Research on the damping properties of Fe$_{12}$O$_{19}$Sr/the polyurethane elastomer composite

Y Li, Yan Qin¹, P C Sun and Z X Huang

Key Laboratory of Advanced Technology for Specially Functional Materials Ministry of Education, Institute of Materials Science and Engineering, Wuhan University of Technology, Wuhan Hubei, 430070, China

E-mail: qinrock@sina.com

Abstract. Magnetic elastomer composite is a promising damping material. In this paper, both strontium ferrite (Fe$_{12}$O$_{19}$Sr) powders and polyurethane elastomer which were mixed by mechanical blending method were used as the magnetic filler and as the matrix respectively, the properties of the magnetic damping composite materials were studied. The results show that the magnetic properties of the magnetic elastomers composite are enhanced with the ferrite loading. The mechanical properties and Shore hardness are highly influenced by mass fraction of ferrite particles. The damping properties of magnetic elastomer composite reach best when the strontium ferrite loading is 15phr, and the damping properties deteriorate when the loading continue increasing. The damping properties of the composites with the X direction of magnetization are better than that with Y direction of magnetization.

1. Introduction

Damping materials are functional ones, which can absorb mechanical vibration energy and change vibration energy into heat[1]. Among the damping materials, magnetic elastomers material as a high-performance damping material is highly valued [2]. The magnetic damping mechanism is magnetic hysteresis; magnetic domains play irreversible movement under alternating stress, so the mechanical vibration energy change into heat energy and then dissipate [3]. It can play the role of elastic damping of ordinary elastomers, while interconversion of elastic magnetic energy can also generate magnetic-mechanical coupling damping, so the magnetic elastomers composite has effective damping function[4]. Chinese researchers have also started a study on magnetic damping elastomers, but the products have a certain gap compared with similar foreign products in magnetic properties and damping performances and other aspects[5].

Therefore, this article intends to adopt polyurethane elastomers as the matrix, strontium ferrite powders as a functional body, and to study a new high-performance magnetic damping composites by adding different strontium ferrite loading ratios.
2. Experimental

2.1 Materials
All materials were used as received. Polyurethane elastomers were purchased from Ausbond (China) Co., Ltd. Strontium ferrite powders (Fe$_{12}$O$_{19}$Sr) are from Wuhan Xinda Magnetic Materials CO., LTD.

2.2 Sample preparation
The strontium ferrite loading is 5phr, 15phr, 25phr, 30phr respectively. The strontium ferrite and polyurethane elastomers were blended by pre-mixer at the temperature of 25°C for 5 mins, then transferred to a kneader, kneaded 15mins at 25°C, removed and placed in the mold then the mixture was cured in the oven at the temperature of 70°C for 3 hours.

2.3 Characterization
The mechanical properties and Shore hardness were measured by RGM 4100 type universal testing machine and TH200 Shore A hardness tester. The dynamic mechanical performances were obtained in shear mode by using the STDA 861e dynamic mechanical analyzer (DMA) at the frequency of 10Hz, at the temperature ranging from -80°C to +120°C, as well as the heating rate being 4°C/min. The magnetic properties were tested under the condition of 1TGS for 20mins at the temperature of 25°C by using JDAW-2000B-type vibrating sample magnetometer (VSM), and the VSM samples were the same as the DMA samples, both were small and round whose diameter was 6.60mm and thickness was 5.00mm. The set up used for these measurements can be seen in the Figure. 1.

(a) universal testing machine (b) dynamic mechanical analyzer (c) vibrating sample magnetometer

Figure. 1. Set up used for these measurements

3. Results and Discussion

3.1 Magnetic properties of magnetic elastomer composite
Figure.2 shows the hysteresis loops for magnetic elastomer composites with a function of ferrite content. With the addition of strontium ferrite, the coercivity of magnetic elastomers composite remain unchanged, and remanence enhances accordingly. Strontium ferrite is hard magnetic powder, whose remanence, saturation magnetization and coercivity are higher than that of other ferrites. As can be seen from Figure.2, the hysteresis loop of strontium ferrite is broad, and performs strong anti-demagnetization.
The variation of coercive force $H_c$ and saturation magnetization $B_r$ of magnetic elastomers composite with a function of ferrite content are shown in Figure 3. When the magnetic powder loading is small, the interaction between the magnetic powder particles is not active, so coercive force $H_c$ of the composite is basically unchanged. Saturation magnetization $B_r$ is determined by the ferrite mass fraction, thus, saturation magnetization $B_r$ enhances with the increasing of ferrite mass fraction.

![Figure 2: Hysteresis loops for magnetic elastomers composite with a function of ferrite content](image2)

![Figure 3: Coercive force $H_c$ and saturation magnetization $B_r$ with a function of ferrite content](image3)

3.2 The mechanical properties of magnetic elastomer composite

The mechanical properties of magnetic elastomers composites are strongly influenced by magnetic filler and the polymer matrix properties, such as the type, size, shape, dispersion and loading of magnetic filler, as well as the interfacial bonding between the ferrite and the matrix [6].

The variations of elongation at break and tensile strength of magnetic elastomers composite as the function of ferrite loading are shown in Figure 4. The tensile strength of the magnetic elastomers composite deteriorates with the addition of ferrite. The tensile strength of pure polyurethane is 3.18MPa, when the ferrite loading is 30phr, while the tensile strength of the composite is down to 1.3MPa. This is because that the interface of magnetic powder – elastomer increase with increasing ferrite loading, the interactions between the strontium ferrite and polyurethane matrix is inferior, and the gap between filler and matrix also leads to a decline in tensile strength. With the increase of ferrite loading, the elongation at break of composite decrease. The elongation at break of pure polyurethane is 920.53%, when the ferrite loading is 30phr, whereas the elongation at break is only 446.32%. The increasing of ferrite loading leads to the decreasing of the relative density of polymer matrix in composite, which makes the elongation at break decrease.

The variation of Shore A hardness of magnetic elastomers composite as the function of ferrite loading is shown in Figure 5. We can find that the Shore A hardness of pure polyurethane is 30, and the Shore A hardness of composite gradually increase with the increase of ferrite loading. This is because the hardness of strontium ferrite is higher than that of the polyurethane, ferrite particles effectively fill the hole of the polymer matrix on one hand, on the other hand, rigid particles are uniformly dispersed in a resin matrix, the material can lead to crazing when subjected to damage, thus consuming a large amount of impact energy and better withstanding the external stress [7].
3.3 The damping properties of magnetic elastomer composite

The relationship between temperature and tan δ of magnetic elastomers composites with different content of strontium ferrite powder loading is presented in Figure 6. When temperature increases, the damping factor of the magnetic elastomers gradually enhances. Glass transition temperature of magnetic elastomers is -45°C, while the damping factor increases dramatically with rising temperature. The damping factor reaches a maximum at -15°C and then fall. When temperature exceeds 85°C, the damping factor is reduced to about 0.08 and substantially unchanged, and we can see the characteristic temperature of the polyurethane elastomer is not affected by the loading of strontium ferrite powders. The operating temperature of magnetic elastomers is determined by the matrix.

The maximum damping factor of the magnetic elastomers is shown in Table 1. Both Viscoelastic damping and magnetic damping contribute to the damping property of magnetic elastomers. When the ferrite loading rises, magnetic damping is greater than that under the condition of increasing amount of viscoelastic damping, therefore the whole damping properties of the composite are improved, and reach their best at the loading of 15phr. When the content of magnetic powders continues increasing, it
could, on one hand, not only enhance magnetic damping property of the composite, but also increases the proportion of the magnetic powder in the matrix, on the other hand, decreases the volume ratios of polyurethane matrix occupying in the same volume of composites, which results in deterioration of the viscoelastic damping property of magnetic elastomer composites. In addition, the improvement of magnetic damping is insufficient to compensate for the decline of viscoelastic damping, which in return, leads to the decrease of damping properties of the composite.

![Figure 6](image_url)

**Figure 6.** tanδ-T curves of magnetic elastomers with a function of ferrite content

| Ingredient          | polyurethane | 5phr | 15phr | 25phr | 30phr |
|---------------------|--------------|------|-------|-------|-------|
| (tan δ)_{max}       | 1.51         | 1.68 | 1.72  | 1.45  | 1.37  |

### 3.4 The damping properties analysis of composites with different directions of magnetization

The samples of composites with different ferrite loading were characterized by DMA, and the magnetic field of 1 TGS was exerted in different directions. It can be seen in the Figure 7.

![Figure 7](image_url)

**Figure 7.** different directions of magnetization
Figure. 8. \( \tan \delta - T \) curves of magnetic elastomers with X and Y magnetization direction

In Figure. 8 (a) we can see that the max \( \tan \delta \) value of the sample which is given the magnetization of X direction is higher than the sample given the magnetization of Y direction; it also can be seen in Figure. 8 (b). When the loss factor of the sample is tested in the shear mode, the direction of the force goes along the X direction, so it means the external magnetic field in different directions affects different stress. The changes in the macro magnetic field, the vortex formation, the reversible and irreversible movement of the domain walls, all these are different from each other leading to the little changes of the loss factor in the X and Y magnetization direction, which may play a role in practical applications.

4. Conclusions
- With the addition of strontium ferrite, the coercivity of magnetic elastomers composite remain unchanged, while remanence enhances accordingly. Thus the magnetic properties of the composite improve.
- The elongation at break and tensile strength of the magnetic elastomers composite decrease with the increasing ferrite loading, but the Shore A hardness increase oppositely.
- With the increase of the strontium ferrite, the damping properties enhance accordingly, when the ferrite loading is 15phr, and the damping properties of the composite have the best performance, while when the ferrite loading continues increasing, the damping properties deteriorate.
- Given the different direction of magnetization, the damping properties of the composites with the X direction of magnetization are better than that with Y direction of magnetization.

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