UTS UNIVERSITY OF TECHNOLOGY SYDNEY

CHARACTERISATION AND MODELLING FOR ELASTOMERIC AND GEL-LIKE MAGNETORHEOLOGICAL MATERIALS

by Shaoqi Li

Thesis submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

under the supervision of Yancheng Li

University of Technology Sydney
Faculty of Engineering and IT

February 2021

CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Shaoqi Li declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Civil and Environmental Engineering at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

This research is supported by the Australian Government Research Training Program.

Production Note:
Signature: Signature removed prior to publication.

Date: 17 February 2021

CHARACTERISATION AND MODELLING FOR
ELASTOMERIC AND GEL-LIKE
MAGNETORHEOLOGICAL MATERIALS

by

Shaoqi Li

Submitted to the School of Civil and Environmental Engineering
on 22 February 2021, in partial fulfilment of the
requirements for the degree of
Doctor of Philosophy

Abstract

Magnetorheological (MR) material is an aspiring branch of smart material. It can change its mechanical properties rapidly and reversibly subjected to an externally applied magnetic field, so-called MR effect. Due to the sensitivity to magnetic field and the versatility in physical states, i.e., liquid (MR fluid), gel-like (MR gel), elastomeric (MR elastomer), MR materials have tremendous application potential in engineering industries, especially in civil engineering, involving vibration reduction and isolation for infrastructures. However, some MR materials have inherent limitations: sedimentation and instability of MR fluid, and low MR effect and large energy consumption of MR elastomer. MR gels were fabricated to gain the merits of both MR fluid and MR elastomer, i.e., high MR effect and excellent sedimentation resistance.

This work focuses on the two types of MR materials: MR elastomer and MR gel. They both significantly improve the sedimentation problem of MR fluid, yet the current knowledge and design techniques are inadequate to deliver efficient and effective applications. For MR elastomer, this work implements the hybrid magnets (permanent magnet and electromagnet) configuration in both characterisation and engineering applications to resolve the large energy consumption issue. Moreover, an improved magnetic circuit model is proposed to serve as an effective and efficient approach for designing and analysing MR elastomer devices with complicated structures, i.e., hybrid magnets and laminated structure. In a pioneering manner, the field-dependent dynamic stress-strain hysteresis of MR gel is characterised and shows a unique stress overshoot phenomenon. A simple hysteresis model with support vector machine generalisation technique is formulated and validated the experimental results. Finally, thixotropy of MR gel is characterised by a proposed test protocol considering the variables of shear rate, magnetic field, shearing time and resting time. A thixotropy model for MR gel is proposed and agrees well with the experimental date under all test conditions considered.

Thesis Supervisor: Yancheng Li

Title: Senior Lecturer, School of Civil and Environmental

Engineering, University of Technology Sydney

Acknowledgement

This doctoral thesis is the result of three and a half years of dedicated work with my supervisor, Yancheng Li, to whom I am incredibly grateful for his unwavering patience and guidance. I sincerely appreciate my co-supervisor, Jianchun Li, for his advices and contributions that greatly improved this work. I particularly thank Hong Guan and Xiaobo Qu who encouraged me to embark on this PhD journey. I also would like to acknowledge Yang Yu, Peter Watterson, Peter Brown, and Scott Graham who generously offered their expertise and support. Lastly, my family, thank you for always being there.

List of Publications during the candidature

1. **Li, S.**, Watterson, P., Li, Y., Wen, Q., & Li, J. (2020). Improved magnetic circuit analysis of a laminated magnetorheological elastomer devices featuring both permanent magnets and electromagnets. *Smart Materials and Structures*, *29*(8), 085054.
2. **Li, S.**, Liang, Y., Li, Y., Li, J., & Zhou, Y. (2020). Investigation of dynamic properties of isotropic and anisotropic magnetorheological elastomers with a hybrid magnet shear test rig. *Smart Materials and Structures*, *29*(11), 114001.
3. **Li, S.**, Tian, T., Wang, H., Li, Y., Li, J., Zhou, Y., & Wu, J. (2020). Development of a four-parameter phenomenological model for the nonlinear viscoelastic behaviour of magnetorheological gels. *Materials & Design*, *194*, 108935.
4. Yu, Y., Li, J., Li, Y., **Li, S.**, Li, H., & Wang, W. (2019). Comparative investigation of phenomenological modeling for hysteresis responses of magnetorheological elastomer devices. *International journal of molecular sciences*, *20*(13), 3216.
5. Wang, H., Chang, T., Li, Y., **Li, S.**, Zhang, G., Wang, J., & Li, J. (2020). Characterization of nonlinear viscoelasticity of magnetorheological grease under large oscillatory shear by using Fourier transform-Chebyshev analysis. *Journal of Intelligent Material Systems and Structures*, 1045389X20959466.
6. Yu, Y., Royel, S., Li, Y., Li, J., Yousefi, A. M., Gu, X., **Li, S.**, & Li, H. (2020). Dynamic modelling and control of shear-mode rotational MR damper for mitigating hazard vibration of building structures. *Smart Materials and Structures*, *29*(11), 114006.

Contents