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Experimental investigation of effect of ingredient particle size on dynamic damping of RTV Silicone base Magnetorheological elastomers

Sriharsha Hegde[a]*, Umanath R Poojary[a], K.V. Gangadharan[a]

[a]*Department of Mechanical Engineering, National Institute of Technology, Surathkal, Mangalore-575025, India*

Abstract

Magnetorheological elastomers (MRE) are a type of smart materials which responds to an externally applied magnetic field which results in enhanced mechanical properties. MRE consists of a non-magnetic matrix material like rubber and a ferromagnetic ingredient. The size of the particle ingredient plays an important role in the property enhancement of the MRE. In the current work, MRE samples were prepared using Room temperature vulcanising Silicone as matrix material and 2 different samples of carbonyl iron powder (3.15µm and 6.25µm diameters) were used as particle ingredients. Microstructure of the sample were studied under Confocal microscope, which showed the smaller diameter powders results in more agglomeration even though the distribution of powders in the matrix were fairly uniform. A test set up was made to conduct dynamic tests to investigate the influence of particle size on the dynamic performance of the prepared MRE samples. Test results in these experiments showed that smaller diameter particle ingredients results in better MR effect.

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Keywords: RTV Silicone; Carbonyl iron powder;Dynamic tests;Magnetic field;MRE

1. Introduction

Materials which respond to changes in the surrounding conditions in an intelligent manner can be classified as smart materials. Some of the most popular smart materials are piezoelectric materials, thermo-chromic and photo-

* Corresponding author. Tel.: +91-8147756715;.
E-mail address: sriharsha.mangalore@gmail.com

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chromic materials, shape memory alloys and magneto-sensitive materials. Magnetorheological fluids, foams and elastomers belong to such category of smart materials whose rheological/mechanical properties can be reversibly and rapidly controlled by an external magnetic field of certain intensity (Weihua Li et.al. 2008). MR fluids contains base oil in which ferromagnetic iron powders are uniformly distributed and in MR foam is an absorbent material like sponge or fabric which contains MR fluid. These MR fluids and foams have been success fully used to fabricate MR brakes and clutches. But these types of devices have a common problem of settling of ferromagnetic ingredients which tend to reduce the efficiency of the devices. This problem can be solved by using a solid base material like thermosetting plastic or elastomers, which provide a stable medium for the ferromagnetic materials, which are called Magnetorheological elastomers. Apart from the medium, another major difference in MRFs and MREs is in the region of application i.e. MRFs are operational in post-yield regime and MREs are used in pre-yield stress region.

Magnetorheological elastomers are a kind of composite materials which has ferromagnetic ingredients in powdered form instead of fibres as in the case of typical composites. Based on the kind of curing, there are two types of MREs. If a magnetic field is applied during curing, the ferromagnetic particles get aligned along the flux lines making it anisotropic MRE. If the curing takes place without any field, it is classified as isotropic MRE. When it comes to the preparation of MREs, there are lot of potential materials for base materials like Natural rubber and synthetic rubbers like silicone rubber, nitrile and butyl rubber and so on. Most researchers go for RTV-Si because of wide temperature range of working and the ease of handling. When it comes to the choice of ingredient materials, the basic requirement is that it should be ferromagnetic with very low coercivity i.e.no remnant field when the magnetic field is removed. Materials like iron, nickel and cobalt or combination of these materials in powdered form can be used. But the most popularly used material is called carbonyl iron powder of diameter about 1to 10 μm in size.

LI Jian-feng et al (2008) investigated the dynamic damping capabilities of HTV-Silicone rubber and they found that the property enhancement depends on strain amplitude and magnetic field intensity and frequency had very little impact. Yanceng Fan et.al. (2011) studied the interfacial frictional damping properties in cis-polybutadiene based MRE by making use of two different size carbonyl iron powder samples. They observed that samples with smaller size particle ingredients had more agglomerations and it affects the dynamic performance of the MRE. They also found that the performance is influenced by strain amplitude and magnetic field intensity. B X Ju et.al. (2011) prepared a new type of Si based MRE with porosity and tested its damping characteristics under various input conditions. They observed that the MR effect improved with the magnetic field. Lin Chen et.al. (2008) experimentally investigated the damping properties of different samples of MREs and concluded that damping ratio improved up to a magnetic field of 0.3 Tesla and then showed a decreasing trend.

In the current paper, RTV-Si based MREs are prepared using CIPs of 2 different diameters with equal weight percentage and compared with the performance of pure silicone sample. The samples were studied under confocal microscope to analyse the particle distribution in the rubber matrix. Impact of the particle size on the dynamic damping (η) at different magnetic field intensities are investigated.

Nomenclature

MRE	Magnetorheological elastomers
MRF	Magnetorheological fluid
RTV Si	Room temperature vulcanizing Silicone
HTV	High temperature vulcanization
CIP	Carbonyl iron powder
η	Loss factor
NI-PXI	National Instruments PCI eXtensions for Instrumentation

2. Material preparation

In the current work, three test samples were prepared by making use of RTV silicone from Dow Corning as elastomer matrix. An aluminum mould of dimensions 20mm x 20mm x 6mm was fabricated to prepare the samples. Two different samples of CIP samples were used i.e. 3.15 μm and 6.25μm in diameter supplied by Chengdu Nuclear, China. One pure Si sample and two different MRE samples were produced from each of the CIP sample. In case of Pure-Si, 10 grams of resin was mixed with 0.5 grams of curing agent. In both the MRE samples, 20 grams of CIP was mixed with 10 grams of resin and 0.5 grams of curing agent was mixed. After mixing the curing agent properly with the base, it was poured in the mould and kept in vacuum chamber till all the air bubbles were removed. After that it was kept for curing for about 2 hours and then the sample was removed. The following table lists the sample compositions of all samples.

Table 1. Sample compositions

Sample	Carbonyl iron powder (grams)	Silicone (grams)	Curing Agent (grams)
Pure Silicone	0	10	0.5
3.15 μm MRE	20	10	0.5
6.25 μm MRE	20	10	0.5

The microstructures of the samples were studied under Olympus Confocal microscope. The figure 1(a) shows the Pure-Si sample and figure 1(b) and 1(c) show the microstructure of 6.25 μm MRE and 3.15 μm MRE respectively.

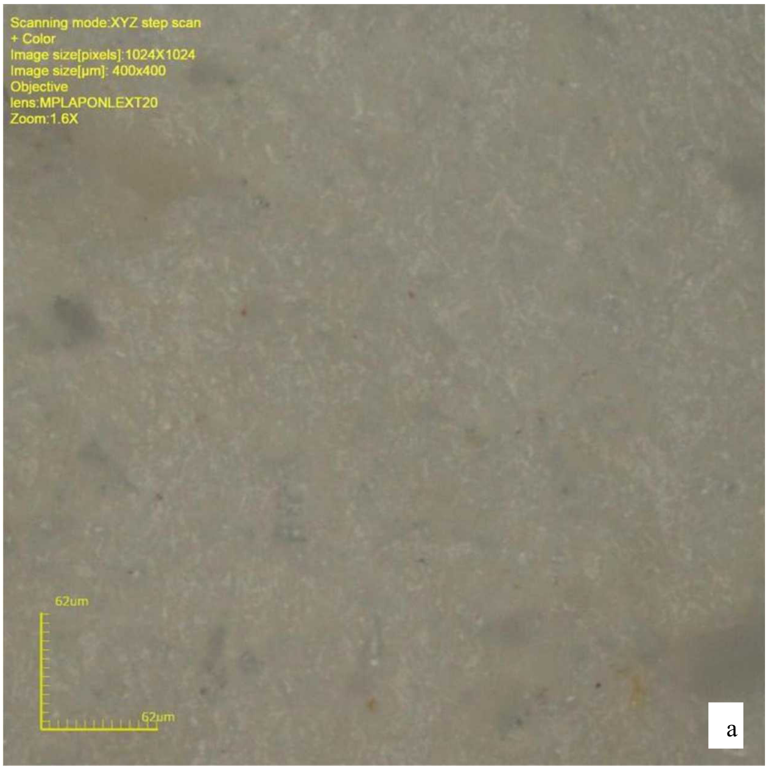

Fig. 1. (a) Pure-Si microstructure

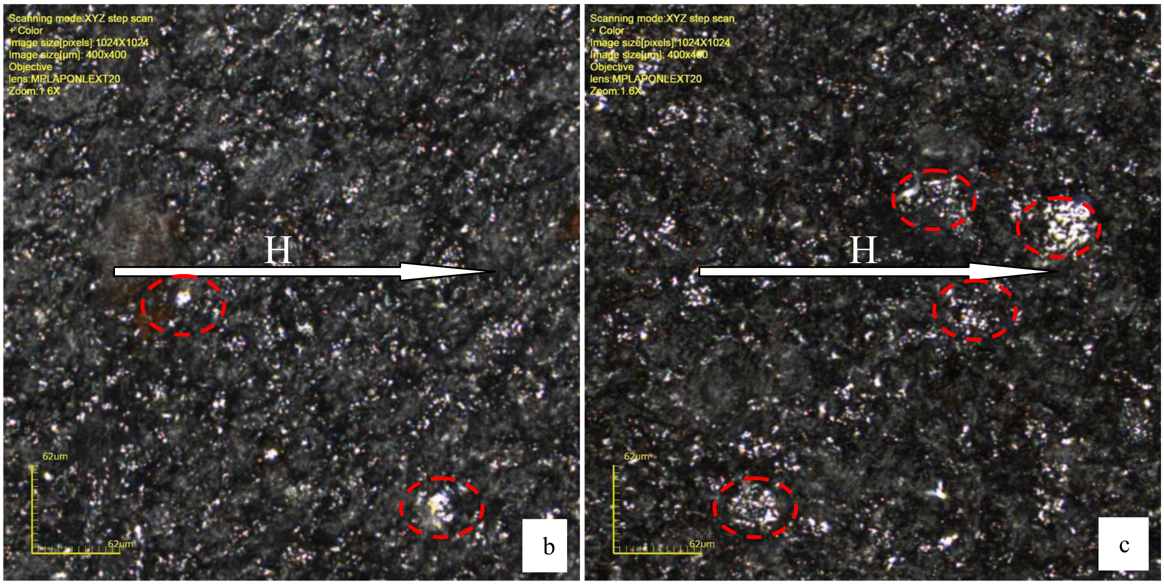

Fig. 1 (b) 6.25 μm: MRE and (c) 3.15 μm MRE.

It can be seen from the microstructure photographs that the distribution is fairly uniform in the 6.25 μm sample MRE and the smaller diameter sample has more agglomerations as highlighted by dotted circles.

3. Experimental method and data acquisition

The schematic representation of the experimental set up is shown in figure2 below. The MRE was fixed to the structure and two force transducers were fixed at the top and bottom of elastomer to measure the input and the transmitted force respectively. A sinusoidal signal generated by function generator, NI PXI-5401 was amplified and fed to the Electrodynamic shaker to generate the input force. A stinger was used to transmit the input force to the MRE only in vertical direction. The harmonic input excitation frequency was increased from 30 Hz to 400 Hz. In the current experiment, manual frequency sweep was used instead of sine sweep to minimize the errors which can occur during data acquisition. Magnetic field was varied from 0 Tesla to 0.3 Tesla in steps of 0.1 Tesla and Neodymium rare-earth permanent magnets were used to supply magnetic field. A modified self-centring vice was used to vary the magnetic field. Lakeshore Gauss meter was used to measure the magnetic flux density. Accelerometer from Kistler was used to measure g value of the input excitation and 2 Kistler force transducers were used to acquire input and output force data for further analysis.

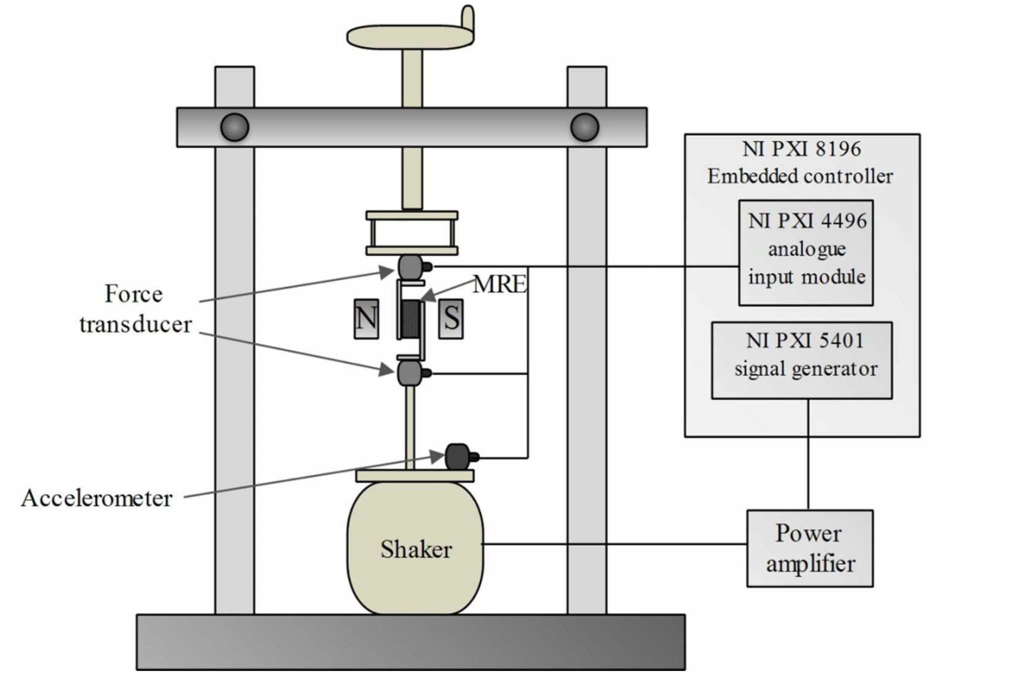

Fig. 2. Schematic representation of the Experimental set-up.

4. Results and Discussions

To compare the behavior of all the samples, the transmissibility ratio acquired from force transducers was plotted against input frequency. The plots of the two MRE samples at different magnetic fields were compared the behavior of Pure-Si sample which are shown in figures 3 (a) and 3 (b) below respectively. The enhancement in the dynamic damping η is the clear indication that the addition of iron powders produces positive effects.

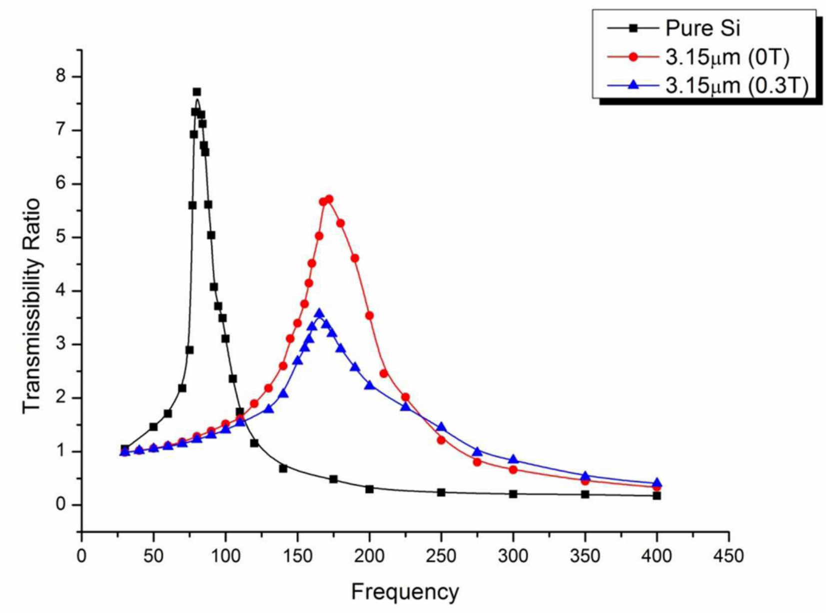

Fig. 3.a. Transmissibility Ratio V/s Input frequency comparison of 3.15μm MRE

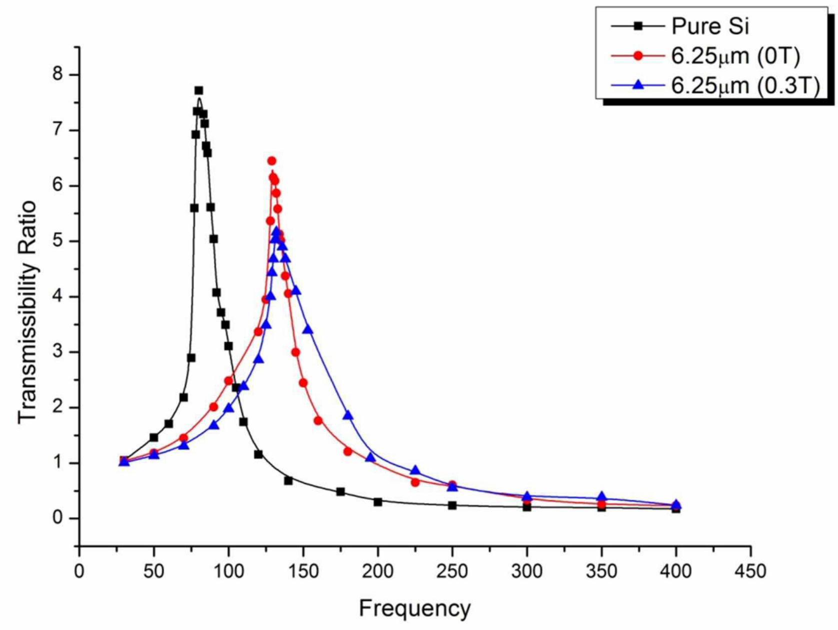

Fig. 3.b. Transmissibility Ratio V/s Input frequency comparison 6.25μm MRE

The loss factor of the samples can be calculated from the above curves by making use of the following equation.

$$\eta = 1/TR \quad (1)$$

Where, η is the loss factor and *TR* is the transmissibility ratio peak. The loss factor is approximately twice as the damping ratio ζ which is the extent of damping capability of any material. Plots reveal that addition of iron powders has improved the damping characteristics of the Si which is evident from the reduction in the transmissibility ratio in the resonance region of the curves. The MR effect can be defined as the ratio change in loss factor to the loss factor of Pure-Si.

$$\Delta\eta = (\eta_{0.3T}^{3.15} - \eta^{Si}) / \eta^{Si} \quad (2)$$

Where $\Delta\eta$ is the change in loss factor, $\eta_{0.3T}^{3.15}$ is the loss factor of 3.15 μm MRE at 0.3T and η^{Si} is the loss factor of Pure- Si sample. The loss factor values and the respective percentage enhancements are listed in table 2 below.

Table 2. Loss factor values calculated from the transmissibility plots.

Sample	Loss factor		% increase	
	0 Tesla	0.3 Tesla	Absolute	Relative
Pure Silicone	0.129	0.129	NA	
3.15 μm MRE	0.175	0.279	35.65	116.27
6.25 μm MRE	0.155	0.1934	20.15	49.92

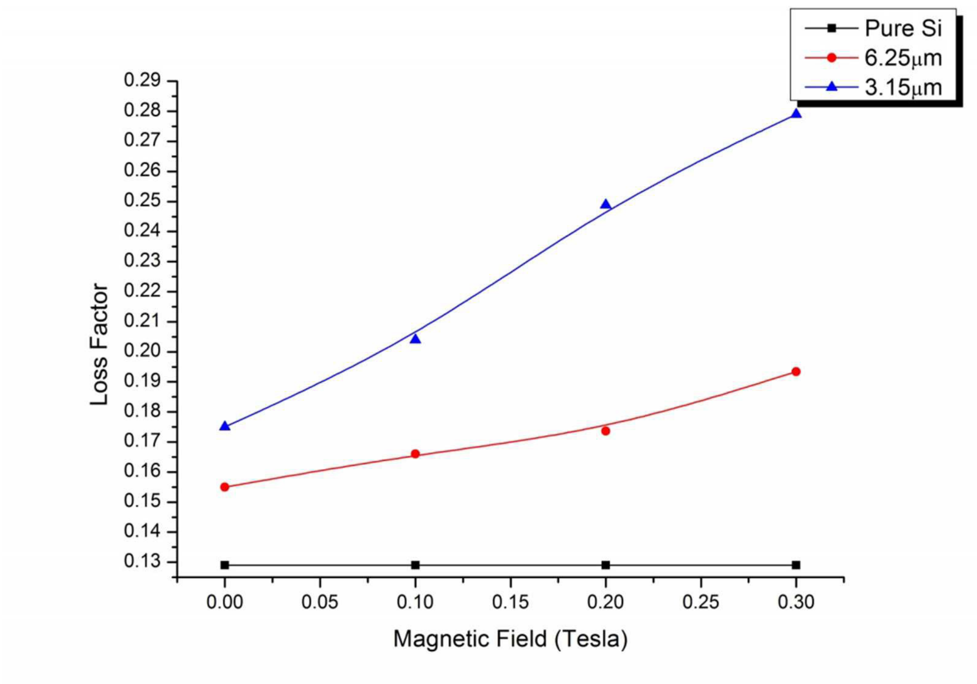

Fig. 4. Loss factor variation with magnetic field

The 3.15 μm MRE showed an improvement of about 115% when compared to Pure-Si sample and 6.25 μm MRE showed about 50% enhancements in loss factor. The loss factor variation of the samples with magnetic field is shown figure 4. The 3.15 μm MRE showed better MR effect than other samples in the current set of experiments. Zero field improvement in the property is due to the composite like behavior of the MREs where the CIP can be assumed as fiber ingredients. The property enhancement of MRE with the magnetic field is due to the fact that the

CIP gets aligned along the flux lines. During this process, there will be interfacial-friction between the iron particles and the elastomer matrix resulting in an improvement in damping property. From the microstructure photographs, it was clear that the 3.15 μm MRE had more agglomeration which results in an increased effective diameter of the particles. Under the influence of magnetic field, there is a dipole moment formation between adjacent particles given by the relation below (X.L. Gong 2005).

$$m_a = 4\pi\mu_m\mu_0 R\beta H \tag{3}$$

Where, μ_0 is the vacuum permeability, μ_p is the relative permeability of the particles, R is the radius of the particles and $\beta = \left(\mu_p - \mu_m\right) / \mu_p + 2\mu_m$

From the relation (3) it can be seen that with increase in the effective radius, because of the agglomeration, the dipole moment is increased which in turn improves the damping properties. It can be demonstrated by a simple diagram (figure 5).

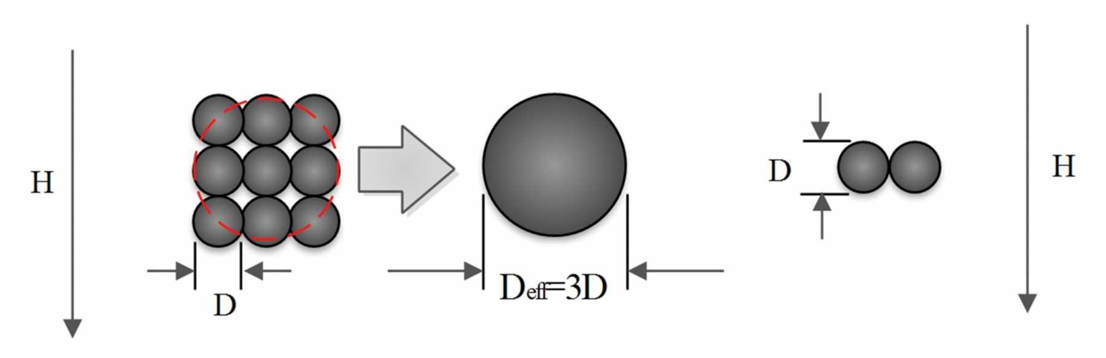

Fig. 5. Increase in effective diameter due to agglomeration

Consider a simple assumed agglomeration of particles and the direction of the field and the direction of the magnetic field are shown with the arrow mark. In the first case, the effective diameter is 3D which is 3 times that of the second case. Obviously in the first case the dipole moment is more resulting in better performance. From the microstructure photographs, it is clear that in case 3.15 μm MRE, the agglomeration in the direction of magnetic field is more than that of 6.25 μm MRE which is evident from the transmissibility ratio plots. Obviously, in the current study, the smaller diameter particles have shown better performance. More studies are necessary to come to concrete conclusions about the extent of influence of the size of particles on the MRE performance by employing different sized particles.

4. Conclusions

The current work was aimed at understanding the influence of particle ingredient size on the performance of Si-RTV based MRE. Test set up was made and the samples were tested at different conditions and the following conclusions can be drawn from the current work. The smaller sized iron particles showed more agglomeration in the matrix. Both sample of MRE showed good enhancements when compared with Pure-Si sample.3.15 μm diameter MRE showed 115% improvement in loss factor, where as 6.25 μm MRE showed about 50%. The agglomeration in the direction of magnetic field was found to be advantageous in the current work which resulted in the smaller sized particle showing better performance. The results show that the RTV-Si MRE can be a potential material for damper.

Acknowledgements

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References

B X Ju, M Yu, J Fu, Q Yang, X Q Lin, X Zheng, 2012. A novel porous magnetorheological elastomer: Preparation and evaluation. Smart Mater. Struct. 035001 (10pp).

J. David Carlson, and Mark R. Jolly, 2000. MR Fluid, foam and elastomer devices. *Mechatronics,* Elsevier Science Ltd., pp.555-569.

Jie Yang, Xinglong Gong, Huaxia Deng, Lijun Qin and Shouhu Xuan, 2012. Investigation on the mechanism of damping behaviour of magnetorheological elastomers. Smart Mater. Struct. 125015 (11pp).

LI Jian-feng, GONG Xing-long, 2008. Dynamic damping property of magnetorheological elastomer. Journal of Central South Univ. Technol. 15(s1): 261−265.

Lin Chen, Xin-long Gong, Wei-hua Li, 2008. Damping of Magnetorheological Elastomers. Chinese journal of chemical physics,5pp.

magnetorheological elastomers. Smart Mater. Struct. 035007 (8pp).

Weihua Li, and Xianzhou Zhang, 2008. Research and Applications of MR Elastomers. *Recent Patents on Mechanical Engineering.* Bentham Science Publishers Ltd, pp.161-166.

X.L. Gong, X.Z. Zhang, P.Q. Zhang, 2005. Fabrication and characterization of isotropic magnetorheological elastomers. Polymer Testing 24. Pp 669–676.

Yanceng Fan, Xinglong Gong, Shouhu Xuan, Wei Zhang, Jian Zheng1 and Wanquan Jiang, 2011. Interfacial friction damping properties in