International Journal of Scientific & Engineering Research, Volume 5, Issue 2, February-2014 1664
ISSN 2229-5518

Testing of RTV-Silicone based thick magnetorheological elastomers under harmonic loading conditions

Sriharsha Hegde, K.V. Gangadharan

Abstract— Magnetorheological elastomers (MRE) are a type of smart materials whose properties can be enhanced under the influence of a strong magnetic field.MREs consits of an elastomers matrix dispersed with ferromagnetic powders. In the present work, room temperature vulcanizing (RTV) silicone based isotropic MREs were prepared by varying the percentage volume concentration of carbonyl iron particle ingredients.The sample microstructures were studied under confocal microscope. The dynamic damping charecteristics were investigated under varying magnetic fields by applying harmonic loading conditions using electrodynamic shaker. Transmissibility ratio plots were employed to calculate the damping ratio of the samples.Test results showed that damping ratio of the samples improved under higher magnetic fields. Stress-strain graphs were plotted and these graphs revealed the hysteretic nature of the damping of the prepared samples.

Index Terms— Carbonyl iron powder, RTV Silicone, MRE, Magnetorheological elastomer, transmissibility ratio, dynamic damping, and confocal microscopy.

---

1 INTRODUCTION

THE materials which respond to the changes in the ambient conditions can be classified as smart materials. Smart materials play a major role in improving the performance of real-time systems. Piezoelectric materials, Shape memory alloys, Thermo chromic materials, Photo chromic materials and Magnetorheological Fluids/Elastomers are some commonly used smart materials. Magnetorheological elastomers (MRE) are smart materials which have ferromagnetic particle ingredients in a non-magnetic medium [1] and their rheological properties can be controlled rapidly and reversibly by an externally applied magnetic field [2]. In the recent years, MREs have created lot of interest because of some obvious advantages it has over MR fluids like, the ferromagnetic particles do not settle down and it is easy to store [3]. There are number of materials when it comes to choosing materials for preparations of MRE. Ferromagnetic ingredients used for the preparation of MREs are magnetically polarizable powders of iron, nickel or cobalt particles of size ranging from 5 to 100 □m in diameter. One of the most popular materials is carbonyl iron powder in the range of 1 to 10□m diameter in size.Many different matrix materials are available like natural rubber, silicone rubber, thermosetting rubber, synthetic rubber and so on. Two types of MR elastomers have been classified depending on the curing method, isotropic if it is not cured under strong magnetic field. In this case, the ferromagnetic particles are randomly distributed in the matrix and this is called Elastomer ferromagnetic composite, and it is also referred to as isotropic MRE. When the curing is done under a magnetic field, the ferromagnetic particles get aligned along the direction of flux path and these may be referred to as structured or anisotropic MREs [4].

Li Jian Feng et al (2009) [5]investigated dynamic damping test of MVQ 110-2 high temperature vulcanized MRE and they concluded that strain amplitude and magnetic field influence the dynamic damping of MREs. Hyung Jo Jung et al (2010) [6] performed dynamic characterisation of silicone MRE in shear mode and they found out that Young's modulus of MREs improved with increase in magnetic flux as well strain rate. Various mathematical modelling approaches like Kelvin model, Voigt model, and Maxwell model can be applied to predict the behaviour of MREs. Mark Jolly et al (1996) [7] developed a quasi-static one dimensional model to predict the mechanical and magnetic properties of MRE. The model is semi-empirical i.e. to fit in the experimental data, an unmodelled parameter data should be adjusted to account for magnetic non-linearities. A.C Shivaram and Gangadharan (2007) [8] conducted experimental study on MR fluid damper and found that magnetic field strength and percentage volume fraction of particles are the major influencing parameters.

In the current work, an attempt has been made to understand the influence of percentage concentration of iron powders and the magnetic field intensity on the dynamic performance of isotropic MRE prepared by RTV silicone. The prepared MRE sample can be classified as thick elastomers since the thicknes is 16mm and in most experiments, the samples are about 1mm to 3mm thick. Hysteretic nature of the damping shown by the prepared MREs was also investigated.

2 MATERIAL PREPARATION

In the current work, 2 part RTV silicone from Dow Corning was used as elastomer matrix. An aluminum mould of dimensions 34mm x 34mm x 16mm was fabricated to prepare the MRE samples. 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 from the mould. Four samples were prepared by varying the percentage concentration of carbonyl iron powder ingredients (Pure silicone, 15%, 20% and 25% by volume). Before adding

ISSN 2229-5518

the curing agent, carbonyl iron powder was mixed with silicone resin and was properly stirred to ensure uniform distribution. In this work, BASF carbonyl iron particles of average diameter of about 5 μm were used. Figure 1 below shows the microstructure images of the prepared samples taken from Olympus confocal microscope. The figure (a) shows the microstructure of pure silicone and other three figures (b, c and d) show the 15%, 20% and 25% samples respectively. The addition of carbonyl iron powders results in a change of colour from white to black. The bright spots in the figures b, c and d are the iron powders.The images show the uniformly distributed carbonyl iron powders in elastomer matrix. This shows the isotropic nature of the prepared MRE samples.

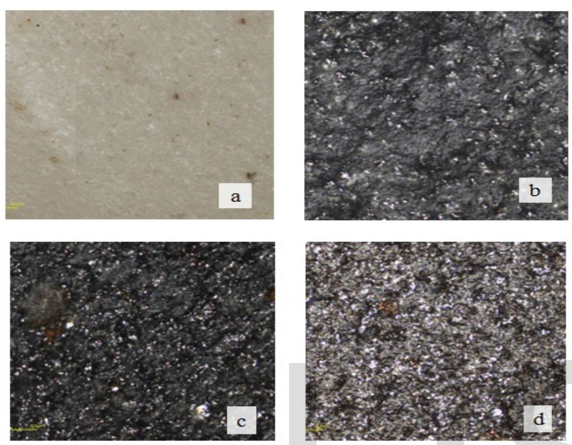

Fig. 1 Microstructure of the samples: a-Pure silicone, b-15%, c-20% and d-25% volume concentration MRE.

3 EXPERIMENTAL METHODS AND INSTRUMENTATION

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. Keeping the acceleration constant at 10 m/sec^2 throughout the experiment, the harmonic excitation frequency was varied from 40 Hz to 300 Hz. In the current experiment, manual frequency sweep was used instead of sine sweep to avoid errors in data acquisition.Neodymium rare-earth permanent magnets (Grade 32) were used as a source of magnetic field. The magnetic field intensity variation across the elastomer is achieved by varying the distance or air gap between the magnets and elastomer using a modified self-centering vice. The magnetic field was varied from 0 Tesla to 0.3 Tesla in steps of 0.1 Tesla.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.

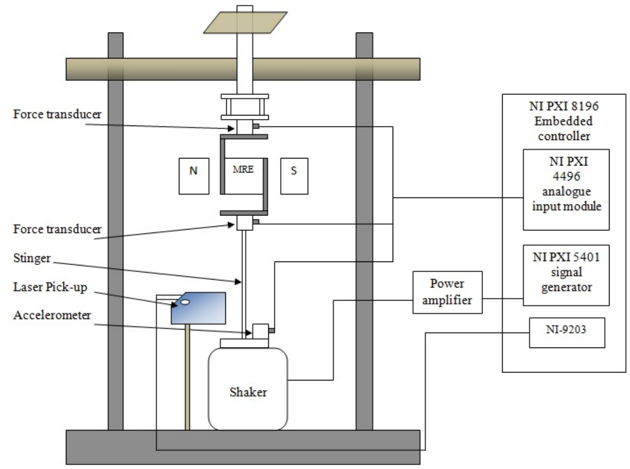

Fig.2. Schematic representation of Experimental setup Microstructure of the samples: a-Pure silicone, b-15%, c-20% and d-25% volume concentration MRE.

4 RESUTLS AND DISCUSSIONS

4.1 Transmissility Ratio analysis

From the data acquired from the experiments, Force transmissibility was plotted against the input frequency as shown in figure 3, to analyse the dynamic damping charecteristics of the prepared samples. For clarity of represenatation, the pure silicone graph is fully shown and only the resonance regions of the other samples are highlighted. For the ease of comparison, only plots of 0 Tesla and 0.3 Tesla magnetic fields are shown. The loss factor □ of all the samples can be computed from the graphs by making use of Mechanical vibrations theory. Transmissibility ratio peak and the loss factor are related as shown in the equation below.

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

Where η is the loss factor and TR is the transmissibility ratio peak.The loss factor and the damping ratio are related by,

$$\eta = 2\varsigma \quad (2)$$

Where, ζ is the damping ratio of the material which is the ratio of damping coefficient of the material C (Ns/m) and critical damping coefficient Cc of the sample. The loss factor value is the extent of damping capability of a material and by making use of the above equation, the loss factor of all the samples were calculated from the transmissibility curves.From the graphs, the improvement in loss factor can be deduced in two ways, one is that at resonance region there is a decrease in the transmissibility ratio peak and other is the width of the graphs at resonance is increasing. The loss factor values of all the samples are tabulated in the table below.

It can be observed from the graph that the loss factor of sample increased with the increasing carbonyl iron powder percentage as well as with the magnetic field. The improvement in the zero-field preoperties is due to the fact that the addition of iron powder in the rubber matrix makes it like a composite material which improves the mechanical properties of the MRE which is evident from the improved loss factor.

TABLE 1 LOSS FACTOR OF MRE SAMPLES

Material	Loss factor		% increase	
	0Tesla	0.3Tesla	Absolute	Relative
Pure Silicone	0.132	0.132	NA	NA
15% MRE	0.135	0.145	2.35	10
20% MRE	0.153	0.167	15.9	26.9
25% MRE	0.235	0.290	77.8	125.0

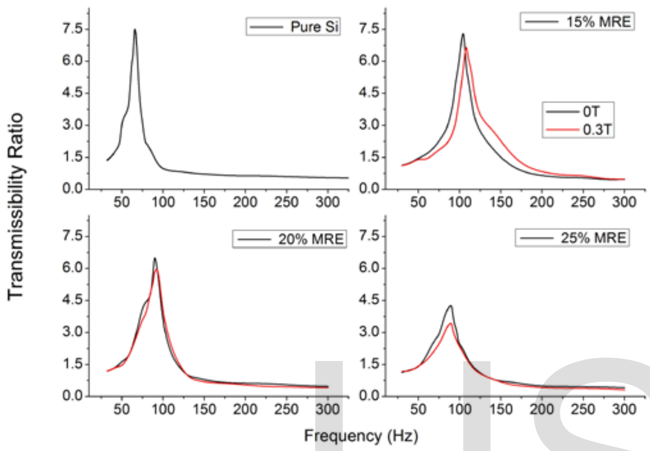

Fig.3. Transmissibility ratio plotted against the input frequency.

Under the influence of the magnetic field, the embedded iron particles gets aligned in the direction of flux lines which results in enhancement in the properties. In the current experiment, the loss factor of pure Silicone sample was found to be 0.132 and the 25% MRE sample 0.235 showing an improvement of about 75%.

The variation of loss factor with the magnetic filed of all samples are shown in figure4. The loss factor increased as the percentage of iron powders were increased, also with the variation of magnetic field. In the current experiment, the loss factor variation with magnetic field was higher for the higher percentage concentration samples (25% MRE showed better results than other samples).

It was interesting to note that eventhough there was an improvement in damping ratio when carbonyl iron powders were included; the change in natural frequency of the system was not significant. It increased from sample to sample with increase in percentage concentration, but the relative change with the magnetic field effect was not eveident. This is propably because of the influence of the modal mass which was much higher when compared to the changes in the stiffness of sample.

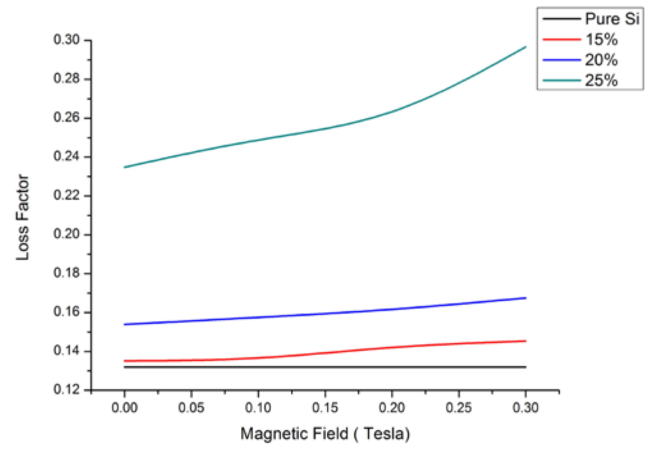

Fig.4. Loss factor variation of all the samples with magnetic field

4.2 Hystersis Plot analysis

In order to investigate the damping nature of the MREs, stress versus strain graphs were plotted. By making use of a non contact type displacement sensor, the displacement was measured at a frequency of excitation of 6 Hz. Human beings are most sensitive to vibrations of frequencies between 4 to 9 Hz ; hence in the current experiment a frequency of 6 Hz was chosen. The graphs are displayed in the figure 5 below.

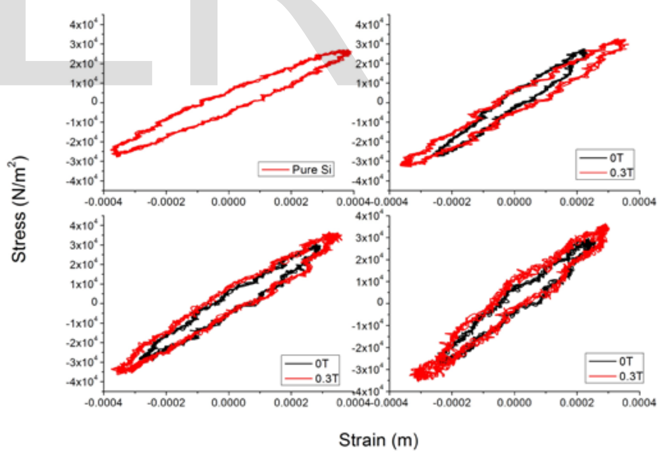

Fig.5. Stress versus strain plots of the samples

Graphs revealed the hysteretic nature of damping of all the prepared samples. The area under the curve indicates the energy dissipated per cycle of operation. The area of the curves increased with percentage concentration as well as with magnetic field. This indicates that the thick MRE samples also show viscoelastic behavior. Also, as magnetic field is increased, the dynamic damping capabailities were observed to increase. The sample with the higher percentage of iron powders showed better performance, this probably is because with the increasing ferromagnetic ingredients, the magnetic permeability of the MRE increases which results in better response of the sample to the applied magnetic field.These results also promise that RTV silicone can be a potential material in dampers. As seen from the figure 5, the shape of the curves for all the samples was fairly symmetrical. If the behavior is non-linear, the curves would be unsymmetric. This proves the linear behaviour of the samples in this frequency.

5 Conclusions

RTV silicone based MREs were prepared and tested to investigate the enhancement of dynamic damping properties and the hysteretic nature of the samples. The following conclusions were made.

- By incorporating ferromagnetic carbonyl iron powders in the elastomer matrix, the dynamic properties can be improved. In the current set of experiments, the loss factor improved not only with the increasing particle concentration, but also with the magnetic field.
- Tested MREs with higher percentage concentration showed better performance than the samples with lesser particle concentrations.
- Stress versus strain graphs showed that the behaviour of the prepared MREs were linear at 6 Hz frequency.
- It was also observed that natural frequencies of the sample increased with increase in particle concentrtion, but not with magnetic field.

Acknowledgment

The experimental facilities for the current work were provided by the Centre for System Design (CSD), NITK and SOLVE, the Virtual Lab, Government of India.

References

[1] J. David Carlson, and Mark R. Jolly, "MR Fuid, foam and elastomer devices," *Mechatronics,* Elsevier Science Ltd., pp. 555-569, 2000.

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

[3] Marke Kallio, "The elastic and damping properties of magnetorheological elastomers," *VTT publications.* , pp. 1-149, 2005.

[4] C. Ruddy, E. Ahearne, and G. Byrne, "A review of magnetorheological elastomers: Properties and applications," *Proceedings of the International Manufacturing Conference (IMC) 24,* pp. 999-1005.

[5] LI Jian-feng, and Gong Xing-long, "Dynamic damping property of magnetorheological elastomer," *Journal of Central South Univ. Technol.J.* , pp 261−265, 2008.

[6] Hyung-Jo Jung, Sung-Jin Lee, Dong-Doo Jang, In-Ho Kim, Jeong-Hoi Koo, and Fazeel Khan" Dynamic Characterization of Magneto-Rheological Elastomers in Shear Mode", *IEEE Transactions on magnetics, vol. 45, NO. 10*,2009.

[7] Mark R Jolly, J David Carlson, and Beth C Mu˜noz, "A model of the behaviour of magnetorheological materials," *Smart Materials and Structures*, pp. 607–614, 1996.

[8] A C Shivaram, and K V Gangadharan, "Statistical modelling of a magnetorheological fluid damper using the design of experiments approach," *Smart Materials and Structures*, pp. 1310–1314, 2007.

[9] G YZhou, and J R Li, "Dynamic behavior of a magnetorheological elastomer under uniaxial deformation: I. Experiment," *Smart Materials and Structures*, pp. 859–872, 2003.