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HEAT EXPOSURE EFFECT ON THE VISCOELASTIC PROPERTIES OF MAGNETORHEOLOGICAL ELASTOMER

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ABSTRACT

Heat is an unavoidable challenge inside an engine bay, and its influence can significantly alter the properties of magnetorheological elastomers (MREs); a promising class of smart materials for adaptive engine mount applications. While MREs are valued for their tuneable stiffness under magnetic field strength, their response to prolonged thermal exposure is crucial for real-world reliability. This study investigated silicone-based MREs containing 70 wt.% of iron particles, and exposed to 100°C, 125°C, and 150°C for 24 hours, individually. The proposed temperatures represent those experienced by rubber-type engine mounts. The findings show that both heat and exposure duration modify the storage modulus and magneto-response effect of each MRE, with these changes becoming more pronounced under magnetic fields activation. The findings also indicate that thermal exposure influenced the cross-link density of matrix, potentially stabilising the internal structure and altering controllable stiffness of the material. The outcomes would give clearer insight into the behaviour of MRE, supporting the development of robust, heat-resilient engine mounts.

KEYWORD

Magnetorheological Elastomer, Heat, Storage Modulus, Magneto-response Effect, Thermal Stiffening, Thermal Softening

INTRODUCTION

Magnetorheological (MR) materials are a class of smart materials where rheological properties can be rapidly changed magnetic fields (Hafeez et al., 2020). Magnetorheological elastomer (MRE), a solid-typed MR material is composed of micron-sized magnetic particles that are dispersed in an elastomeric matrix such as natural rubber (Yusoff et al. 2025), silicone (Si) rubber (Johari et al. 2022) or other kind of rubber materials. MREs are promising candidates for engine mounts since they can dynamically adjust its stiffness and damping with magnetic fields, ensures structural integrity under engine load, and absorb vibrations effectively under semi-active systems, making them superior compared to conventional passive mounts. Carbonyl iron particles (CIP) meanwhile are used as magnetic particles due to its high magnetic saturation, low remanence and permeability, and reversible particle interactions with different magnetic field directions (Vatandoost et al., 2021). The performance of MREs is further governed by several factors, including strength of magnetic fields applied and resultant particle–matrix interactions (Alam et al., 2021).

Beyond the formulation, environmental conditions especially heat plays a significant role in altering the behaviour of rubber-based materials, including stiffness, crosslink density and viscoelastic response of the matrix. Including heat experienced by an MRE, it may alter the storage modulus and magneto-response effect of the material upon exposure (Aziz et al., 2021). These heat-induced would influence not only the base elastomer but also the interactions among magnetic particles within the matrix, ultimately impacting the overall magneto-mechanical properties of the material. This issue is especially critical for engine mount applications, where components are continuously subjected to high and fluctuating temperatures. Heat generated within the engine bay can modify both the mechanical and magneto-responsive characteristics of MREs, potentially affecting their stability, vibration isolation efficiency and long-term durability.

In other studies, heat has been used as a treatment to improve the microstructure and overall properties of MREs. Heat treatment is a well-known approach for enhancing material performance including in polymers, where specific properties can be tailored by controlling the structural changes through various thermal processes. Although heat treatments have been successfully improved most material characteristics, thermal exposure may also deteriorate the performance depending on the conditions applied. Yan-Xiang et al. investigated the effect of temperatures on the dynamic properties of MREs. Their findings showed that temperatures significantly influenced the dynamic modulus of Si rubber-based MREs under uniaxial compression. The loss modulus decreased with increasing temperatures up 50°C, then increased with further temperature elevation.

Despite the relevance of thermal treatment for enhancing material properties, its effects on active rubber systems like MREs serve a different purpose and studies on how heat alters their performance, whether positively or negatively are remain limited. While passive rubbers are known to undergo changes in hardness, strength and structural stability after thermal exposure (Wang et al., 2016), the thermal sensitivity of MREs, whose properties depend on both mechanical and magnetic responses would require further investigation. Therefore, this study examines how exposure to different temperature levels influences the rheological properties of MREs. Understanding these thermally induced changes is essential for assessing their reliability and functional stability in heat-intensive applications such as adaptive engine mounts.

MATERIAL AND METHODOLOGY

The research methodology was divided into three phases, began with the fabrication of MRE samples. The samples were prepared by uniformly mixing the carbonyl iron particles (CIPs) into liquid Si rubber, followed by the addition of a curing agent for the solidifying process. The mixture was immediately casted into a cylindrical mould and cured to produce uniform sheet-type specimens for testing. In the second phase, heat exposure was applied to the MRE samples at three different temperatures which were 100°C, 125°C, and 150°C. Each sample was held at its respective temperature for 24 hours to ensure consistent thermal exposure.

The third phase involved with rheological testing of both heat-exposed and non-heat-exposed MREs. A rotational rheometer was used to perform the strain sweep and magnetic field sweep tests, with the strain levels ranging from 0.001% to 10% at a frequency of 1 Hz. Then, magnetic fields that ranged from 0 to 0.83 T were applied to evaluate how magnetic forces, together with the imposed shear deformation could influence the stiffness and magneto-responsive properties of the heat-exposed MREs.

RESULT AND DISCUSSION

The storage modulus findings in Figure 1 show that the non-heat-exposed and heat-exposed MREs exhibit a stable modulus at low strain amplitudes, between 0.00001–0.01%, followed by a slight reduction at higher strains, from 0.01–0.1%. This marked the onset of non-linear deformation of MRE samples, indicating the microstructural rearrangements occur non-linearly within the MRE matrix. Different heat exposure however, produced noticeable shifts in the baseline stiffness of the material. MRE sample that exposed at moderate temperature of 100°C display a slight increase in the storage modulus (0.42 MPa) compared to the non-heat-exposed MRE (0.31 MPa), likely due to additional crosslinking within the Si matrix with heat. In contrast, samples exposed to higher temperatures (125°C and 150°C) exhibit revers effects (0.37 MPa and 0.30 MPa), which can be attributed to either thermal softening or partial microstructural degradation. Despite these differences, all MRE samples maintain a strong magneto-stiffening response, with the storage modulus consistently increased with applied magnetic fields (0–0.83 T). This shows that the interactions of magnetic particles within the matrix remain intact after heat exposure.

Meanwhile, Figure 2 depicts the comparison between all MRE samples, particularly for applied magnetic field at 0.83 T. The storage modulus of MREs increased with increasing of heat-exposed temperatures from 100-150°C, suggesting the soft-softening effect of MRE may improve the magnetic interaction of particles within the matrix medium. The findings also can be related to the magneto-response effect of the MRE samples, signifying by the range in the storage modulus between the lowest (0 T) and maximum applied magnetic fields (0.83 T). It can be observed that the MRE underwent 100°C-exposed heat has the lowest magneto-response effect, about 0.21 MPa compared to 0.248 MPA for 125°C and 0.259 MPa for 150°C. It is due to the thermal softening effect of MRE samples that were exposed to higher temperatures.

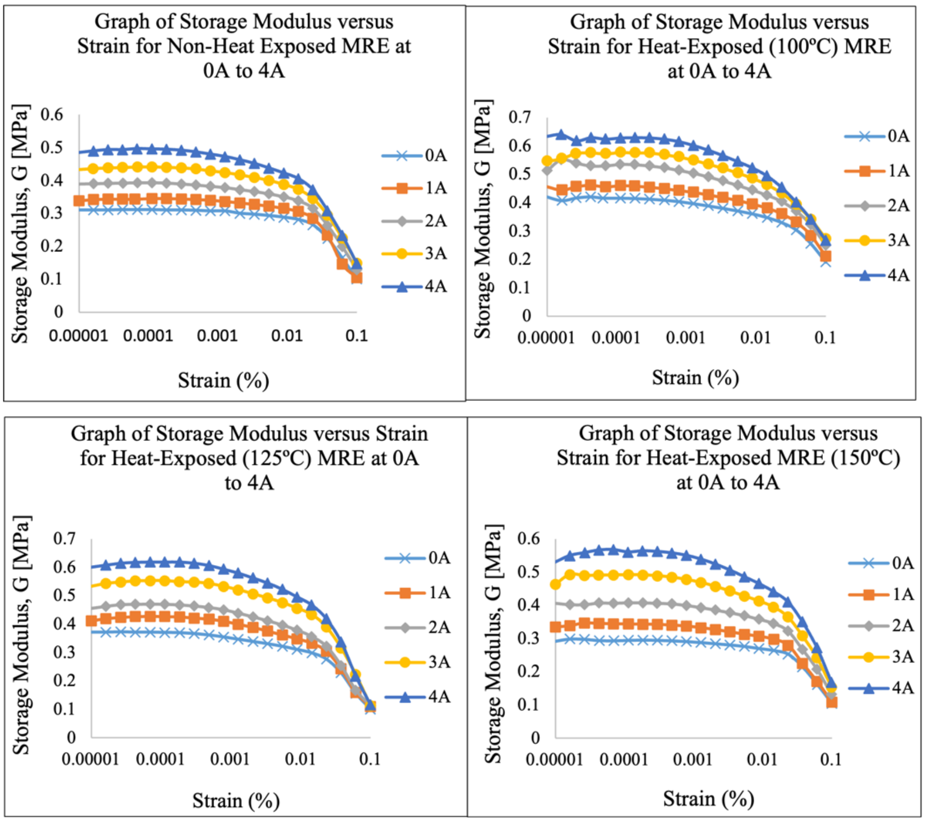

Figure 1: Storage modulus of MRE samples for non-heat-exposed, heat-exposed temperatures (25°C, 100°C, 125°C and 150°C)

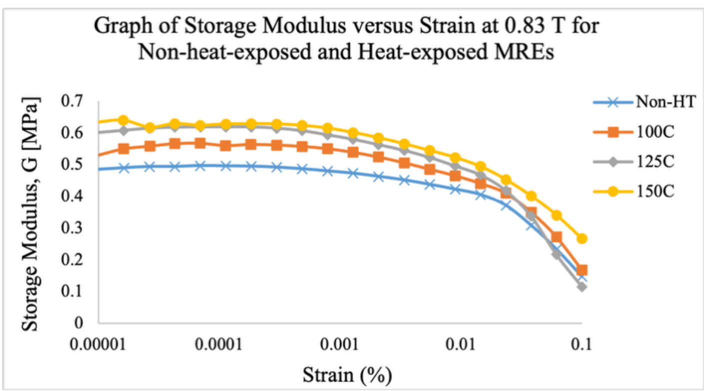

Figure 2: Comparison of storage modulus for MRE samples at 0.83 T

For engine mount applications, the thermally driven modulus shifts might be relevant. The increase in baseline stiffness after moderate heat exposure may enhance load-bearing stability at elevated temperatures commonly encountered in engine bays, whereas thermally softened matrices at higher temperatures may offer improved low-frequency vibration absorption during idle conditions. In addition, the preserved magneto-stiffening capability across all heat levels ensures that the material can still be actively tuned to adapt its stiffness in response to varying magnetic fields and load conditions, supporting the functional demands of semi-active engine mount systems.

CONCLUSION

This study shows that heat exposure would affect the stiffness (storage modulus) and magneto-responsive effect of MREs. All heat-exposed samples (100°C, 125°C, 150°C) maintained clear magneto-stiffening, indicating stable particle interactions after heat exposure. The 100°C-exposed sample slightly increased the storage modulus might be due to additional crosslinking in the matrix phase, while higher temperatures have softened the matrix. Meanwhile, the 125°C-exposed MRE produced the highest magneto-response effect because its lower initial modulus allowed a larger stiffness changed under magnetic fields. For engine mounts, these effects are beneficial as increased stiffness supports static loads at high temperatures, while softer matrices with strong magneto-response effect would improve vibration isolation and adaptability under varying engine conditions.

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