Pressure-sensitive conductivity of Magnetorheological Elastomers

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Abstract

The electrical conductivity of the magnetorheological elastomers(MREs) is affected by viscoelastic. A kind of MREs conductivity test components was designed based on the reliability of components of the MREs conductivity. Further we designed the test device for the entire electrical conductivity device. Experimental results showed that the stability test of the electric conductivity can be achieved by using this device and the influence of pressure- sensitive is very obvious. Under the action of an external pressure, the flowing current and applied on the sample voltage is nonlinear relationship. Under the same voltage, the change of electric current depended on the change of pressure through the test data analysis.

Keywords

Magnetorheological Elastormer; Conductive element; Test device; Electrical conductivity; Pressure-sensitive.

1. Introduction

Magnetorheological Elastomers (MREs) are composites of micron sized soft magnetic particles in non-magnetic polymer matrix. The magnetically permeable particles are mixed into the liquid precursors of polymers, and the mixture vulcanizes in the presence of the magnetic field until the vulcanization is finished. The particles align themselves in the direction of the magnetic field by field-induced antiparticle interaction and then chainlike structure is formed and fixed in the matrix [1]. Not only elastic modulus but also electromagnetic properties of MREs can be controlled by an external magnetic field [2]. Furthermore, MREs are electrically conducting composites because the fillers are conducting materials. It is expected to obtain high conductivity composites with a low volume fraction of fillers because of the standardization of filler particles.

The direction of the conductive path of MREs is along the chain structure and results in anisotropic conductivity. The conductivity in this direction is maximum and regarded as the conductivity of MREs generally. The total current flowing through an MRE is the sum of tunnel current and conduction current [3]. The dependence of conductivity of MREs on external electric intensity is nonlinear [4]. The conductivity varies with external loads, such as force and magnetic field. The intrinsic mechanism of the variation is that the interaction force between adjacent particles in particle chains varies when MREs are subjected to external loads.

In this study, we investigated the effect of viscoelasticity of matrix on conductivity of MREs subjected to a varying force, and we measured conductivity of MREs under constant velocity stress. A new model for low particle volume fraction MREs with a high conductivity has been established and verified.

2. Theory

MREs have a very important property of electrical conductivity and pressure- sensitivity [5]. The electrical conductivity of MREs is dependent on the changes of the external load and the deformation of the particles in a particle chain [6]. The load caused by the deformation of the particles in MREs is not equal to the force between two neighboring particles in a particle chain is a variable over time. When a load applied to MREs, the viscoelasticity of the matrix will cause the attenuation of the compressive load and the deformation of the particles. In addition, under the action of external load, the deformation of the particle chain will result in the increase of pressure on the non deformed surface of the particles, so as to reduce the effective load of the deformation of the particles.

In conclusion, there is a steady load in MREs, when the MREs is subjected to the action of the external load. Consider the external load make MREs in compression and pressure releasing process, here, the effective load of particle deformation is

$$\sigma_{eff}(t) = \sigma(0) + \sigma - \sigma_{re}(t) \pm \sigma_{ad}(t) \quad (1)$$

Here, σ is the external load, $\sigma(0)$ is a steady load in MREs, $\sigma_{re}(t)$ is equivalent load acting on non deformable surfaces, $\sigma_{ad}(t)$ is equivalent additional load for deformation of the particle chain. The minus sign is the compression process, the release process is plus. Considering the relaxation time and delay time of additional load, this is converted to the variation law of effective load under the instantaneous load

$$\sigma_{eff}(t) = \sigma(0) + \left[1 - \exp\left(-\frac{t}{\tau}\right)\right]\sigma \pm \frac{[\sigma(0)+\sigma]\tau_1}{\sigma_c(\tau_2-\tau_1)}\left[\exp\left(-\frac{t}{\tau_2}\right) - \exp\left(-\frac{t}{\tau_1}\right)\right]\sigma \quad (2)$$

Where, $\tau1$ is the relaxation time, $\tau2$ is the delay time.

Therefore, the viscoelasticity of the matrix is consistent with the principle of Boltzmann superposition according to the above analysis. The complex variable load can be processed according to the principle of Boltzmann superposition. Thus, the effective load under constant velocity stress is

$$\sigma_{eff}(t) = \sigma(0) + k_\sigma \tau \exp\left(-\frac{t}{\tau}\right) \pm k_\sigma \frac{\sigma(0)+k_\sigma t}{\sigma_c}\left\{\tau_1 - \frac{\tau_1}{\tau_2-\tau_1}\left[\tau_2 \exp\left(-\frac{t}{\tau_2}\right) - \tau_1 \exp\left(-\frac{t}{\tau_1}\right)\right]\right\} \quad (3)$$

Here, k_σ is the rate of variation under stress.

3. Experiments

MRE samples were prepared and tested to verify the relationship described by equation (3). In order to obtain an appropriate resistance, a low particle volume fraction of 1% and low magnetic induction of 15 mT was used to prepare the MRE samples [7]. Silicon Rubber (Sylgard 184, Dow Corning) was used as the polymer matrix. Carbony1 iron powder with a diameter of 0.5-6μm (MPS-MRF-35, Jiangsu Tianyi Super Fine Metal Powder Co. Ltd) was used as the ferromagnetic particles, and the average diameter was 3.14 μm. The magnetic rheological elastomer sample was prepared (shown in Fig 1). The microstructure of the longitudinal section of the magnetic rheological elastomer was observed under the vacuum scanning tunneling microscope (shown in Fig 2).

We designed the test device (shown in Fig.3) for the entire electrical conductivity device based on reliability of the conductive element. A test of pressure sensitive characteristic of MREs was carried out by using the device.

Fig 1. MRE

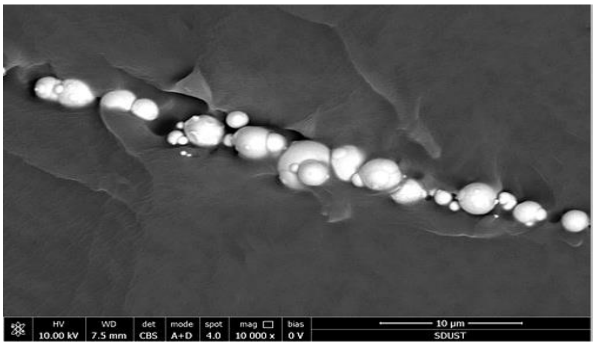

Fig 2. Microstructures of MRE samples

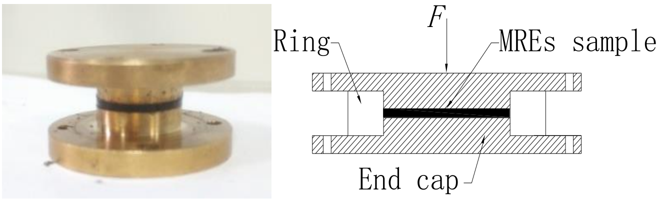

Fig.3 The structure of Conductive Element

The end cap and the MREs sample which are connected together are placed on a press platform which is controlled by the step motor, and the press platform is moving at a constant speed in the experiment. The compressive force during compression was measured by the force sensor and the current was measured by the ammeter. The DC power supply was in the range of 0-32V, and the minimum resolution of the ammeter used was 0.1 nA. The current flowing through the sample was measured under different compressive forces and voltages.

4. Results and discussions

The experimental results show that the current-voltage dependence is significantly nonlinear, as show in Fig.4. The results are analyzed according to the above theoretical model. Fig.4 shows that the theoretical analysis can predict the current dependence on the electric field and compression of the MRE very well. The current increases with increment of voltage when the pressure is constant. A higher current can be obtained when an MRE is compressed by a higher pressure. Tunnel current equals the conduction current at 8.25V, and then exceeds the conduction current when the voltage exceeds 8.25V. Therefore, the main component of the total current is the conduction current when the voltage is lower than 8.25V, while the tunnel current is the main contribution when the voltage is higher than 8.25V.

At the same time, the time-varying current and pressure values of the MREs samples are measured. In pressure loading and releasing cycle, the change of stress was kept constant. The rate of variation under stress is 13.86kPa/s. The current depends on the change of pressure, which is linear with time in the two processes.

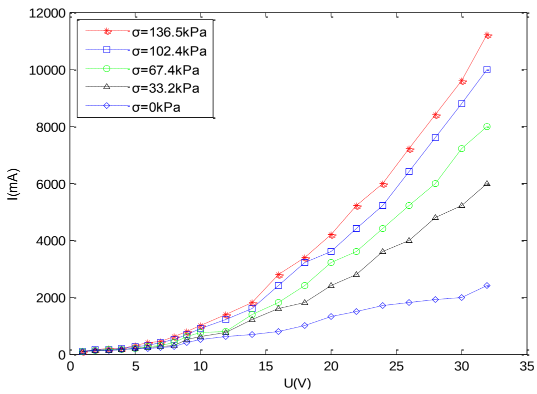

Fig.4 The relationship between voltage and current under different pressures

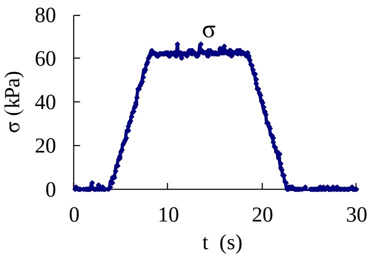

Fig.5 The the effective load changes of MREs in a pressure cycle

Based on the effect of the viscoelasticity of the matrix, the components of the effective load are analyzed. The results are shown in Fig 5. Parameters are used in the fitting process τ=0.3s，τ_1=1s，τ_2=2s.

After many experiments and data analysis, it can be seen that the change of current and pressure is basically synchronous. Illustrated by the changing trend, when the load is released, the current response rate is faster than that of the loading. During the loading phase, the current is affected by the viscoelasticity, and the boundary point is not obvious when the load is abrupt. During the unloading, the change of current is very obvious in the mutation load.

5. Conclusions

Due to the viscoelasticity of the matrix, the effective load of the particles in MREs is a variable with time. Under the influence of the viscoelasticity of the matrix, the response of the current to the load of MREs is basically linear. The current increases with the compressive stress by increasing the effective cross-sectional area. The thickness of the polymer film through which the current flows are thought to be invariant, so the effects of the electric field and compressive stress on the conductivity are non-coupled. A model for the dependence of the conductivity on the electric field and compressive stress is presented. Experimental results agree with the theoretical predictions well. This model is helpful to design MREs with preferable piezoresistivity.

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