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PREPARATION AND PERFORMANCE STUDY OF MAGNETORHEOLOGICAL (MR) FOAM

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Porous material performs good deformation compression and has been widely used in soft actuators and sensors. In this study, a new kind of magnetorheological (MR) sponge was prepared by combining carbonyl iron particles with polyurethane porous structure. The static compressive property of MR foam was studied using a commercial rheometer. The relationship between magnetic particle composition, magnetic field and rheological properties was summarized and analyzed. The research contributes to a deeper understanding of magnetorheological sponge materials, and provides inspiration and theoretical basis for the design of soft actuators ,which may provide inspiration for novel application field.

Keywords: polyurethane; magnetorheological foam; scanning electron microscopy; magnetic properties; mechanical properties

INTRODUCTION

Soft matter refers to all complex substances between solids and ideal fluids, generally composed of macromolecules or groups (solid, liquid, gas), such as liquid crystals, polymers, films, foams, surfactants, colloids, particulate matter, biological macromolecules, biological tissues [1,2]. With the advanced research on soft matter, complex rheological behavior tends to play an increasing role in the solution to technical challenges in some frontier field, Such as the application of flexible electronic devices such as liquid crystals, biomedical research, 4 D printing and other aspects. Among the viscoelastic soft materials, porous polymer materials are attracting increasing attention because of their light weight, excellent elastic properties, ability to absorb or accommodate other medium, and low preparation costs [3]. In particular, its high compression set capability meets the demand for high-performance soft actuators, which can be applied to a variety of complex situations with design innovations in software grippers, mobile platforms and other soft- ware structures.

Magnetorheological elastomers can be dividedinto many kinds according to the different substrates and magnetic particles [4].Magnetorheo-

logical elastomers were first prepared by RIgbi[5] and others by adding ferromagnetic particles to natural rubber. Bossis [6] added different content of ferromagnetic particles to the silicone rubber matrix and applied a pre-structured magnetic field to study the properties, and the results showed that the rheological effect increased linearly with the increase of ferromagnetic particle content. Chen [7] studied the internal particle microstructure of MRE and measured the corresponding shear modulus and found that the magnetorheological elastomer has the largest magnetorheological effect and less deformation in the shear mode.

Although the magnetic elastomer has excellent characteristics, there is always a problem of unstable material properties and difficulty in improving the magnetic properties and mechanical properties at the same time, which is caused by the poor dispersion of magnetic particles in the elastomer and serious agglomeration. Starting from the preparation process of magnetorheological elastomer [8,9], this paper combines the microstructure observation of magnetoelastomer, mechanical properties and magnetic properties to improve the dispersion of magnetic particles in the elastic matrix and further optimize the performance of magnetoelastomers.

MATERIALS AND METHOD

Magnetorheological sponge is prepared by combining carbonyl iron powder magnetic particles with a low-density (PU) sponge elastic matrix using a silane coupling agent. Principles of magnetorheo-logical sponge synthesis is shown in Figure 1.

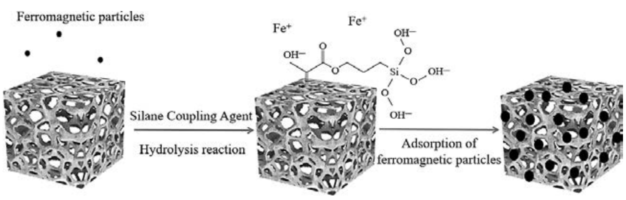

Figure 1 Principles of magnetorheological sponge synthesis

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The carbonyl iron particles (CIPs) adopted in this study were purchased from Jikang material Corporation, Hangzhou, China, with an average diameter of 10 μm. The silane coupling agent (SCA) is of KH-570 type produced by Macklin Biochemical Technology Corporation, Shanghai, China. The matrix of the foam was a commercial soft polyurethane (PU) foam supplied from Paojia, China.

Firstly, a precursor suspension was prepared by mixing CIPs deionized water together according to specific volume fraction. The calculation of particle quantity was based on the density of its bulk state and its expected volume fraction. The volume fraction of SCA was chosen as 1 % to make reliable connection between CIPs and PU foam. The precursor was stirred under a mechanical agitator at a speed of 500 rpm for 30 min.

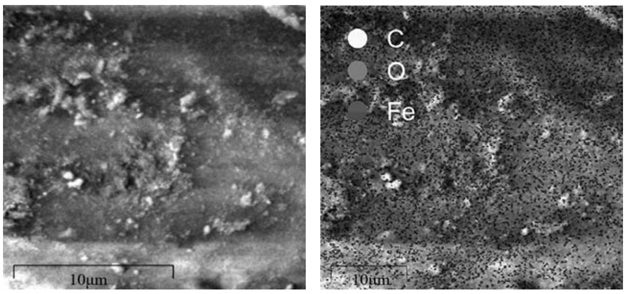
Secondly, the PU foam was soaked in the precursor and the mixture was treated by ultrasonic waves for 5 hours. With the help of ultrasonic vibration, the CIPs move into the micropores of the foam matrix and further connect to the PU framework with the aid of SCA.

Finally, the CIPs coated PU foam was dried in the oven at 80 °C for 4 hours. During the process, the connection between CIPs and PU framework become firmer. As shown in Table 1:

Table 1 **Magnetic liquid composition ratio**

Sample serial number	GIPs /*vol %*	Deionized Water /*vol %*	OMBT / *vol %*
1	5	94	1
2	15	84	1

Morphological observation of magnetorheo- logical elastomers was performed using electron microscopes, as shown in Figures 2 a and 2 b.



(a) – Electronically scanned structural drawing;
(b) – Optical microscope scanning.

Figure 2 Scanning Electron Microscope

The carbonyl iron particles were uniformly distributed in the pores of the sponge, and there was no obvious particle agglomeration, and the corresponding energy spectrum mapping diagram and data table further proved that the Fe element was evenly dispersed on the sponge, and the bonding effect with the sponge was good.

The magnetization properties of the MR foam was measured under a BKT-4500 vibrating sample magnetometer (VSM), as shown in Figures 3 a and b. As a whole, the MR foam shows a ferromagnetic nature due

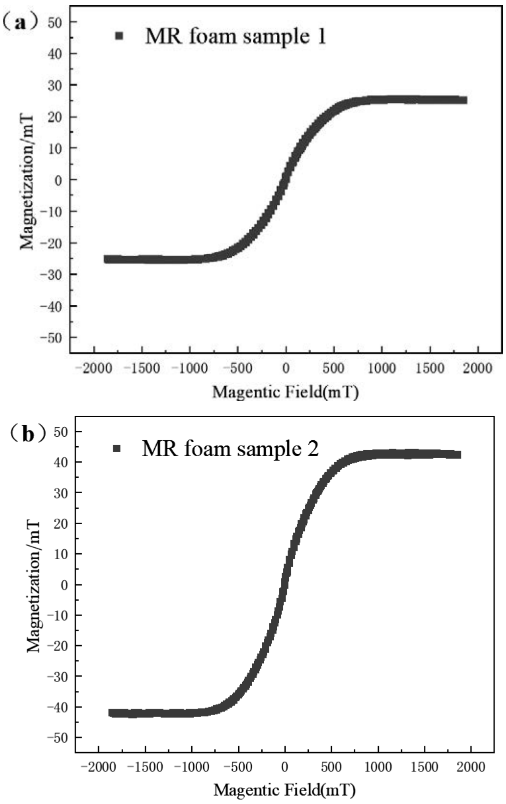


Figure 3 Magnetization curve

to the presence of CIPs on its surface as well as inside its cores. From the magnetization curves, under 500 mT, the magnetization of sample 1 is 23,7 mT, which reaches 85,37 % of the saturation magnetization value, the magnetization of sample 2 is 40,1 mT, which reaches 86,23 % of the saturation magnetization value. Both samples have good magnetization characteristics, and sample 2 has better magnetization characteristics.

MECHANICAL PROPERTIES MEASUREMENT

A commercial rheometer (Physica MCR 302, Anton Paar Co, Austria) was adoptesdd to exert precise compression on the MR foams and measure the normal force provides by its viscoelastic properties. A solenoid coil with 8 000 turns was set around the mea-suring area, dwhich can provide a magnetic field up to 0.3 T along the vertical direction. A schematic representation on the measurement is shown in Figure 4:

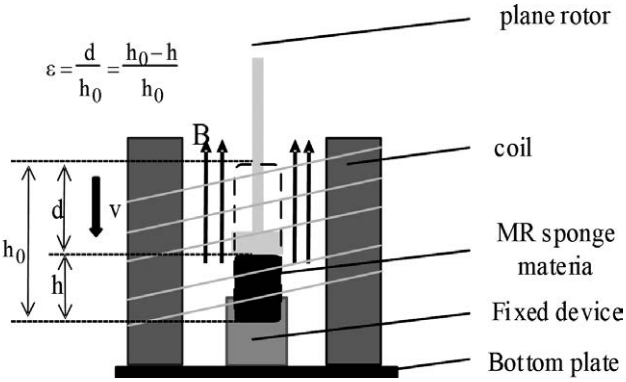
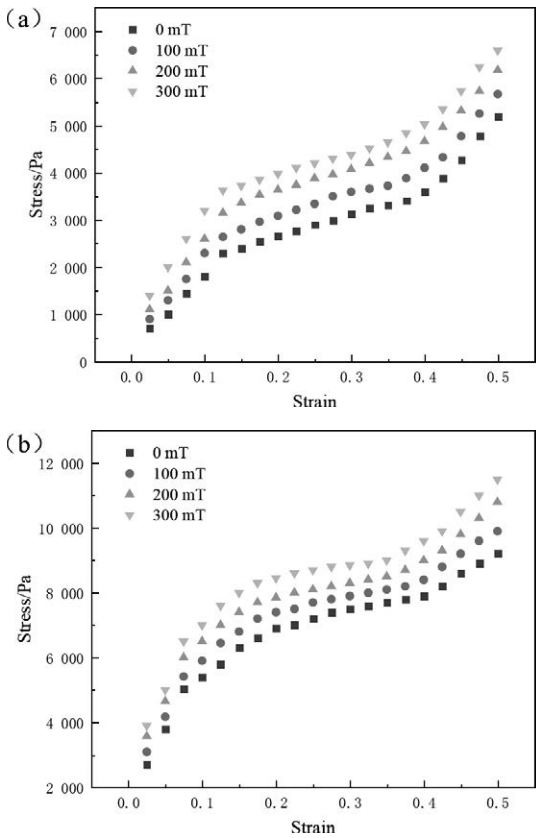


Figure 4 Schematic representation on the measurement

MECHANICAL ANALYSIS OF SPONGES

The two kinds of MR sponges were subjected to static mechanical compression experiments at a strain rate of 0,001 s^{-1}. MR sponge exhibits complex mechanical behavior under external magnetic field strength and load pressure, Stress-strain relationship of MR sponge under different magnetic fields shown in Figures 5 a and b.



(a) – sample 1; (b) – sample 2.

Figure 5 Stress-strain relationship of MR sponge under different magnetic fields

The variation trend of its stress-strain curve is basically the same, and can generally be divided into three stages: linear elastic stage, instability stage and nonlinear densification.

When the strain range of MR sponge is 0,1~0,15, it is in the linear elastic stage. Due to the compression and stretching of the porous structure inside the MR sponge, as well as the anisotropic flux compression combined with ferromagnetic particles, the stress gradually changes with increasing strain, which is roughly linear. When the strain range of MR sponge is 0,15~0,3, it is in the instability stage. Plastic defor-mation and buckling of the porous structure inside the MR sponge, this manifests as a small stress change that can result in significant strain, and the stress change is slow at this stage. When the strain range of MR sponge is 0,3~0,5, it is in the third stage. The porous tissue compacts with each other within the MR sponge, leading to a significant increase in stress.

At the same time, the strength of the magnetic field where the MR sponge is located increases, the stress of MR increases under the same strain and the rate of increase increases. This is related to the magnetization of ferromagnetic particles to produce various anisotropic structures. Comparing two types of samples, under the same conditions, MR sponge with a large proportion of internal carbonyl iron has a faster rate of stress increase and a higher Young’s modulus.

CONCLUSION

In this study, a novel magnetorheological (MR) foam was prepared. When MR foams are loaded under the action of magnetic field, there are three stages: elastic stage, instability stage and nonlinear densification. The applied magnetic field increase the elastic deformation of MR foam, and the Young’s modulus also increases with the proportion of carbonyl iron particles in MR foam. The study contributes to a deeper understanding of MR foam, which may provide inspiration for novel soft robotic forms.

REFERENCES

[1] Nagel S R. Experimental soft-matter science [J]. Reviews of modern physics 89 (2017) 2,025002.
[2] De Gennes P G. Soft matter [J]. Science 1992,256 (5056),495-497.
[3] M. E. Davis, “Ordered porous materials for emerging applications,” Nature 417 (2002) ,813-821.
[4] Kuznetsova I E, Kolesov V V, Zaitsev B D, et al. Electrophysical and acoustic properties of magnetic elastomers structured by an external magnetic field[J]. Bulletin of the Russian Academy of Sciences, Physics 81 (2013) 945-949.
[5] Bastola A K, Hossain M. A review on magneto-mechanical characterizations of magnetorheological elastomers [J]. Composites Part B: Engineering 200 (2020), 108348.
[6] Runov V V, Bugrov A N, Smyslov R Y, et al. Mesostructure of composite materials based on segmented poly (urethane imide) containing ferrite nanoparticles [J]. Russian Journal of Inorganic Chemistry 66 (2021), 225-236.
[7] Yan X, Hu M, Liu J, et al. Compressible metalized soft magnetic sponges with tailorable electrical and magnetic properties [J]. ChemNanoMat 6 (2020) 2,316-325.
[8] Maslowski M, Miedzianowska J, Strzelec K. Reinforced, extruded, isotropic magnetic elastomer composites: Fabrication and properties [J]. Advances in Polymer Technology 2019 (2019).
[9] Zhu D, Handschuh-Wang S, Zhou X. Recent progress in fabrication and application of polydimethylsiloxane sponges [J]. Journal of Materials Chemistry A 5 (2017) 32, 16467-16497.

Note: The responsible translator for English language is J.L. Miao - North China University of Science and Technology, China