DYNAMIC CHARACTERIZATION OF MAGNETORHEOLOGICAL ELASTOMERS IN COMPRESSION MODE

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Characterization of magnetorheological elastomers (MREs) in compression mode is a fundamental step toward designing and modeling of MRE-based vibration control devices. The present study investigates dynamic properties of MREs under different loading conditions including the strain amplitude and magnetic field intensity. A reasonably compact U-I shape electromagnet assembly was designed employing multi-parameter optimization method to achieve the target magnetic flux with minimal overall size and weight. A series of tests were carried out at various strain amplitudes (5 and 20%) and magnetic field intensities (0-750 mT). The measured data were then analyzed to establish effects of strain amplitude and magnetic field intensity on dynamic properties of MREs working in compression mode. The results demonstrated that the viscoelastic properties of the MRE strongly depend on the strain amplitude and applied magnetic field.

Keywords: Magnetorheological elastomers (MREs), Characterization, compression mode

1. Introduction

Magnetorheological elastomer (MRE) is a class of functional intelligent materials, which consists of solid polymeric matrix as well as magnetic particles, and exhibits variable/controllable mechanical properties in response to an external magnetic field. They can be easily fabricated by embedding micrometer-sized magnetizable particles in a rubber-like matrix such as silicone or natural rubber. Applying an external magnetic field results in variations of stiffness and damping properties of the MREs. The response time for these materials is less than a few milliseconds and mostly depends on the viscoelastic properties of the matrix [1]. Regarding their rapid response to the applied magnetic field, the MREs are considered ideal candidates for many engineering applications such as vibration isolator for highway bridges[2], vehicle seat suspensions [3], engine mounts [4], adaptive tuned vibration absorbers (ATVAs) [5], force sensors [6], soft actuator [7], sealing eye retina detachments[8] and artificial lymphatic vessels [9].

Owing to MRE’s attractive potentials, considerable efforts have been made toward their characterizations seeking for guidance on their fabrication and design for different applications. While shear properties of MREs and MRE based devices have been widely investigated [10-13], very limited study has been conducted either theoretically or experimentally on characterization of MREs in tension/compression modes.
The common challenge among all the tension/compression (T/C) mode experiments is basically how to simultaneously impose magnetic field and mechanical force on the MRE samples during the characterization; it is because that not only the mechanical load and magnetic field should be provided in one direction but also neither standard Dynamic Mechanical Analyzer (DMA) machines nor Material Testing System (MTS) machines can provide magnetic fields. In this study dynamic properties of different types of MREs have been investigated experimentally in compression mode. A series of experiments under different strain amplitudes and magnetic flux densities were carried out. The data are plotted into stress-strain hysteresis loops and then physically interpreted to evaluate MRE’s behavior.

2. Experiment

2.1 MRE fabrication

Different kinds of MRE were manufactured in the laboratory with variable contents of the ferromagnetic particles and particle distributions. BASF-SQ spherical carbonyl iron powder (CIP) with the average diameter of 3.9 to 5 μm were poured into the silicone rubber (Eco-Flex Series, Smooth-on) as the matrix material corresponding to the part per hundred rubber (PHR) for each volume fraction. Thereafter, all the ingredients were blended thoroughly in a beaker using an electrical mixer inside a glove box for approximately 5 minutes. The mixture was then degassed in a vacuum chamber for 5 minutes under pressure of -29 in-Hg. The blend was afterward poured in the fabricated cylindrical shape molds made of plexiglass and left for 24hr at laboratory temperature to be cured.

2.2 Test setup

The compression test setup consists of a servo-hydraulic material testing machine (MTS) and a tailor-made UI shape electromagnet device including three winding coils and UI magnetic core as shown in Figure 1. The lower fixture was connected to the actuator and upper fixture was attached to the load cell. Two identical MRE samples were placed between the “U” shape and “I” shape magnetic cores. The controlled displacement was applied from the bottom by a hydraulic actuator and the force was measured using a load cell installed at the upper part of the MTS machine. MRE samples for the compression experiments were bonded to the UI magnetic core using a thin layer of an industrial super glue.

![Figure 1: The schematic of the test setup equipped with the UI shape electromagnet device.](image)

2.3 Testing procedure

A series of compression training set data tests were performed on two identical MRE samples by varying the magnetic flux density and strain amplitude. Magnetic flux densities were varied from $B = 0$ mT to $B = 150, 300, 450, 600$ and $750$ mT by changing the electrical current using a power supplier. The MTS machine was employed to apply a sinusoidal vertical displacement on the two MRE test specimens. The experiments were performed at two strain amplitudes including 5% and 20% at constant frequency...
of 10 Hz. Different hysteresis shapes of stress-strain curves of tested MRE are obtained which are discussed in the next section.

3. Results and discussion

3.1 Hysteresis stress-strain curves

The hysteretic behavior of MREs is attributed to its viscoelastic nature. The energy within a perfectly elastic material is completely recovered when the stress is removed but the viscous contribution, which is produced by internal molecular friction, retards the elastic strain response and energy is dissipated [14-17]. Hysteresis loops of the MRE tested under different level of applied magnetic flux densities are shown in Figure 2 (a) and Figure 2 (b) for strain amplitude of 5% and 20%, respectively. By increasing the strain amplitude, the hysteresis curves change from linear elliptical to nonlinear asymmetric shape. Moreover, Figure 2 illustrates that both the slope and the area of the hysteresis loops, which indicates the equivalent stiffness and damping of MREs, respectively, enhance by increasing the magnetic flux density. The variable stiffness and damping properties offer potential of MREs in numerous engineering applications such as vibration and noise suppression.

4. Conclusion

Dynamic behavior of magnetorheological elastomers under wide range of magnetic flux densities were experimentally investigated. The results were collected in hysteresis stress-strain curves. It was shown that by increasing the magnetic flux density, the slope of major axis and enclosed area of hysteresis loops enhanced. These parameters represent the equivalent stiffness and equivalent damping of MREs, respectively. Moreover, the effect of the strain amplitude on the behavior of the MRE in compression mode was presented. Field dependent stiffness and damping characteristics of MREs can be employed in designing smart adjustable vibration isolators.

REFERENCES