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UNDERSTANDING MAGNETORHEOLOGICAL ELASTOMER VISCOELASTICITY FOR ENGINE MOUNT-RELEVANT CONDITIONS

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ABSTRACT

Magnetorheological elastomers (MREs) are smart materials with tuneable viscoelastic properties, relevant for vibration mitigation in automotive systems. This study examines their strain-dependent behaviour using strain-sweep rheology. Storage modulus (G′) and loss modulus (G″) were measured across a broad strain range, revealing nonlinear trends that reflect the evolving balance between elastic and viscous responses. The damping factor, derived from these measurements, highlights how energy dissipation changes with increasing strain, indicating potential for adaptive vibration control. These findings provide a clear, quantitative understanding of MRE viscoelasticity under engine-mount-relevant conditions, offering a foundation for further exploration of their performance in dynamic applications and guiding the formulation and evaluation of elastomeric systems for automotive vibration management.

KEYWORD

Damping, Magnetorheological Elastomer, Storage Modulus, Rheology, Viscoelastic

INTRODUCTION

The Magnetorheological elastomers (MREs) are a class of smart materials that integrate an elastomeric polymer matrix with ferromagnetic particles, such as carbonyl iron particles (CIP), enabling tuneable viscoelastic properties in response to external stimuli (Bastola et al., 2020; Jaafar et al., 2021). This unique combination allows MREs to adjust their stiffness and damping characteristics under mechanical or magnetic influence, making them highly attractive for adaptive vibration control applications, including automotive engine mounts, robotics, and structural damping systems. In automotive contexts, engine mounts are critical components subjected to dynamic and often nonlinear loading. The material's ability to store and dissipate energy, quantified through storage modulus (G′) and loss modulus (G″), directly influences vibration isolation, ride comfort, and noise reduction.

Over the past decade, research on MREs has predominantly focused on their magneto-responsive behaviour, frequency-dependent dynamics, and low-strain viscoelastic properties (Lejon & Kari, 2013; Shenoy et al., 2019). For instance, studies have shown that magnetic fields can significantly enhance stiffness and alter damping characteristics, while frequency sweeps reveal complex viscoelastic transitions under oscillatory loading. However, fewer studies have systematically examined how MREs behave under increasing strain, despite evidence that nonlinear viscoelastic effects become significant at moderate-to-high strain levels (Johari et al., 2021, 2022). This strain-dependent behaviour is particularly relevant for engine mounts, which experience variable deformation during real-world operation. Understanding these effects is essential for evaluating the material's damping efficiency and mechanical stability under practical conditions.

Strain-sweep rheology provides a robust approach to probe the nonlinear viscoelastic response of MREs, capturing how G′, G″, and the damping factor evolve with increasing deformation. Such analyses can reveal transitions between elastic-dominated and viscous-dominated responses, offering insight into energy dissipation mechanisms under realistic operating conditions. The schematic (Johari et al., 2020) in Figure 1 summarizes how an MRE responds to increasing shear strain, beginning with the linear viscoelastic (LVE) region where both the particle network and polymer matrix deform reversibly. As strain increases, the material gradually transitions into the non-linear regime, marked by changes in the balance between elastic and viscous contributions. Variations in storage modulus, loss modulus, and loss factor reflect the evolving mobility of the polymer chains and the reorganization of embedded particles. The illustration also contrasts isotropic and anisotropic particle arrangements, demonstrating how internal morphology influences stiffness, energy dissipation, and the shift from solid-like to more fluid-like rheological behaviour. The present study employs strain-sweep measurements to investigate the viscoelastic behaviour of MREs, aiming to provide a comprehensive understanding of their strain-dependent properties and implications for vibration mitigation in engine mount-relevant scenarios. These findings establish a foundation for further optimization of MRE formulations and highlight their potential for adaptive damping applications in automotive engineering.

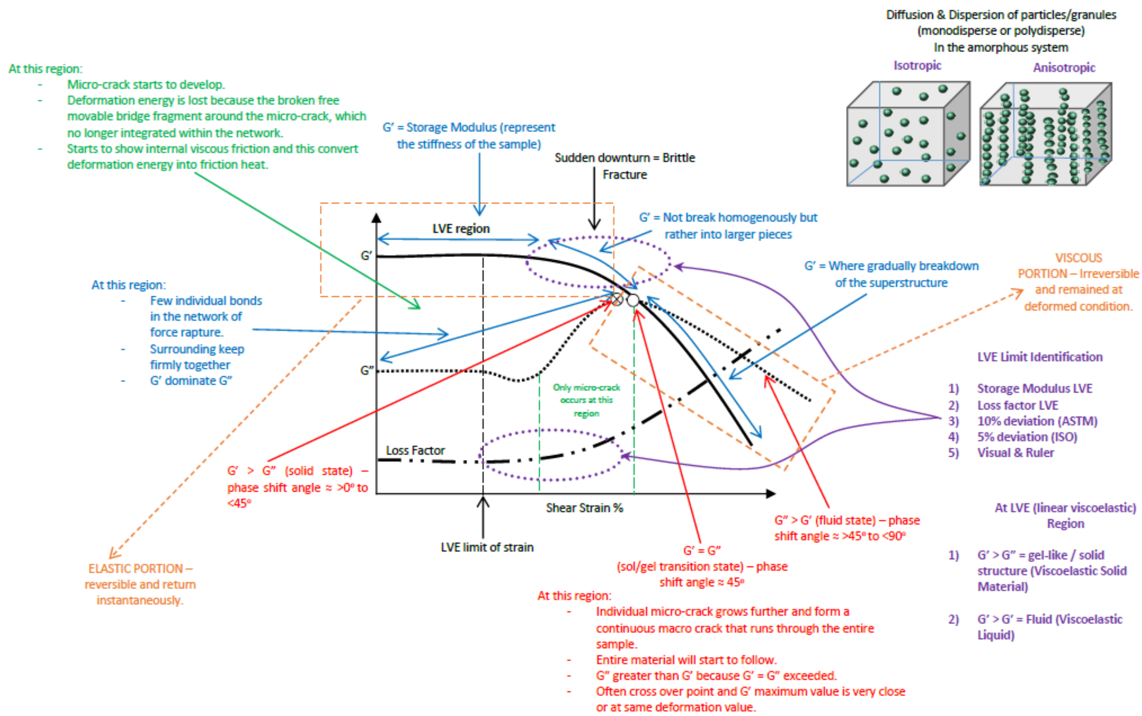

Figure 1: Strain-Dependent Viscoelastic Response of Magnetorheological Elastomers (Johari et al., 2020)

MATERIAL AND METHODOLOGY

This method was used to understand how MREs behave under conditions relevant to engine mounts. The material was made by mixing carbonyl iron particles evenly into silicone rubber, adding a small amount of curing agent, and curing the mixture in a mould to produce uniform sheets for testing. A rotational rheometer was then used to measure how the MRE stores and dissipates energy. Strain sweeps from 0.001% to 10% at 1 Hz were performed to represent both light and moderate deformation similar to engine-mount vibration levels. A magnetic field up to 0.83 T was applied to observe how the material's stiffness can change when magnetised. By recording storage modulus, loss modulus, and damping factor, this approach provides a simple way to understand the basic stiffness and damping behaviour needed for future MRE-based engine-mount applications.

RESULT AND DISCUSSION

Figure 2 shows the strain-dependent storage modulus and loss modulus of the MRE under off-state and various magnetic field intensities. In the off-state, G′ remains stable across the low-strain region (0.001 – 0.1 %), indicating a well-defined LVE behaviour. This plateau reflects a strong particle–matrix network that resists small deformations. As strain increases beyond approximately 1 %, G′ gradually decreases, marking the transition into the nonlinear regime where the internal structure begins to reorganize, and the material softens. When the magnetic field is applied, the stiffness response increases uniformly across all strain levels. Higher applied current produces a consistently higher G′, demonstrating the field-induced reinforcement expected from magnetically aligned particles. The increase in G′ from off-state to the highest current level indicates effective field-responsive behaviour, which is critical for tuneable engine-mount concepts where load-bearing stiffness must adapt to changing vibration conditions. Notably, the LVE plateau extends slightly under stronger magnetic fields, suggesting enhanced structural stability before nonlinear deformation sets in.

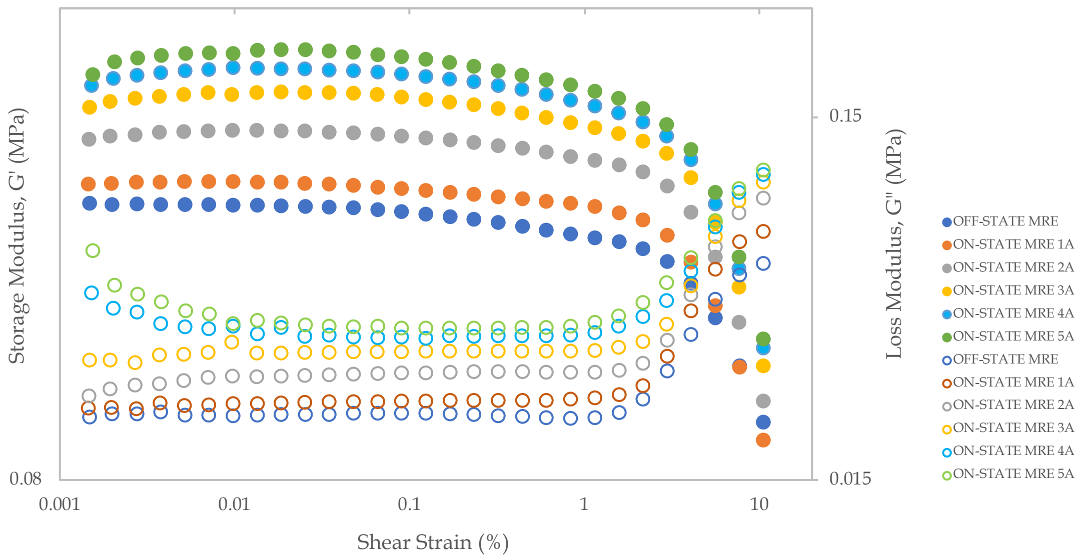

Figure 2: Viscoelastic Behaviour of the MRE Under Engine-Mount–Relevant Strain Conditions.

The loss modulus, G″, follows a similar trend. In the off-state, G″ decreases slightly as strain increases in the low-strain region, then rises at higher strains. This behaviour reflects a shift from elastic-dominated to more viscous-dominated energy dissipation. Under the magnetic field, G″ increases at all current levels, showing that magnetic activation not only stiffens the material but also enhances its damping capability. This dual increase in G′ and G″ is desirable for engine-mount applications, where both load support and controlled energy dissipation are required. Across the entire strain range, the separation between G′ and G″ remains clear, confirming that the MRE maintains a predominantly solid-like character even under large deformation. The gradual decrease in moduli at high strains suggests that the material can accommodate large displacement events, such as engine start-up or sudden torque fluctuations, without losing structural continuity. Overall, the strain-sweep results highlight the MRE's ability to balance stiffness and damping while offering tunability through magnetic fields. These characteristics align well with the functional needs of adaptive engine mounts, where vibration levels vary with engine speed and load, and real-time adjustment of mechanical response is beneficial.

CONCLUSION

This study examined the strain-dependent viscoelastic behaviour of an isotropic magnetorheological elastomer to support its use in engine-mount–related applications. The material showed a clear linear viscoelastic region at low strains, followed by gradual softening as strain increased. Application of a magnetic field consistently enhanced both storage modulus and loss modulus, demonstrating effective stiffness tuning and increased damping capacity. These trends confirm that the particle–matrix network responds reliably to magnetic activation across the full strain range. The combined increase in stiffness and energy dissipation under magnetic fields highlights the potential of MREs for semi-active engine mounts, where adaptive control of vibration and load conditions is required. Overall, the results provide foundational rheological insight needed to guide future development and optimisation of MRE-based mounting systems.

ACKNOWLEDGEMENT

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