Materials Research Bulletin 48 (2013) 2002–2005

Contents lists available at SciVerse ScienceDirect

Materials Research Bulletin

journal homepage: www.elsevier.com/locate/matresbu

Short communication

High damping properties of magnetic particles doped rubber composites at wide frequency

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ARTICLE INFO

Article history:
Received 18 June 2012
Received in revised form 20 December 2012
Accepted 7 January 2013
Available online 23 January 2013

Keywords:
A. Magnetic materials
C. X-ray diffraction
D. Magnetic properties
D. Mechanical properties

ABSTRACT

A new kind of rubber composite was prepared by doping $SrFe_{12}O_{19}$ nanoparticles coated with silane coupling agents (Si-69) into nitrile butadiene rubber (NBR) matrix, which was characterized by the scanning electron microscopy and X-ray spectroscopy. The results showed that the $SrFe_{12}O_{19}$ nanoparticles were well dispersed in rubber matrix. Furthermore, the mechanical and magnetic properties of the rubber composites were investigated, in which the high tensile strength (15.8 MPa) and high saturation magnetization (22.9 emu/g) were observed. What is more, the high loss factor of the rubber composites was also obtained in a wide frequency range (0–100 Hz) at high loading (80 phr). The result is attributed to that the permanent magnetic field in rubber nanocomposites can absorb shock energy. These results indicate that the new kind of permanent magnetic rubber is expected to be a smart isolator material, in which the isolator will be able to adapt to a changed frequency.

1. Introduction

Vibration and noise often lead to undesirable consequences such as unpleasant noise, fatigue and failure of structures, decreased reliability and degraded performance [1]. Rubber is a commonly used material in controlling noise and vibration because of its high damping property. It should be noted that the loss factor can be used to evaluate damping properties of rubber. Generally, the larger the loss factor is, the better the damping property is. And lots of works have reported about the improvement of loss factor [2–5]. In fact, the loss factor of rubber isolator strongly depends on the vibration and noise frequencies, and the rubber isolator will not be able to adapt to a changed vibration and noise frequencies [6].

Recently, the magnetic fluid was studied as a new kind of damper [7]. The generated magnetic field on the magnetic fluid can create a repulsive force which is proportional to the outer vibration force. The moving magnet behaves like a viscous damper, which is independent of vibration and noise frequencies. According to this theory, the magnetic particles are doped into rubber matrix and the generated magnetic field on the rubber composite is expected to absorb the outer shock energy, resulting in improvement of the loss factor in wide frequency range. Although there were some studies reporting magnetic fluid dampers [7–9] and soft magnetic rubber dampers [6,10–13], it is a necessity for the work in the presence of a magnetic field. Therefore, it would be very convenient and intriguing if the damping properties of the rubber composites can adapt to a changed environment in the presence of a magnetic field. The permanent magnetic rubber composites are expected to be applied in adaptation to changed environments. But there are few studies on investigating the damping properties of the permanent magnetic rubber composites. In addition to this, strontium ferrite ($SrFe_{12}O_{19}$) has received a wider attention as hard magnetic particles due to its superior cost efficiency, large coercivity and specific magnetic saturation associated with its high magnetic and chemical stability [14]. It is fit to be used as a magnetic filler of permanent magnetic rubber composite applied on rubber vibration isolators.

In this paper, the $SrFe_{12}O_{19}$ nanoparticles doped composites were prepared and the effect of $SrFe_{12}O_{19}$ nanoparticles with surface modification on the damping properties of rubber composites was further investigated. The result shows brand new phenomenon, which can be regarded as a guide to further studying this kind of permanent magnetic rubber as smart isolator materials, in which the isolator will be able to adapt to a changed environment.

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0025-5408/$ – see front matter © 2013 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.materresbull.2013.01.035

2. Experiments

2.1. Preparation of $SrFe_{12}O_{19}$ nanoparticles coated with silane coupling agents (Si-69)

$SrFe_{12}O_{19}$ nanoparticles coated with Si-69 were prepared by two steps as follows: 60.8 g $FeCl_3 \cdot 6H_2O$, 35.8 g $FeCl_2 \cdot 4H_2O$, 10.8 g $SrCl_2 \cdot 6H_2O$ and 20.0 g PEG-6000 were dissolved in 900 mL distilled water to form a mixing solution. Then 924 mL aqueous solution containing 49.4 g NaOH and 5.6 g Na_2CO_3 was dropped into the mixing solution under vigorous stirring. The reaction continued for 2 h at 40 °C. And a precursor was obtained by centrifuging method (20,000 rpm). The precursor was further calcined at 850 °C for 4 h followed by quenching back to room temperature.

Silane coupling agents Si-69 were dispersed in ethanol at room temperature. The calcined particles were added and stirred for half an hour at room temperature. And the composite nanoparticles were dried by an oven for 24 h. Its structure was characterized by TEM and IR, suggesting that the average size of the magnetic particles is about 89.0 nm and the magnetic particles were coated by Si-69.

2.2. Preparation of permanent magnetic rubber composites

Ingredients of the rubber compounds were mixed in a two-roll laboratory mill (80 mm × 300 mm) with a rotating speed of slow roll of 24 rpm and a gear ratio of 1.4. The ingredients were added as follows: 100 phr nitrile rubber (NBR), 40 phr carbon black N330, 10 phr di octyl phthalate (DOP), 3 phr sulfur, 5 phr ZnO, 1 phr stearic acid, 1 phr rubber antioxidant RD and 2 phr rubber antioxidant 4010NA, 1.2 phr accelerator CZ and 0.8 phr accelerator DM. The mass fractions of the $SrFe_{12}O_{19}$ nanoparticles in the matrix were 20, 40, 60, 80 phr, respectively. The vulcanization process was performed by compression molding process at 160 °C for 15 min under a pressure of approximately 15 MPa from an electrical resistance heating press. After that, the rubber composites were sealed and placed in a magnetic field of 1.5 T for 5 min, the samples obtained were labeled as “B samples”, which were permanent magnetic rubber composites that had magnetic field inside them. At the same time, the rubber composites without treatment of magnetic field were kept as “A samples”.

2.3. Characterizations

Tensile tests were performed on a Universal Testing Machine (WD-5D, Chang Chun, China) with a crosshead speed of 50 mm/min at 25 °C. The average of five tests is reported here.

The phase structural identification of the products was characterized by the X-ray diffraction (XRD) with Cu Kα radiation.

The structure investigations of magnetic rubber were analyzed with a Hitachi Su-1500 scanning electron microscope (SEM).

The dynamic mechanical performances of the magnetic rubber were obtained by using a Mettler Toledo SDTA861^e dynamic mechanical analyzer (DMA). The samples were analyzed in tensile mode at a frequency range of 0–100 Hz.

The hysteresis loops were conducted by using a Lake Shore 7407 vibrating sample magnetometer (VSM) at room temperature with a maximum magnetic field of 17 kOe.

3. Results and discussion

The formation of the rubber composite is confirmed by the X-ray diffraction as shown in Fig. 1A. It clearly shows lots of X-ray diffraction peaks growing parallel to (1 1 0), (1 0 7), (1 1 4), (2 0 0), (2 0 3), (1 1 6), (2 0 5), (2 0 6), (2 0 9), (2 1 7), (2 0 1 1) and (2 2 0) planes of hexagonal $SrFe_{12}O_{19}$. The results indicate that the rubber composite doped with $SrFe_{12}O_{19}$ nanoparticles is formed [15]. In addition to this, the average size (ca. 89 nm) of the $SrFe_{12}O_{19}$ nanoparticles doped in rubber matrix can be calculated according to the Debye–Scherrer [16]. It is suggested that the $SrFe_{12}O_{19}$ nanoparticles have good stabilization and well dispersion in rubber matrix [17]. Fig. 1B shows the hysteresis loops of the rubber composite. It records 22.9 emu/g saturation magnetization and 4193.1 Oe coercive force. The result indicates that the rubber composite is a permanent magnetic material, which can form permanent magnetic field inside it after applying a magnetic field [15]. It provides an opportunity to study the damping property of the rubber composite.

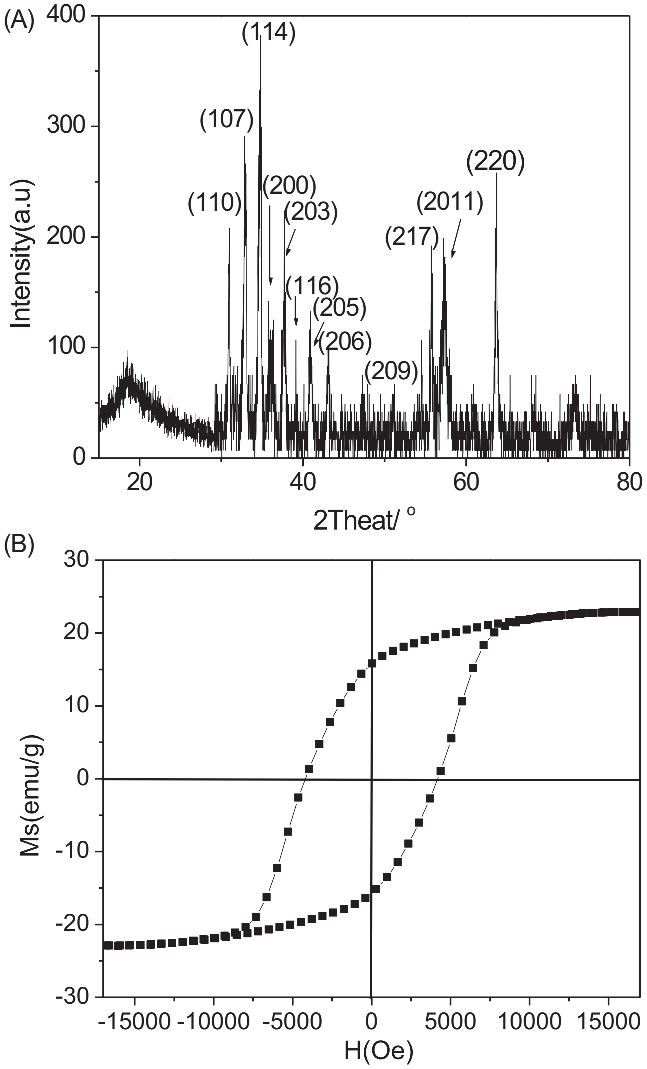

Fig. 1. (A) XRD and (B) VSM of magnetic rubber doped with $SrFe_{12}O_{19}$ nanoparticles (80 phr).

The structure of A sample and B sample are compared by the SEM images as shown in Fig. 2A and B, respectively. As shown in Fig. 2, there are few particles aggregated. Furthermore, the gaps between $SrFe_{12}O_{19}$ nanoparticles and rubber matrix cannot be also seen. These results further indicate the good dispersion of $SrFe_{12}O_{19}$ nanoparticles in rubber matrix, resulting from surface modification of $SrFe_{12}O_{19}$ nanoparticles by Si-69. At the same time, it shows different spatial distribution characteristics of $SrFe_{12}O_{19}$ nanoparticles in rubber matrix for both A and B samples. As shown in Fig. 2A, these magnetic particles are irregularly dispersed in rubber matrix without treatment of magnetic field. Contrarily, these magnetic particles are dispersed in rubber matrix at regular