Enhanced performance of core-shell hybrid magnetorheological elastomer with nanofillers

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Abstract

The effects of addition of magnetic nanoparticles (MNPs) in core-shell hybrid magnetorheological elastomers (MREs) are reported in this study. The main idea of a core-shell hybrid MREs was recently demonstrated in our previous paper (Bastola et al., Colloids Surf A, 583:123975, 2019). It is observed in the current study that the MNPs enhanced the rheological properties of the suspension in magnetorheological fluid including the improvement of the sedimentation behaviour. Furthermore, magneto-active nanoparticles substantially improved the magnetorheological response of the core-shell hybrid MRE composites.

1. Introduction

Magnetorheological (MR) materials have been recognized as smart and intelligent materials with a swift change in their mechanical and rheological properties as well as shape under an externally applied magnetic field. The MR materials have shown great potentials to be used in many practical and industrial applications such as shock absorbers, vibration isolators, tunable stiffness systems and even soft sensors and actuators etc. [1-4], to mention a few. The

MR materials consist of a non-magnetic matrix loaded with magnetic fillers that are typically soft in magnetic nature (e.g. low magnetic remanence) in which the particles (widely used particles: carbonyl iron powders (CIPs)) are in micron size [1, 3, 5]. The matrix can be fluid as well as solid and therefore MR fluids and MR elastomers can be distinguished easily. The MR fluids are known for change in the properties such as shear viscosity and yield stress. On the other hand, the solid counterpart of MR fluids, the MREs are known for change in modulus, thanks to the externally applied magnetic field. One of the common issues of MR fluid is that they suffer big sedimentation problem over time and need a container or storage device. On the other hand, MRE overcomes these issues related to MR fluid however are still characterized by the low MR effect (change in properties in the presence of a magnetic field) [1, 3]. But it must be noted that there has been remarkable progress in the field of the MREs both in experiment and modelling in recent years [1-3, 6-13].

In one of our recent contributions [14], we presented a gap bridging magnetorheological materials by forming a core-shell structure in which an MR fluid acts as the core and elastomeric casing becomes the shell. Such hybrid MREs can be free from the sedimentation problem of the MR fluids and also can exhibit a higher MR effect than conventional MREs. Furthermore, the core-shell MREs exhibit anisotropic characteristics depending on the direction of the applied magnetic field. It is noteworthy to mention that, in core-shell hybrid MREs, there was no need for the application of a magnetic field during the crosslinking process as typically required for the conventional MREs to develop an anisotropic property [1, 15].

In this study, enhancement of the MR effect of such core-shell hybrid MREs by adding magnetic nanoparticles (MNPs) as a magneto-active additive is reported. MNPs are one of the best choices of additives to enhance the stability and performance of MR fluid [3, 16, 17]. Such MNPs are also widely used in conventional MREs as one of the effective additives to increase the MR effect [18, 19]. Therefore, we were interested to investigate whether the impact of such MNPs was also meaningful in the case of core-shell hybrid MREs. Here, MNPs are added with two aims, (1) to enhance the MR effect and (2) to increase the viscosity of the MR core to overcome the sedimentation issue. The effect of the addition of MNPs to 80% w/w of CIPs into core fluid has been studied by adding MNPs up to 2% w/w.

Figure 1 provides the overall scheme of the study. The stability and rheological performance of the core fluid were studied first and the performance of core-shell MREs was then studied using forced vibration analysis.

The materials and method can be found in details in our previous study [14].

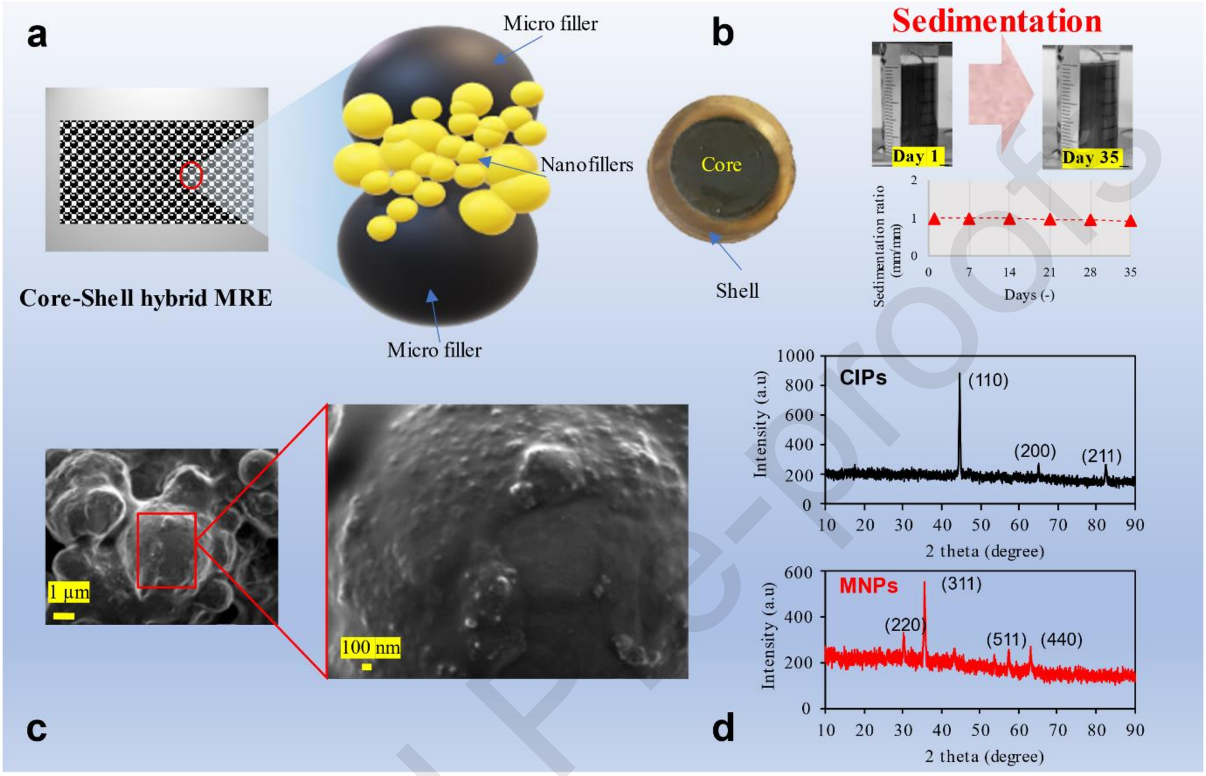

Figure 1. Core-shell hybrid MREs with micro-nano fillers. (a) Illustrative representation of hybrid MRE system. (b) Picture of the MRE sample and sedimentation behaviour of the core fluid and (c) scanning electron microscope images of micro-nano filler system and (d) X-ray powder diffraction patterns of CIPs and MNPs.

2. Results and Discussion

The magnetorheological results for the addition of MNPs and compared to 80% CIPs are given in Figure 2. Both shear stress and viscosity were found to be increased with increasing MNPs both in the presence and absence of a magnetic field. Upon the application of the magnetic field, the enhancement of shear stress and viscosity is higher than that of 80% CIPs. The MNPs can fill the voids between micro-CIPs making the chains stronger in the presence of a magnetic field. The shear-thinning (change in viscosity with increasing shear rate) was also enhanced with the addition of MNPs. The rheological result showed the significance of the addition of MNPs to enhance the viscosity and MR effect of suspensions. In addition, resistance to sedimentation was also improved by the addition of MNPs. The MR core with added MNPs were found to be very stable and the sedimentation was not observed over 30 days (Figure 1(b)). However, we observed notable sedimentation of magnetic particles with only CIPs core in our previous study [14] and such sedimentation of CIPs is a common issue in MR fluid-related studies [16, 20].

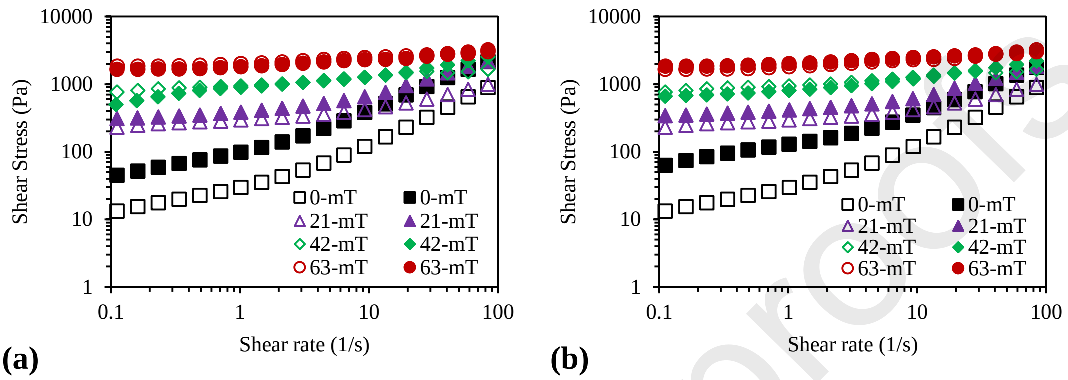

Figure 2. Shear stress versus shear rate with added MNPs (closed symbols ■) on 80% CIPs and compared with low viscosity with 80% CIPs (open symbols □) at different magnetic flux densities. (a) 1% MNPs and (b) 2% MNPs.

The effect of the addition of MNPs for the core-shelled hybrid MREs was investigated using the forced vibration analysis. The magnitude transmissibility curves obtained from the forced vibration testing in a squeeze mode at various magnetic flux densities is given in Figure 3. The zero-field stiffness (defined by the peak of the transmissibility curve) is slightly increased with the addition of MNPs, which is plausible, as the resistant to external force will be increased when the viscosity of the fluid is increased. On the other hand, the peak of transmissibility curves slightly decreased with an increase in the concentration of MNPs. The decrease in the peak of the transmissibility curve signifies that the damping ratio of the MRE system is increased, which is a result of increased viscosity of MR core. When the magnetic field was applied, the shifting of the transmissibility curve was found to be substantially increased by the addition of MNPs. However, the shifting of the transmissibility curve was found to be gentler when magnetic flux density was higher than 300 mT, which was also noticed in our previous study with other fluid core samples [14] and attributed to the MR effect plateau of the MR fluid around 300 mT. The natural frequency of the system was increased to 134.7 Hz from 72.35 Hz for the sample with 1% MNPs, to 176.7 Hz from 86.05 Hz for the sample with 2% MNPs, whereas the natural frequency only increased to 94.92 Hz from 67.7 Hz for the sample with only 80% CIPs. The relative increase (well known as the MR effect) in natural frequency of the system with core-shell hybrid MRE samples is 141%, 105% and 40% for samples with 2% MNPs, 1% MNPs and 80% CIPs, respectively. On the other hand, an increase in the stiffness of the elastomer would be even higher than that was achieved for the natural frequency as the increase in the stiffness depends on both the initial value and the increasing amount of the natural frequency with respect to a magnetic field. The relative increase in stiffness was found to be 322%, 246% and 96% for samples with 2% MNPs, 1% MNPs and 80% CIPs, respectively.

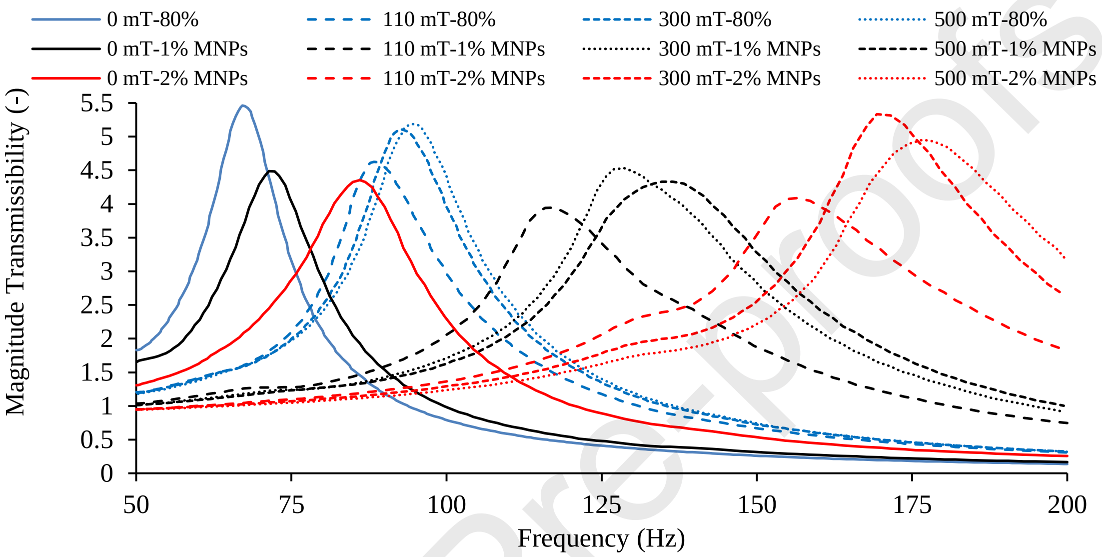

Figure 3. Forced vibration results of the core-hybrid MREs. Magnitude transmissibility is plotted against the excitation frequency at various magnetic flux densities.

3. Conclusions

In summary, the addition of MNPs was proven to be noteworthy. Firstly, it enhanced the rheological properties of the suspension in both the absence and presence of a magnetic field, so the sedimentation behaviour of the MR core was also improved. Secondly, even though MR response of pure suspensions was not significantly enhanced by added MNPs, a substantial improvement in the MR response of the core-shell hybrid MRE composites was observed. It was considerably noticed that the increased viscosity of the core-fluid by adding MNPs did not inhibit the MR performance of the core-shell MREs. It is therefore always worth considering the magnetic nanoparticles as additives to enhance the performance of MR materials.

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Declaration of conflicting interests

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Mokarram Hossain: Formal analysis, Writing - Original Draft, Writing - Review & Editing

Highlights

- Effects of addition of magnetic nanoparticles (MNPs) were investigated for core-shell hybrid MR elastomers
- MNPs enhanced the rheological properties of the suspensions in the MR core including the improvement of the sedimentation behaviour
- MNPs also improved the overall MR effect of core-shell hybrid MR elastomers when added up to 2% w/w