Field Dependent Response of Magnetorheological Elastomers Utilizing Spherical Fe Particles Versus Fe Nanowires

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Abstract. This study compares the dynamic response of nanowire-based magnetorheological elastomers (MREs), to those containing conventional spherical particles. MRE samples were fabricated by curing the iron particle laden elastomeric material in a magnetic field. Material characteristics of the MRE samples were evaluated using a material test machine that was modified to measure static and frequency dependent characteristics of these samples under different magnetic fields. The MRE samples consisted of a silicone rubber matrix containing various weight fractions of iron particles of differing morphology. Nanowires were used to enhance the interaction forces and contact area between particles. The static and dynamic properties of the MREs were evaluated under a compressive load for the various compositions and weight fractions. The stress vs. strain characteristics were measured for each sample. The equivalent damping coefficient of the MRE samples was measured and characterized under magnetic fields of differing intensities. The dynamic characteristic (dynamic stiffness) was measured under sinusoidal excitation in the frequency domain.

1. Introduction

Elastomers are commonly used for passive shock and vibration control. More recently, controllable magnetorheological elastomers (MREs) with varying magnetic fields have attracted great interest [1-3]. MREs are a smart material having static and dynamic properties that can be controlled by varying the intensity of an applied magnetic field. Characteristics of MREs depend on the dispersant volume fraction (or weight fraction or solids loading), dispersant characteristics (such as particle size, composition, and morphology), matrix material, and magnetic field intensity.

Various compositions of MREs have been assessed. For example, iron flakes have been dispersed in a silicone elastomer [1]. MREs have been experimentally shown to have changeable properties with the volume fraction of particles. Magnetostrictive properties of MREs have been presented [2], where irregular carbonyl iron particles with an average size of 5 µm were used. Magnetostriction effects increased with increasing volume fraction. A more recent study examined the properties of MREs consisting of a silicone elastomer matrix containing spherical carbonyl iron (3-5 µm) as the magnetisable filler in which the particles were aligned with an external magnetic field during the curing process [3]. The mechanical properties were examined in a cyclic compressive load with the intensity of magnetic fields in the frequency domain. In this study, the field dependent characteristics
of MREs with two different Fe particle morphologies (spheres and nanowires) were evaluated under static and dynamic (harmonic) excitations. Frequency domain characteristics were evaluated under sinusoidal excitation while maintaining a compressive bias load.

2. Composition of MREs and Experimental Setup

Figure 1 shows photographs of MRE samples. The height and diameter of each MRE sample was 25.4 mm and 9.5 mm as shown in Fig. 1(a). The diameter of the spherical particles ranged from 6-10 µm. The nanowires were 15 µm long with a diameter of 298 ± 40 nm. Magnified images of 10 wt% samples are shown in Fig. 1(b). During curing, a magnetic field was applied to the cylindrical samples using permanent magnets. This resulted in the alignment of the particles in the direction of the applied magnetic field (due to the induced magnetic dipoles of the particles). The aligned particles can be seen in Fig. 1(b). For the sphere-based MREs, particle loadings of 10, 30, 50 and 70 wt% were chosen. In the case of nanowires, particle loadings of 10 and 30 wt% were selected.

The experimental setup is presented in Figs. 2 and 3. The internal temperature of the magnetic cell was monitored with a thermocouple and cooled using an external cooling fan. The MRE sample was installed inside of the magnetic cell as shown in Fig. 3. The upper and lower fixtures are connected to the piston rod and the load cell of the Instron test machine. A Hall probe is used to measure the magnetic flux density which is located on top of the lower fixture.

![Figure 1](image1.png)

**Figure 1.** Photograph of an MRE sample (a) with 10 wt% spherical Fe particles and (b) magnified images of MREs containing 10 wt% spherical and nanowire Fe particles.

![Figure 2](image2.png)

**Figure 2.** Photograph of the experimental setup for static and dynamic testing.

![Figure 3](image3.png)

**Figure 3.** Schematic diagram of the magnetic cell.
3. MRE Characteristics

Characteristics of the MRE samples were evaluated using a modified Instron test machine. All tests were performed under a compressive bias load. The static characteristics of the MRE samples in the absence of magnetic field are shown in Fig. 4. In the case of both particle geometries, the static stiffness increased as the weight fraction increased. However, the increase in stiffness is significantly larger for nanowires than for spherical particles because the contact area of the nanowires with the silicone elastomer is far greater, and the oriented structures within the MRE samples were strengthened as a result. In the case of 30 wt% solids loading, nanowire-based MRE samples had a static stiffness of 55.24 kN/m, which is nominally 2.7 times that of the spherical particle-based MREs.

Figure 4 presents the stress-strain characteristics under a compressive load in the absence of a magnetic field. The maximum applied strain level was set to 1%. As seen from these results, the hysteresis behavior generally increases as the weight fraction is increased. The area of the hysteresis loop is a measure of the dissipated energy (damping).

Stress-displacement data are shown in Figs. 6 and 7 for MREs with a solids loading of 30 wt% for both spherical particles and nanowires. MRE samples were excited sinusoidally under compressive preloads that correspond to 1% of strain. The amplitude of displacement corresponded to a maximum 1% strain in the MRE sample. From the force vs. harmonic displacement data, the damping properties were calculated. The controllable damping effect with the applied magnetic field can be represented using the equivalent viscous damping as a function of excitation frequency [4]. Figs. 8 and 9 show the equivalent damping coefficient in the frequency domain. Here, the equivalent damping coefficient can be obtained from the dissipated energy per cycle. In the case of 10 wt% nanowires, the equivalent
damping increased remarkably as the intensity of the magnetic field increased and decreased as the excitation frequency increased as shown in Fig. 9. The dynamic stiffness of the MREs is presented in Figs. 10 and 11. The values increased as the applied magnetic field is increased and also slightly increased as excitation frequency increased. The controllable stiffness range is larger for nanowire-based MREs than for the spherical particles-based MREs.

4. Conclusion

MRE samples were prepared using iron particles of differing morphology (spheres and nanowires) and varying weight fraction. The nanowire-based MREs had static stiffness greater than that of the sphere-based MREs in the absence of a magnetic field at the same weight fraction (10 and 30 wt%). Stiffness and damping were measured for frequencies ranging from 1 – 20 Hz. The 30 wt% nanowire-based MRE had an off-state dynamic stiffness about 3.5 times that of the 30 wt% sphere-based MRE, although both materials exhibited similar increments in dynamic stiffness at 0.2 T. The off-state damping of the 30 wt% nanowire-based MRE was greater than that of the 30 wt% sphere-based MRE. The controllable field-dependent damping was much greater for the nanowire-based MRE - at 1 Hz, the controllable damping was nearly twice as much as that of the sphere-based MRE.

References

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