Research Status and Engineering Application of Magnetorheological Elastomers

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Research Status and Engineering Application of Magneto-rheological Elastomers

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Abstract. Magneto-rheological elastomer is a new type of magneto-rheological material characterized by controllable reversibility of rheological properties and very short response time. Moreover, the stability is good and the structure design is simple, so it has broad application prospects in the fields of intelligent vibration reduction and noise reduction, electromagnetic sensors and active control. The research status of magneto-rheological elastomers at home and abroad is introduced systematically, including the mechanical model of magneto-rheological elastomers, magneto-mechanical properties, influencing factors and engineering applications, and several problems that should be further studied in the future are proposed.

1. Introduction

Magneto-rheological Elastomer (MRE) is a new type of magneto-rheological material prepared by dispersing magnetic particles in a solid or gel-like matrix and curing. The magneto-rheological effect of magneto-rheological elastomers is controllable and reversible, and the response speed is very fast.

The magneto-rheological elastomer solves the problem of particle sedimentation stability of magneto-rheological fluid well, and does not require a sealing device, so it brings great convenience to engineering applications. In this paper, the research status and engineering application of magneto-rheological elastomers are reviewed, and several problems that should be studied in depth are proposed.

2. Survey of Magneto-rheological Elastomers

In 1995, T.Shiga of Japan proposed the concept of magneto-rheological elastomers[1], and studied the magnetic viscoelasticity of materials prepared by mixing silicone and iron powder.Subsequently, Jolly of the US Lord Company developed a silicone rubber-based magneto-rheological elastomer, and found that the shear modulus of the elastomer[2] increased by about 40% compared with the original under the action of an external magnetic field. Ford's Ginder[3] studied the viscoelastic properties and applications of natural rubber-based magneto-rheological elastomers[4], and designed a controllable stiffness automotive bushing based on magneto-rheological elastomers and adjustable vibration absorbers. Davis[5] found that the optimum volume ratio of the particles was 27%, and the relative change in the shear modulus of the magnetic saturation of the particles was about 50%[6]. France's Bossis[7] studies the electrical and magnetic properties of electromagnetic rheological elastomers. France's Bossis studies the electrical and magnetic properties of magneto-rheological elastomers. Bednarek[8] of Poland studied the magnetostrictive properties of magneto-rheological elastomers. Swedish Lokander studied the effects of different substrates on the properties of magneto-rheological elastomers[9]. Canada's Y.Shen studied magneto-rheological elastomers of polyurethane and natural rubber. Their shear modulus increased by 28%[10] .

The University of Science and Technology of China has carried out material selection, preparation process, physical model, test method and application research of magneto-rheological elastomers, and the magneto-rheological elastomers developed by them have a relative magneto-rheological effect of more than 500%.

3. Mechanical model of magneto-rheological elastomer

When the magneto-rheological elastomer is solidified under a magnetic field, the particles are aggregated into a chain, column or layer structure in the matrix to obtain an anisotropic material called a prestructured magneto-rheological elastomer. At present, the mechanical model of the magnetization effect of pre-structured magneto-rheological elastomers is mainly studied.

Generally, the magnetic charge is used to treat the magnetic particles in the magneto-rheological elastomer as a magnetic dipole. The total magnetic energy and magnetic energy density inside the material are calculated, and then the relationship between the magnetic energy density and the material deformation is used to solve the material.

Jolly studied magneto-rheological elastomers in which particles aggregated into a chain structure after solidification. Obtaining a magnetic shear modulus.

$$G \cong \frac{\phi J^2{}_{\mathrm{p}}}{2\mu_1\mu_0 \mathrm{h}^3} \qquad \gamma < 0.1 \qquad (1)$$

In the formula：ϕ -Volume fraction of particles

h-Ratio of particle spacing to particle diameter

μ_0 -Vacuum permeability

μ_1 -Magnetic permeability of the substrate

J_{p} -Magnetization of particles

It can be seen that the magneto-induced shear modulus of the magneto-rheological elastomer is related to the applied magnetic field, the size, spacing and volume fraction of the magnetic particles. From the perspective of material design, the use of particles with large particle size and high saturation magnetization to reduce the particle spacing and increase the volume fraction of the particles can improve the magnetic shear modulus. From the application point of view, increasing the applied magnetic field can increase the magnetic shear modulus.

Y.SHEN based on the local field effect, that is, the particles will generate an additional magnetic field after being magnetized under the external field, and the two together act to cause the magnetization of the particles. Obtaining a magnetic shear modulus：

$$\Delta G = \frac{9}{8}\frac{\Phi C \mathrm{m}^2(4-\gamma^2)}{\mathrm{r}_0{}^3\pi^2\mathrm{a}^3\mu_0\mu_1(1+\gamma^2)^{7/2}} \qquad (2)$$

In the formula：Φ - Volume fraction of particles

m - Magnetic dipole moment of particles

r_0 - Initial spacing between particles

a - Particle radius

μ_0 - Vacuum permeability

μ_1 - Magnetic permeability of the substrate

γ - Shear strain of elastomer

Fang Sheng used the equivalent permeability method to study the mechanical model of the magneto-rheological elastomer of the columnar aggregate structure as shown in Figure 1. The model considers that the magnetic shear stress generated by the magnetic field is caused by the change of the magnetic permeability of the magneto-rheological elastomer after the deformation of the material.

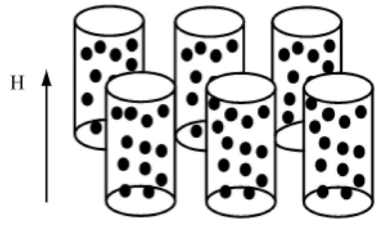

Figure 1. Schematic of the column structure

By calculating the magnetic permeability in the axial and radial directions of the columnar structure, the magnetic shear modulus at small strain is obtained.

$$G = \mu_0 \left[\frac{H}{1+\chi_{//}} \right]^2 (\chi_{//} - \chi_{\perp}) \tag{3}$$

In the formula：H - Applied magnetic field

$\chi_{//}$ - Magnetic permeability of the columnar structure in the axial direction

$\chi_{\perp}$ - Magnetic permeability of the columnar structure in the radial direction

ZHU yingshun.and DANG hui.established a modified mechanical model of a chain or columnar magneto-rheological elastomer. These models can effectively explain the influencing factors of magneto-rheological properties of magneto-rheological elastomers, and approximate the magnitude of magneto-modulus. However, most models do not consider the properties of the matrix material, the preparation process, the interaction between the matrix deformation energy and the particle magnetic energy. In addition, for the case where the particle spacing is small, it is necessary to consider the particle nonlinear magnetic, Problems such as the relationship between the magnetic dipole moment and the external field.

4. Magneto-mechanical properties of magneto-rheological elastomers

Magneto-rheological elastomers have the characteristics of magneto-rheological materials and elastomer materials. In addition to the conventional mechanical properties, magneto-rheological elastomers are an important indicator of magnetic mechanical properties, which directly determines the application range and application effect of materials[11-12].

Marke studied the dynamic mechanical properties of prestructured magneto-rheological elastomers under compression and the applied magnetic field.The results show that the dynamic stiffness and loss factor of the magneto-rheological elastomer increase with the increase of the magnetic field strength. When the external field is constant, the dynamic stiffness increases with increasing frequency, which is the same as that of a conventional elastomer, while the loss factor is larger at lower frequencies. As the strain amplitude increases, the magnetic modulus decreases and the loss factor changes little.

Jung and Jolly used a two-layer elastic shear model to study the mechanical properties of silicone rubber magneto-rheological elastomers in shear mode. Jung et al. obtained that the magneto-rheological effect of the magneto-rheological elastomer increases with the increase of the magnetic field strength and the loading frequency, and the elastic modulus of the precompressed magneto-rheological elastomer is larger than that without precompression, Similar to the extrusion enhancement effect of magneto-rheological fluids. Jolly found that the elastic modulus of magneto-rheological elastomers decreases with increasing strain amplitude, while the loss factor increases.

Zhang Xianzhou and Fang Sheng of Zhongke University used the method of solving the transfer function in the frequency domain of the system to analyze the vibration characteristics of the silicone rubber elastomer under different magnetic field strengths. It is concluded that the shear modulus increases with the increase of the magnetic field until it reaches The magnetic saturation state, while

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the loss factor does not change much. Zhou Gangyi tested the shear storage modulus and loss factor of silicone rubber-based magneto-rheological elastomers by free response method. Experiments show that the shear modulus of the magneto-rheological elastomer increases with the increase of the magnetic field until the magnetic saturation, and the shear modulus changes up to 60%, and the loss factor decreases extremely slowly with the increase of the magnetic field.

Li coated the carbonyl iron powder with polymethy methacrylate and found that it can effectively increase the storage modulus of the magneto-rheological elastomer and help to improve the bonding strength between the particles and the matrix. Yao Jingjing also found that the surface modifier can promote the formation of self-assembled structure of ferromagnetic particles, which is beneficial to improve the magneto-rheological effect.

In general, the research on the magneto-mechanical properties of magneto-rheological elastomers has made breakthroughs, but the results are not completely consistent. On the one hand, At present, there is no uniform test standard and test method ; on the other hand, when the traditional test method is used, there are different degrees of coupling between the added magnetic field generating device and the test device, and the test results are often different.

5. Engineering application of magneto-rheological elastomer

The viscoelastic properties of magneto-rheological elastomers under magnetic fields can vary widely and can be used in the design of various controllable stiffness or damping devices. At present, magneto-rheological elastomers have been successfully applied in the field of vibration and noise reduction, such as suspension systems, bushings, and vibration absorbers, showing broad application prospects.

5.1. Magneto-rheological elastomer dampe

It is reported that the current American AMAD company developed a magneto-rheological elastomer damper for the naval submarine underwater weapon launching system as shown in Figure2. The stiffness characteristics of the magneto-rheological elastomer damper can be increased by about 60% within 1 millisecond, and it has good impact isolation effect on external impact loads. When the external control system fails, it can be regarded as a passive protection device with the function of safety insurance. The device is currently expected to be used in SSGN weapon launch protection systems.

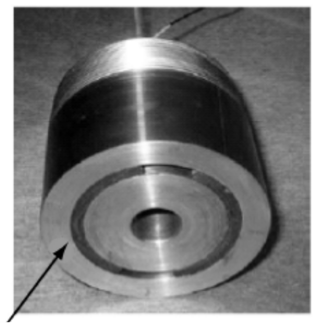

Figure 2. MRE tuned vibration absorber

5.2. Variable stiffness bushing

Watson et al. developed a variable stiffness bushing for automotive suspensions as shown in Figure3. The magneto-rheological elastomer is located between the inner and outer sleeves of the bushing, and the mechanical properties of the magneto-rheological elastomer are changed by controlling the current inside the coil to change the strength of the magnetic field. The experimental results show that the radial stiffness and axial stiffness of the bushing are controllable, and the response time is only a few milliseconds.

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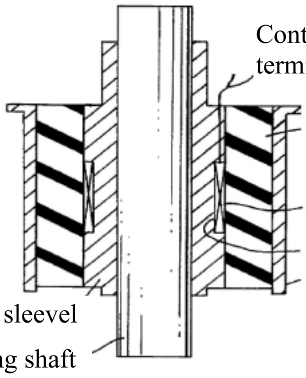

Figure 3. Schematic of a prototype bushing

5.3. Adjustable vibration absorber

Ginder et al. designed an adjustable vibration absorber based on magneto-rheological elastomer. By changing the magnetic field, the resonance frequency of the vibration absorber is shifted, so that it has good vibration damping effect in a wide frequency band. Deng Huaxia et al. developed a frequency-modulated semi-active vibration absorber as shown in Figure4.

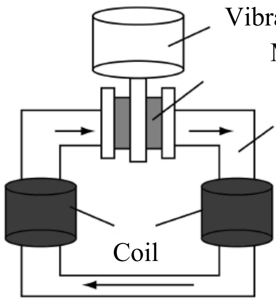

Figure4. Schematic of the tuned vibration absorber

Experiments show that the vibration absorber has a certain frequency modulation capability, wide vibration absorption bandwidth and good vibration damping effect.

6. Exhibition

At present, magneto-rheological elastomers have received more and more attention at home and abroad for their broad application prospects. At the same time, we also see that there is still a certain gap between the material properties of magneto-rheological elastomers and practical applications, and many application studies are only ideas. Therefore, in-depth research on magneto-rheological elastomers is needed.

(1)Research on high performance magneto-rheological elastomers. The magneto-rheological elastomers currently developed are all added to the matrix. The magneto-rheological effect of the magneto-rheological elastomer prepared by this method is not very large, and the mechanical properties such as tensile, compression and tear of the material are reduced. Large, and in order to improve the magnetic effect, usually use a softer matrix material, which results in a certain gap between the performance of the magneto-rheological elastomer produced and the actual engineering application. Therefore, in the design of magneto-rheological elastomers, not only should new technologies be used to improve the magnetic permeability and saturation magnetization of magnetic particles, but also new preparation processes should be studied to improve the bond between the matrix and the magnetic particles. The magnetic effect does not degrade the mechanical properties of the material.

(2)Study on the rheological mechanism of magneto-rheological elastomers. The structural evolution of the magneto-rheological elastomer under the coupled field, the conversion between magnetic energy and material strain energy needs further study. In the mechanical model analysis, factors such as matrix material properties and particle nonlinear magnetization need to be considered.

(3)Research on magneto-rheological elastomer testing methods. At present, most of the test methods for magneto-rheological elastomers do not consider the coupling between test devices, and the test results are often different. Therefore, it is important to establish a precise test method.

(4)Applied research of magneto-rheological elastomers. Various variable stiffness and variable damping devices can be developed using the magneto-mechanical properties of magneto-rheological elastomers. The magneto-strictive performance can be used for active control, and its magnetro resistance characteristics and strain characteristics can be used for sensor elements and the like.

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