Modeling of Effect of Particle Size on Macroscopic Behavior of Magnetorheological Elastomers

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INTRODUCTION: MREs are a class of composite materials consisting of soft magnetic particles embedded into a polymer matrix (Figure 1). Under the influence of a magnetic field the MRE is activated causing a change of stiffness in the bulk[1-2]. As result these materials have been found highly desirable for a range of applications such as tunable vibration absorbers and actuators. As a result, there has been a need to improve their efficiency. Several factors have been established to significantly influence the so-called magnetorheological effect such as the polymer matrix, particles-volume fraction, properties, and size of the magnetic particles. In this study, using finite element simulation we determine the correlation between the latter and the overall behavior of MREs.

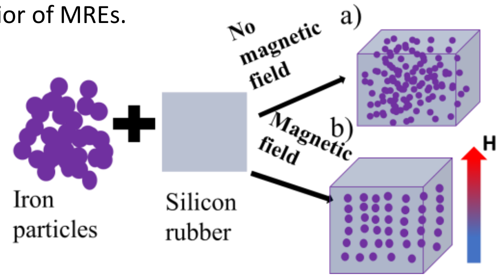

Figure 1.MREs a) Isotropic b)Anisotropic

COMPUTATIONAL METHODS: Based on continuum formulation theory and computational homogenization, microscopically motivated model was used to predict the composite's macroscopic behavior. The magnetic and mechanical fields were defined and explicitly resolved. Using a two-dimensional representative volume element (RVE) and applying periodic conditions (Figure 2) the simulation was performed for unaligned and aligned MRE with a constant particle-volume fraction (ϕ=20%) and varying mean particle sizes (Φ=5, 10, 20 and 30 µm). This method seeks to solve static conservation of momentum with Maxwell's equations for magneto-statics. The primary equations are[3],

$$\nabla . \mathrm{T} + \rho f = 0$$
$$\Delta . B = 0$$
$$\nabla \times H = J$$

Where for coupled magnetomechanical problem, T is considered to be the sum of mechanical (σ) and magnetic (T_m) contributions. The 2-D model used for numerical simulation and applied BCs is as shown in Figure 3.

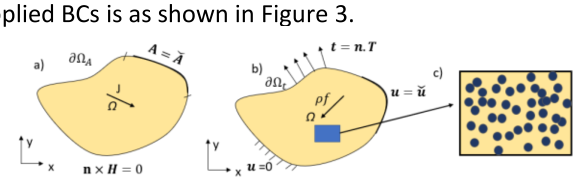

Figure 2. Different boundary conditions defined to the material body a) Electromagnetic boundary value problem (BVP) -prescribed magnetic vector potential **A** with applied current J in material domain Ω b)Coupled magneto—mechanical BVP - prescribed displacements **u**= $\tilde{u}$ on ∂Ω**,** surface tractions **t** and mechanical body foce density Pf in Ω c) Schematic diagram of MRE RVE

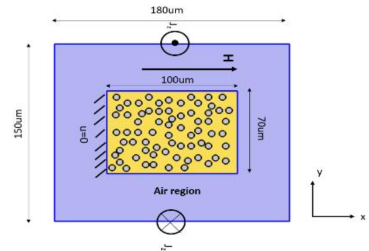

Figure3: 2-D model description for the numerical simulation of the MRE sample where J_z represents the applied surface current in the z-coordinate (circle with a dot is out and with a x is into the board)

RESULTS: Using Maxwell stress (Tm) over the boundary surface of the particles in order to couple magnetic and elastic forces and performing a parametric sweep of the surface current (Sc) the simulation was carried out as shown in Figures 4 and 5.

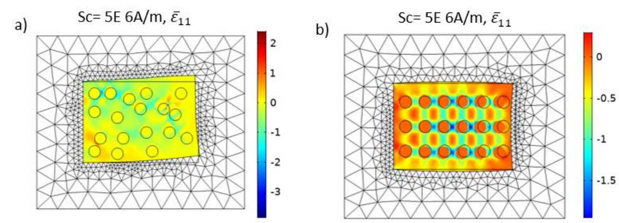

Figure 4. Effective magneto-induced strain ($\bar{\varepsilon}_{11}$) for a) unaligned b) aligned MRE with 10um sized and 20% volume fraction.

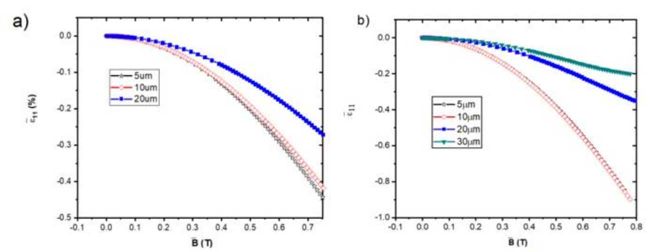

Figure 5. Effective magneto-induced strain ($\bar{\varepsilon}_{11}$) for a) unaligned b) aligned MRE with 20% volume fraction and varying particle sizes

CONCLUSION: From the simulation study, we show that the size of the particles strongly influences the overall deformational effect in the MRE for both the unaligned and aligned microstructures. The effective magneto-induced strain effect is observed to decrease with increase in the average particle sizes. This can be attributed to reduced particle surface area with larger interparticle distance leading to decrease in the composite's permeability, thus the magnetic particles are less magnetized.

ACKNOWLEDGMENT: This work was supported by Link Manufacturing Ltd, the Center for Industrial Research and Service (CIRAS) Iowa State University, and the Regents Innovation Fund**.**

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