon fiber is a better conductive filler than metal plated graphite powder.

In the present work, nickel plated Ni-CF was prepared by an electroplating method. After mixing with silicone rubber and a curing agent, Ni-CF/silicone rubber composite was obtained. The effect of the Ni-CF content on the electrical resistivity and SE properties of silicone rubber composite was investigated.

2. Materials and methods

The rubber was a methyl vinyl silicone and the curing agent was 2,5-dimethyl-2,5-di(tert-butylper-oxy)-hexane. The CF had 12000 filaments in each bundle with a diameter of 7 μm.

Before electrodeposition, heat treatment of CF was performed at 500 °C for half an hour in air to burn out the organic binder. The basic composition of the electrolyte and the plating conditions are shown in Table 1.

Ni-CF was cut into 2-3 mm lengths, then mixed with silicone rubber and curing agent on a two-roll mill. The total mixing time was 30 min. Samples of the silicone rubber composite were placed in a stainless steel mold with a diameter of 115 mm and a thickness of 2 mm. They were then compression molded at 160 °C and a pressure of 10 MPa for 10 min in an electrically heated press. The loadings of Ni-CF mixed in silicone rubber were 30, 60 and 80 phr.

The morphology of Ni-CF and Ni-CF filled silicone rubber composite was observed by a Philips modelMV2300 scanning electron microscope (SEM) and Olympus-PME3 optical microscope (OM). The resistance and volume resistivity of silicone rubber composite samples were calculated according to GBT2439-2001. The resistance of the samples was measured by a TH2512/BDC resistance test instrument. The coaxial transmission line method according to ASTM ES-7-83 was used to measure the EMI shielding effectiveness (SE). The SE was evaluated by measuring the attenuation or reduction of the electromagnetic waves by the shield in the frequency range from 30 to 1200 MHz.

Table 1
Composition of the electrolyte and deposition parameters.

Deposition parameters	Amount
Nickel sulphate	150 g/L
Ammonium chloride	15 g/L
Boric acid	15 g/L
Dodecyl benzenesulfonic acid, sodium salt	2 g/L
Temperature	30 ± 1.5 °C
pH	2.5 ± 0.2
Current density	1.5 ± 0.2 A/dm^2
Plating time	10 ± 0.5 min

3. Results and discussion

3.1. Morphology of Ni-CF

Fig. 1(a) shows the SEM micrograph of CF. Fig. 1(b) shows the SEM micrograph of Ni-CF, the black part in center is carbon fiber, the outer gray part is Ni coating. It is observed that the coating is dense and continuous. Fig. 1(c) shows the cross section morphology of Ni-CF carried out by OM. It is revealed that the coating was deposited uniformly around each fiber. The average thickness of the coating is 1.2 μm.

Fig. 2 shows the morphology of silicone rubber composite filled with different amounts of Ni-CF. It is seen that the fibers mixed in the silicone rubber were uniformly dispersed and were physically cross linked with each other. The lengths of fibers appear different due to their different orientations, the round dots are fibers that are perpendicular to the observation direction. The fibers in different directions and cross linked with each other could form a three-dimensional conductive pathway network in the matrix, which possesses better conductivity than the case of powder addition, even though the amount of fiber addition in the present case is much less than that of powder addition. It is reported that nickel plated graphite and Ag-coated cenosphere particles need to be added at more than 200 phr to meet the conductivity requirement [17,18].

3.2. Electrical resistivity and SE properties of silicone rubber composites

The resistance and volume resistivity of silicone rubber composites filled with different concentrations of Ni-CF are given in Table 2. The silicone rubber composite filled with 30 phr Ni-CF shows high volume resistivity (5.238 Ω cm) due to the low amount of crossing points between fibers in the composite (Fig. 2(a)). A small amount of fibers surrounded by silicone rubber cannot guarantee that fibers connect with one another very well. Therefore, Ni-CF does not meet the requirement of high conductivity of rubber when the filler concentration is less than 30 phr. As the concentration of the filler increases, fibers gradually connect well with each other and the amount of crossing points between fibers gradually increases (Fig. 2(b) and 2(c)). Thus, the volume resistivity of the composites consistently decreases. The value of volume resistivity reaches 0.042 Ω cm when the concentration of Ni-CF is up to 80 phr, which is much higher than the value in the case of nickel plated graphite.

It is observed from Fig. 2 that the number of the crossing points between fibers increases when the filler loading increases further from 60 phr to 80 phr. However, the volume resistivity of composite silicone rubber composites decreases relatively slowly. This could be attributed to the fact that, with the increase of filler loading, the new electrically conductive pathways will not be further formed proportionally because most of the fibers have already connected very well at the 60 phr content level.

Fig. 3 shows the variation in SE of silicone rubber composites filled with Ni-CF in the frequency range of 30