International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-7 Issue-4S2, December 2018

Effect of Graphite Reinforcement on the Resistivity Property of Magnetorheological Elastomer (MRE)

Muhammad Kashfi Shabdin, Mohd Azizi Abdul Rahman, Saiful Amri Mazlan, Siti Aishah Abdul Aziz, Irfan Bahiuddin

Abstract*: *Resistivity property of graphite based MRE is demonstrated in the present research. In this paper, a study on the force sensitive property by using a composite of graphite (Gr) and magnetorheological elastomer (MRE) is suggested where graphite powder was used as a conductive element in the composite. The carbonyl iron particles and graphite powder were mixed in the silicon rubber to produce the Gr-MRE composite. The resistivity properties are then identified from a designated test rig that delivers different magnitude of the applied force on the sample. Results showed that the resistivity of the material decreased as the applied force increase from 700 to 1000g, where the magnitude of the resistance decreases approximately 79 to 66%. By having higher magnetic flux density in the material, the stiffness of the Gr–MRE could possibly be controlled depending on the magnitude of the force.

Index Terms*: *Magnetorheological Elastomer, Graphite, Resistivity Property.

I. INTRODUCTION

Magnetorheological elastomer (MRE) is a group of material that can reflect smart material because of their rheological and mechanical properties including modulus and damping capability, that can change reversibly and continuously when introduced to magnetic field (Dang, Ooi, Fales, & Stroeve, 2000; de Vicente, Klingenberg, & Hidalgo-Alvarez, 2011; Jolly, Carlson, & Muñoz, 1999; Park, Fang, & Choi, 2010; Sorokin et al., 2014). MRE comprises micro size magnetic particles (carbonyl iron) which suspended in a nonmagnetic medium such as silicon rubber (Carlson & Jolly, 2000; W. H. Li, Du, Chen, Yeo, & Guo, 2002). The arrangement of the particles in MRE leads to either isotropic or anisotropic MRE (Ju et al., 2015; Kaleta, Królewicz, & Lewandowski, 2011; Yoon et al., 2013). When magnetic field subjected to the magnetic particles in the MRE, they aligned to form anisotropic MRE while isotropic MRE has no particles alignment because the magnetic field is absent during curing process. The advantages of using MRE are we do not have to deal with sedimentation and leakage issue as in magnetorheological fluids (MRF) (Fuchs, Zhang, Elkins, Gordaninejad, & Evrensel, 2007; Yang, Qin, Rao, Ta, & Gong, 2014), and the shape of MRE is flexible, which makes it applicable to various engineering fields. However, MRE has some limitations as in low MR effect, mechanical and damping properties, which still limit its usage in the further application.

While significant researcher focuses on the magnetic field dependent properties of MREs, some researchers diverge their focus on the magnetostrictive properties of MRE. In (Bossis, Abbo, Cutillas, Lacis, & Métayer, 2001), showed that the isotropic MRE showed resistance change detected from about 5^6 to 0.7^1 when the magnetic field applied was increased from 0-6000Oe. This experiment demonstrates a phenomenon where the external magnetic fields, in fact, reduce the resistance of MRE. Another researcher (W. Li, Kostidis, Zhang, & Zhou, 2009), showed that the optimum MRE composition was 55% carbonyl iron, 20% silicon rubber and 25% graphite powder with the standard method used to fabricate the MRE.

The resistivity property usually tested by using a designated test rig. The mechanical part of the design by Li et al. consists of 8 components which: upper plate, O – ring, casing/cover, spring, button, MRE sample, base holder, and a lower plate. With the proposed design, it can detect a normal applied force of 0 – 50 N, with a reduction of resistance in magnetic field from 0mT to 600mT. However, to the author's best knowledge, there is insufficient work on the development of Gr-MRE with high graphite composition (more than 30wt%) that can detect the force with specific magnitude while controlling the stiffness of the MRE. There is no report on the correlation between the resistance property with stiffness control, and this work aims to address the point at issue.

This paper is organized as follows. Followed by the introduction, the fabrication of Gr – MRE samples was detailed.

The resistivity properties will be reported in the results and discussion section. The

Revised Manuscript Received on December 30, 2018.

Muhammad Kashfi Shabdin, Advanced Vehicle System Research Laboratory, Malaysia Japan International Institute of Technology, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, Kuala Lumpur, 54100, Malaysia, (co-first author).

Mohd Azizi Abdul Rahman, Advanced Vehicle System Research Laboratory, Malaysia Japan International Institute of Technology, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, Kuala Lumpur, 54100, Malaysia, (co-first author).

Saiful Amri Mazlan, Advanced Vehicle System Research Laboratory, Malaysia Japan International Institute of Technology, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, Kuala Lumpur, 54100, Malaysia, , , (co-first author).

Siti Aishah Abdul Aziz, Advanced Vehicle System Research Laboratory, Malaysia Japan International Institute of Technology, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, Kuala Lumpur, 54100, Malaysia, (co-first author).

Irfan Bahiuddin, Department of Mechanical Engineering, Vocational College, Universitas Gadjah Mada, Jl. Yacaranda Sekip Unit IV, Yogyakarta 55281, Daerah Istimewa Yogyakarta, Indonesia, Irfan.

major result will be compiled in the conclusion section.

II. EXPERIMENTAL METHODS

2.1 Materials

The carbonyl iron particles (CIP) used was purchased from BASF, Germany with an average size of 6µm. RTV Silicone Rubber (SR), NS625, was obtained from Nippon Steel Co, Japan. Graphite powder, Gr (code: 8169-00) with an average size of 16 µm and a density of 2.266 gcm^{-3} was obtained from R&M Chemicals, Evergreen Engineering and Resources Co., Malaysia. Silicone oil DC200 (100CS) used was purchased from Yureka Sdn. Bhd, Malaysia.

2.2 Gr – MRE Sample Preparation

The conventional mixing method was used in the fabrication of Gr-MRE sample. Firstly, carbonyl iron was mixed with silicone rubber and silicone oil into a beaker at room temperature and stirred for 10 minutes to ensure a homogenous mixture. Secondly, graphite was added to the mixture and stirred again for another 10 minutes. Then, the mixture was transferred to a mold with 60mm in diameter and 1mm thickness. Finally, the mixture was placed in the mold for curing and left for an hour. After demolding, the sample was ready for testing. The components used to fabricate the Gr-MRE is shown in Table 1. The sample contains the compositions of 12.5g carbonyl iron particles, 22.5g silicone rubber, 20g (33wt%) graphite and 5g silicone oil. The composition used was 60g in total to accommodate the mechanical stirrer used in the experiment. Li et al. (W. Li et al., 2009) and Tian et al. (Tian, Li, Alici, Du, & Deng, 2011) have done their experiment with 30 and 23.81 wt%.

Table 1. Components of Gr–MRE sample

Compound elements	Weights (g)
	Gr-MRE
Carbonyl iron (3-5µm)	12.5
Silicon rubber	22.5
Graphite (16µm)	20 (33wt%)
Silicone oil	5

The conductivity of the Gr-MRE was determined by using a simple digital multimeter (DMM). The complete close circuit shows that Gr-MRE is conductive. A designated test rig was developed to detect the resistance from the exerted force from the subject. Figure 1 shows a complete circuit is connected in parallel order with a power source and a Data Acquisition module (DAQ) – National Instrument™. In this experiment, the force is given by the slotted weights (A3973, Progressive Scientific Sdn. Bhd). The slotted weights are in the range of 10-1000g. After the connection has been set up, the off-state testing is done by placing the 100g weight onto the Gr-MRE followed by other weight in increasing order of 100g for each testing. The on-state testing was carried out in the same condition except for the Gr-MRE was sandwiched between permanent magnets. These magnets are used to introduce magnetic field to the Gr-MRE so that the change in the mechanical properties of the material could be investigated. The off and on-state happen with the absence or presence of magnetic fields respectively.

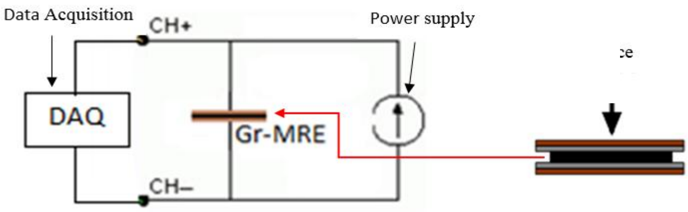

Figure 1. Circuit schematic for resistivity testing.

III. RESULTS AND DISCUSSION

Figure 2 shows the magnitude of the resistance in applied weight in magnetic field variation. The experiment was done by introduced 700 to 1000 g of weight with magnetic field variation of 0 to 0.245T and the magnitude of the resistance were recorded. The calibration of the data acquisition system is fixed at 10kΩ so that the resistance drop can be detected easily instead of fluctuating values. At 0, 0.181, 0.214 and 0.245A, the resistance reduction could be observed at approximately 79, 72, 71, and 66% respectively.

The trend of resistance magnitude that decreases followed by increasing weight exerted on the top of the sample explains the field-induced particle motion. During on-state condition where magnetic field was increased, this would increase the particles magnetization and the attractive force between particles. These particles tend to form a chain structure, which resulted in the increment of conductivity and the reduction of resistance magnitude. The results agree with Li et al. that the resistance magnitude decrease rate is more than 60% with the increase of applied force (W. Li et al., 2009). This phenomenon shows that as the magnetic field intensity increases, the resistance magnitude reduces accordingly.

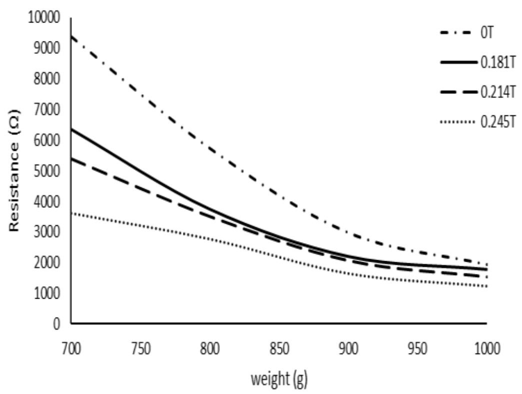

Figure 2. Resistance reduction in magnetic field variation

Figure 3 shows the resistance reduction in specific applied weight throughout 0 to 0.245T of the magnetic field. At 700, 800, 900 and 1000g, the magnitude of resistance reduces to approximate 61, 52, 45 and 37% respectively.

Magnetic fields cause magnetic particles to align themselves thus also interact with the graphite particles. The interaction between these particles reduces the resistance in the sample while controlling the stiffness of the sample during exerting force applied to the sample.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

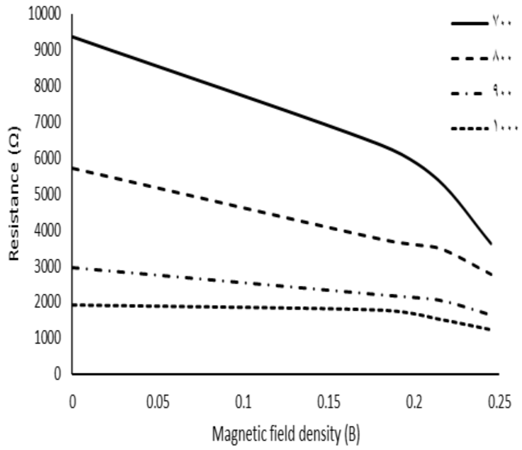

Figure 3. The resistance versus magnetic field at 700g to 1000g.

IV. CONCLUSION

Graphite based MREs were fabricated in this study, and a test rig was set up to detect the resistance magnitude output from the applied weight input. The observation shows that the graphite element filled in the MRE composition affect the formation of particles chain under the influence of magnetic field. The tested graphite weight fraction was 33%, which affect the conductivity of Gr-MRE by the chain alignment of iron and graphite particles and the resistivity reduction detected between 79% to 66% in the range of 700-1000g applied load.

V. ACKNOWLEDGMENTS

The author gratefully acknowledges the financial support by the Ministry of Education Malaysia and Universiti Teknologi Malaysia under grant vote no: 19H94, and PDRU (04E02).

REFERENCES

1. Bossis, G., Abbo, C., Cutillas, S., Lacis, S., & Métayer, C. (2001). Electroactive and Electrostructured Elastomers. *International Journal of Modern Physics B*, *15*(06n07), 564–573.
2. Carlson, J. D., & Jolly, M. R. (2000). MR fluid, foam and elastomer devices. *Mechatronics*, *10*(4), 555–569.
3. Dang, a., Ooi, L., Fales, J., & Stroeve, P. (2000). Yield Stress Measurements of Magnetorheological Fluids in Tubes. *Industrial & Engineering Chemistry Research*, *39*, 2269–2274.
4. de Vicente, J., Klingenberg, D. J., & Hidalgo-Alvarez, R. (2011). Magnetorheological fluids: a review. *Soft Matter*, *7*(8), 3701.
5. Fuchs, A., Zhang, Q., Elkins, J., Gordaninejad, F., & Evrensel, C. (2007). Development and Characterization of Magnetorheological Elastomers. *Journal of Applied Polymer Science*, *105*, 2497–2508.
6. Jolly, M. R., Carlson, J. D., & Muñoz, B. C. (1999). A model of the behavior of magnetorheological materials. *Smart Materials and Structures*, *5*(5), 607–614.
7. Ju, B., Tang, R., Zhang, D., Yang, B., Yu, M., & Liao, C. (2015). Temperature-dependent dynamic mechanical properties of magnetorheological elastomers under magnetic field. *Journal of Magnetism and Magnetic Materials*, *374*, 283–288.
8. Kaleta, J., Królewicz, M., & Lewandowski, D. (2011). Magnetomechanical properties of anisotropic and isotropic magnetorheological composites with thermoplastic elastomer matrices. *Smart Materials and Structures*, *20*(8), 085006.
9. Li, W. H., Du, H., Chen, G., Yeo, S. H., & Guo, N. Q. (2002). Nonlinear rheological behavior of magnetorheological fluids: step-strain experiments. *Smart Materials and Structures*, *11*(2), 209–217.
10. Li, W., Kostidis, K., Zhang, X., & Zhou, Y. (2009). Development of a Force Sensor Working with MR Elastomers, 233–238.
11. Park, B. J., Fang, F. F., & Choi, H. J. (2010). Magnetorheology: materials and application. *Soft Matter*, *6*(21), 5246.
12. Sorokin, V. V., Ecker, E., Stepanov, G. V., Shamonin, M., Monkman, G. J., Kramarenko, E. Y., & Khokhlov, A. R. (2014). Experimental study of the magnetic field enhanced Payne effect in magnetorheological elastomers. *Soft Matter*, *10*(43), 8765–8776.
13. Tian, T. F., Li, W. H., Alici, G., Du, H., & Deng, Y. M. (2011). Microstructure and magnetorheology of graphite-based MR elastomers. *Rheologica Acta*, *50*(9–10), 825–836.
14. Yang, Z., Qin, C., Rao, Z., Ta, N., & Gong, X. (2014). Design and analyses of axial semi-active dynamic vibration absorbers based on magnetorheological elastomers. *Journal of Intelligent Material Systems and Structures*, *25*(17), 2199–2207.
15. Yoon, J.-H., Yang, I.-H., Jeong, U.-C., Chung, K.-H., Lee, J.-Y., & Oh, J.-E. (2013). Investigation on Variable Shear Modulus of Magnetorheological Elastomer Based on Natural Rubber due to Change of Fabrication Design. *Engineering*, *53*(5), 992–1000.
16. A. Nakamura, "Self-adaptive e-learning website for mathematics," International Journal of Information and Education Technology, vol. 6, no. 12, pp. 961-965, 2016, DOI: 10.7763/IJIET.2016.V6.825.
17. A. Nakamura, "Graph drawing of knowledge structure of mathematics," The SIJ Transactions on Computer Science Engineering & its Applications (CSEA), vol. 2, no. 4, pp. 161-165, June 2014.
18. A. Nakamura, "Hierarchy construction of mathematical knowledge," Lecture Notes on Information Theory, vol. 2, no. 2, pp. 203-207, June 2014. DOI: 10.12720/lnit.2.2.203-207.
19. A. Nakamura, "Graph drawing of knowledge structure of mathematics combined with knowledge level," Proceedings of INTED2015 Conference (9th International Technology, Education and Development Conference), 2-4 March 2015, Madrid, Spain, pp. 2576-2579.
20. A. Nakamura, T. Kudo, and K. Nishioka, "Development of the visualizing system of knowledge structure based on STEM e-learning website," Proceedings of the 9th International Conference on Language, Innovation, Culture & Education 2018, 24-25 February 2018, Bangkok, Thailand, pp. 55-61.
21. A. Nakamura, "The development of math learning materials: integrating print materials and web materials utilizing a mobile phone," Proceedings of IADIS International Conference Mobile Learning 2010, 19-21 March 2010, Porto, Portugal, pp. 393-396.
22. A. Nakamura, "Math learning materials combining print materials and web based training," proceedings of 14th International Conference on Interactive Collaborative Learning (ICL2011)– 11th International Conference Virtual University (vu'11), 21-23 September 2011, Piestany, Slovakia, pp. 214 - 218, doi:10.1109/ICL.2011.6059578.
23. A. Nakamura, T. Kudo, and K. Nishioka. "The concept of self-adaptive integrated web based learning environment for STEM," Proceedings of The Fifth International Conference on E-Learning and E-Technologies in Education (ICEEE2016). 6-8 September 2016, Kuala Lumpur, Malasyia, pp. 50-54.
24. K. Nishioka, T. Kudo, and A. Nakamura, "Learning support website of physics with emphasis on connection with mathematics," Proceedings of The 9th International Multi-Conference on Complexity, Informatics and Cybernetics 2018, 13-16 March 2018, Florida, USA, pp. 155-157.
25. KIT Mathematics Navigation (2004-)..Available at http://w3e.kanazawa-it.ac.jp/math/
26. KIT Physics Navigation (2016-)....Available at http://w3e.kanazawa-it.ac.jp/math/physics/
27. KIT Engineering Navigation (2017-)....Available at http://w3e.kanazawa-it.ac.jp/math/engineering/
28. A. Nakamura, "Log analysis of mobile user behavior for a public-facing math e-learning site," GSFT International Journal of Education, vol. 1 no. 2, pp. 38-42, November, 2013.