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Improved antistatic properties and mechanism of silicone rubber/low-melting-point-alloy composites induced by high-temperature cyclic stretching

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ABSTRACT

Methyl vinyl silicone rubber (MVQ)/low-melting-point alloy (SnBi) composites were prepared by mechanical blending. The effect of SnBi content on the surface resistivity, volume resistivity, mechanical properties, and transparency of MVQ were investigated. The results showed that the surface resistivity, volume resistivity, tensile strength, and elongation at break of MVQ/SnBi composites were 1.6×10^{10} Ω, 2.2×10^{11} Ω cm, 8.2 MPa, and 612%, respectively by incorporation of 3 phr SnBi, showing better antistatic properties and mechanical properties. The effect of cyclic stretching temperature, strain, and number of cycles on the aspect ratio (length to diameter), electrical performance, and mechanical properties of MVQ/SnBi composites were also studied. The average aspect ratio of the alloy particles increased with increasing tensile temperature, strain, and cyclic times, resulting in a reduction in electrical resistivity. In addition, the antistatic mechanism of MVQ/SnBi composites was revealed.

1. Introduction

Methyl vinyl silicone rubber (MVQ) exhibits characteristics such as good temperature resistance, weather resistance, ozone resistance, electrical insulation, and physiological inertness, and is widely applied in the fields of aviation, aerospace, electronics, electrical appliances, automobiles, machinery, chemicals, and medicine [1,2]. Because of its high insulating resistance, silicone rubber is mainly used in elastic touch panels, protective sleeves, insulators, wire and cable sheathing, and other applications. However, silicone rubber tends to produce static electricity after friction with other substances. The accumulation of many static charges produces high electrostatic voltage, resulting in high-voltage discharge or even fire accidents. Therefore, antistatic or conductive silicone rubber has become a current research focus area. In order to improve the electrical properties of silicone rubber, the main method is to add some conductive fillers such as carbon black [3–7], carbon fibers [8], and metal powders [9–11] in order to reduce the conductive channels and form a conductive network among the conductive fillers. In recent years, carbon nanotubes [12–15] and graphene [16–18] have been widely used as conductive fillers, and can obtain excellent conductivity with minor additions. However, these black nano-fillers change the color of silicone rubber and decrease its transparency. In addition, some ionic liquids [19], acting as antistatic fillers, result in the reduction of the electrical resistivity of silicone rubber because of their migration performance from the interior to the surface of the rubber. However, the antistatic property is unstable and might degrade over time.

Low-melting-point alloys (LMPAs), containing metal elements such as Bi, Pb, Sn, Cd, In, Ga, Ti, Zn, and Sb are known as “fusible alloys” with co-melting points below 310 °C. Because of their low melting points, LMPAs show *in situ* deformation ability assisted by particular stress in some polymers when the environmental temperature is higher than the melting point of the alloys. Bormashenko [20,21] proposed a method to prepare conductive polyethylene (PE)/LMPA/carbon black composites by extrusion. Resistivity of the composites was investigated and nonohmic behavior of the composites was revealed. Zhu [22] prepared conductive/antistatic polypropylene (PP) fibers by using an LMPA as the conductive filler. It was found that the stretching process could make the conductive networks denser instead of destroying them. In addition, montmorillonite (MMT) can improve the dispersity and stability of the metal filaments, and further increase the conductivity of the polymer fibers. However, the application of

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Table 1
Formulations of MVQ/SnBi composites.

Ingredients ([a]phr)	Pristine MVQ	MVQ/SnBi-1	MVQ/SnBi-2	MVQ/SnBi-3	MVQ/SnBi-4	MVQ/SnBi-5	MVQ/SnBi-6
Silicone rubber	100	100	100	100	100	100	100
DBPMH	2	2	2	2	2	2	2
SnBi	–	1	2	3	4	5	6

[a] Per hundreds of rubber.

LMPA in some elastomers has not yet been investigated.

In this study, the effect of tin and bismuth alloy (SnBi) content on the resistivity, mechanical properties, and transparency of MVQ/SnBi composites was investigated. The effect of cyclic tensile temperature, strain, and number of cycles on the average aspect ratio and morphology of SnBi particles was also studied. The relationship of the electrical properties of the composites and the average aspect ratio of SnBi particles was developed, and the antistatic mechanism of MVQ/SnBi composites was revealed.

2. Experimental methods

Formulations of MVQ/SnBi composites are listed in Table 1. All of the composites were prepared on a two-roll mill (model XK-160, Zhanjiang Machinery Factory, China) with a two-gear speed ratio of 1:1.4 at room temperature. The MVQ (Caiyan CY8540, China) was first softened, and then SnBi alloys (with a tin to bismuth weight ratio of 42:58, Sanhedingxin, Beijing, China) were added until a homogenous batch was obtained. The curing agent 2,5-dimethyl-2,5-bis (*tert*-butyl peroxy) hexane (DBPMH) was then added and processed until a visually good dispersion was achieved. The MVQ compounds were cured with flat sheets by compression molding in a hydraulic press (model KSHR100T, Kesheng, China) at 150 °C for 20 min under 10 MPa pressure.

The mechanical properties of MVQ vulcanizates were tested in an electronic universal testing machine (model Z010, Zwick/Roell, Germany) according to the standard of ASTM D412-2006ae2. The specimens (80 mm long, 1 mm thick, and 25 mm wide) were used for the high-temperature cyclic tensile test, which was conducted in a material testing machine (model 5500, Instron, UK) assembled with an incubator. The specimens were fastened with two clamps in the incubator, and were not stretched until the temperature of the specimens was equal to the setting temperature. The specimen was steadily stretched to a given strain, and then released back to its original length with the same speed as the stretching process; this is called a tensile cycle. The tensile speed was set to be 100 mm min^{-1}; the tensile temperature was set to be 25, 150, 180 and 200 °C; the tensile strain was set to be 100%, 150%, 200% and 250%; and the number of cycles were chosen to be 20, 40, 60 and 80.

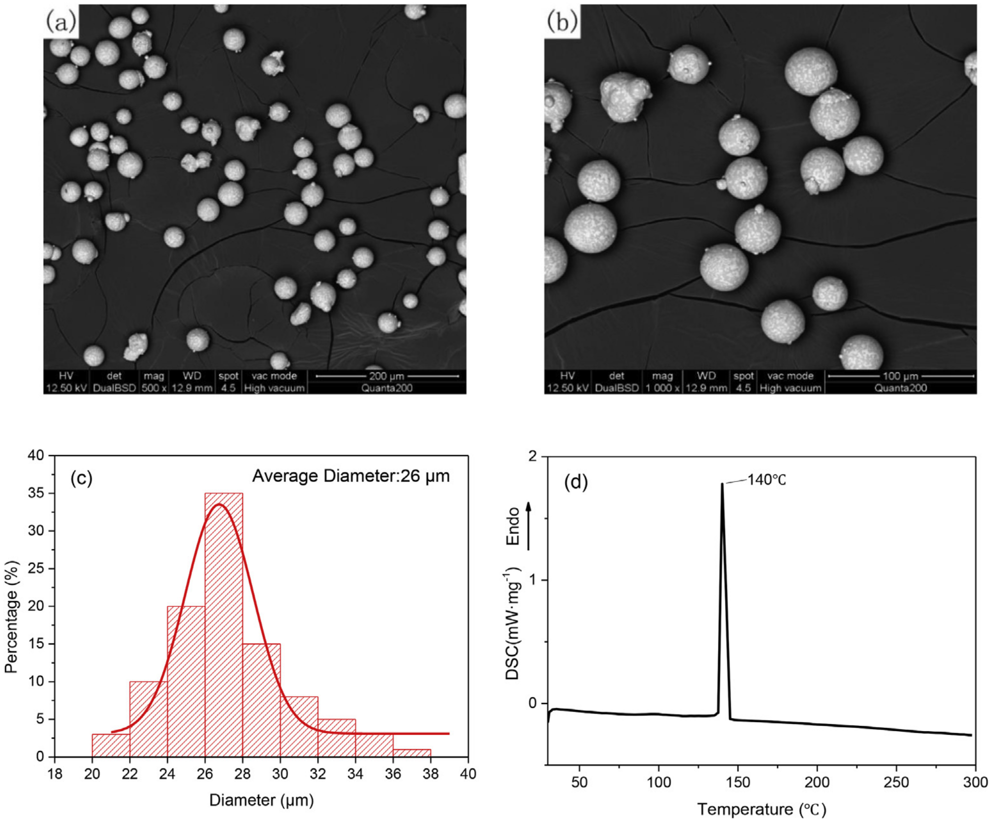

Fig. 1. Characterization of SnBi particles: (a) SEM photograph, (b) magnification of SEM photograph of (a), (c) size distribution (the red curve represents the Gaussian fitting curve of SnBi particle diameter), and (d) DSC curve, showing the melting point of SnBi of 140 °C. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)