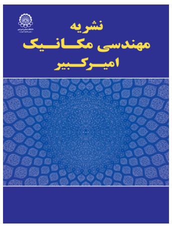


Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 55(10) (2024) 261-264
DOI: 10.22060/mej.2024.22544.7642

Investigating the Effect of Static Pre-Strain on Tension-Compression Mode Properties of Isotropic Magnetorheological Elastomers

A. M. Alimardan[1], M. Norouzi[1]*, M. Ghatee[2], M. B. Nazari[1], M. H. Izadifard[1], A. H. Yaghoobi[1]

[1] Department of Mechanical Engineering, Shahrood University of Technology, Shahrood, Iran
[2] Department of Chemical and Materials Engineering, Shahrood University of Technology, Shahrood, Iran

ABSTRACT: Magnetorheological elastomers are a class of smart materials and possess two unique features, i.e. adjustable hardness and damping capabilities. These characteristics make them widely used in various industrial applications. Hence, understanding their behavior in different systems is necessary. The focus of this work is to study the dynamic behavior of magnetorheological elastomers under different static pre-strains in tension-compression mode. In this study, three isotropic samples were fabricated and their force-deflection features were acquired under harmonic excitation with various strain amplitudes, static pre-strains, frequencies, and magnetic flux densities. Assess the effect of static pre-strain on the dynamic response of the magnetorheological elastomers, studying the effects of other parameters like strains, frequencies, and magnetic flux densities on the dynamic modulus of magnetorheological elastomers, and proposing a novel phenomenological-based model to predict the viscoelastic behavior of magnetorheological elastomers are the innovative aspects of this study. The results showed that the dynamic modulus of magnetorheological elastomers will increase by superimposing the static pre-strain. Furthermore, the relative MR effect decreases when the static pre-strain is applied. The maximum relative MR effect of 288.32% has been achieved at a strain of 4%, a frequency of 7 Hz, and without the application of static pre-strain.

Review History:

Received: Jul. 08, 2023
Revised: Dec. 11, 2023
Accepted: Jan. 08, 2024
Available Online: Feb. 02, 2024

Keywords:

Magnetorheological elastomer
Static pre-strain
Dynamic modulus
Stress-strain
Genetic algorithm

1- Introduction

Magnetorheological elastomers (MREs) are a large class of magnetorheological materials that react to external magnetic stimulation, and their rheological properties can be quickly and reversibly controlled by applying a magnetic field [1-3]. These materials are formed by placing magnetized particles in a rubber matrix and are divided into two groups, isotropic and anisotropic. The production of these two groups of elastomers depends on the presence or absence of magnetic flux density during the curing process [4]. In recent years, MREs have garnered considerable attention in engineering circles due to their tunable stiffness and damping qualities. Upon reviewing existing research, it is generally observed that previous studies have examined the dynamic behavior of MREs with consideration of a constant pre-strain. The current research aims to experimentally investigate the impact of static pre-strain on the tensile and compressive storage and loss moduli, as well as the stress-strain hysteresis traits of isotropic MREs through dynamic tension-compression testing. Additionally, the study aims to develop a comprehensive nonlinear viscoelastic model that incorporates the effect of pre-strain to gain deeper insight into the MRE's behavior under diverse loading conditions. The key innovations of this study include:

- A thorough examination of the impact of static pre-strain on the tensile and compressive storage and loss moduli, as well as the stress-strain hysteresis traits of MREs in dynamic tension-compression testing.
- An exploration into the influence of various parameters, such as frequency, strain, and magnetic flux density, on the dynamic response of MREs.
- The development of a comprehensive nonlinear viscoelastic model considering the impact of static pre-strain, aimed at predicting the stress-strain relationship and dynamic moduli of MREs under various loading conditions.

2- Methodology

In this study, according to ISO 7743 and ASTM D395-03 standards, three cylindrical MRE samples with a diameter of 29±0.5 mm and a height of 12.5±0.5 mm (shape factor 0.58) were fabricated and were composed of 70% mass fraction of carbonyl iron particles (CIPs), 20% mass fraction of silicone polymer, and 10% mass fraction of silicone oil. The dynamic tension-compression test was conducted using an INSTRON 8802 servo-hydraulic fatigue testing system. The experiment design included factorial combinations of

*Corresponding author's email: mnorouzi@shahroodut.ac.ir

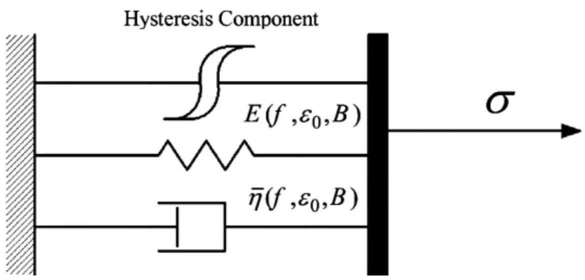


Fig. 1. The viscoelastic model presented by Vatandoost et al. [6]

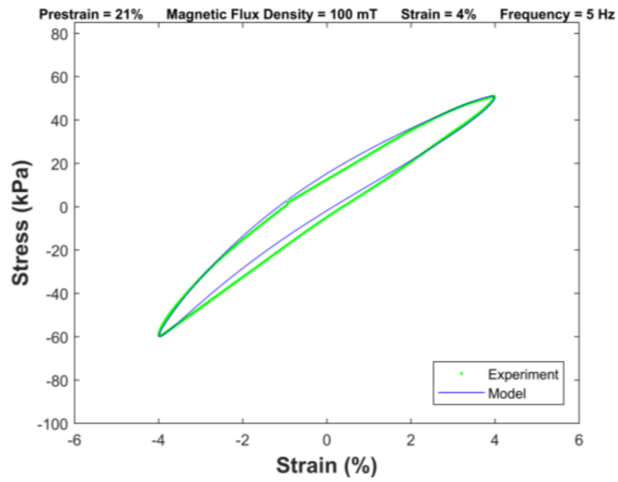
four excitation frequencies (1, 3, 5, and 7 Hz) applied at four different strains (4%, 8%, 12%, and 16%), along with four different amounts of magnetic flux density (0, 100, 200, and 300 mT), and two static pre-strains (0% and 21%) for each elastomer sample, resulting in a total of 128 tests. The steady-state force and displacement data were low-pass filtered. The moving average was selected as the smoothing method which is a low-pass filter. After filtering, the data was averaged, and the resultant mean force-displacement loop was meticulously analyzed to calculate the tensile and compressive storage and loss moduli of the elastomers. In this study, dynamic moduli were calculated by employing the Roger Brown method [5]. After the dynamic moduli calculation, the mean force-displacement loops were transformed into mean stress-strain loops to model the stress-strain hysteresis traits of the MREs. The cornerstone of this research is the introduction of a groundbreaking and comprehensive model, which integrates the effect of pre-strain in forecasting the viscoelastic behavior of MREs. This model is an enhancement of the viscoelastic model previously developed by Vatandoost et al. [6], as illustrated in Figure 1, augmented with the inclusion of a constant pre-strain factor to amplify its predictive accuracy.

By incorporating the static pre-strain constant (ε_p) into the model, its constitutive equations are predicted as Equation (1). In this equation, $\sigma_{(t)}$ and $\varepsilon_{(t)}$ are stress output and strain input, while E, η, α, and β denote the dynamic storage modulus (equivalent stiffness), loss modulus (effective viscosity, equivalent damping), the asymmetric hysteresis (or tension–compression asymmetry), and strain-stiffening behavior, respectively. Furthermore, f, B, ε_0, and ε_p correspond to the driving frequency, magnetic flux density, loading strain, and static pre-strain, respectively.

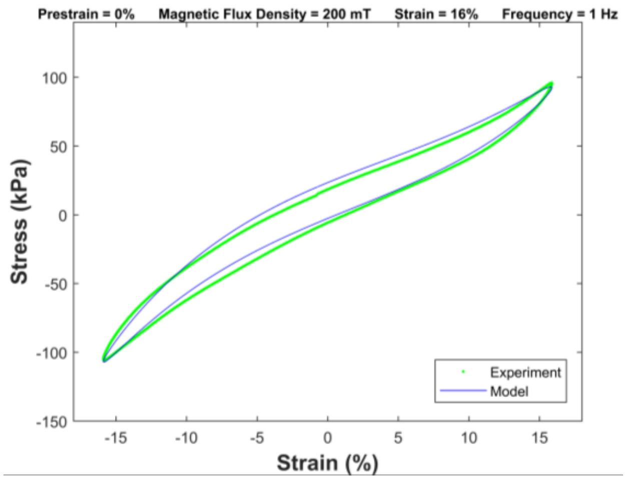
$$\begin{aligned}\sigma_{MRE} &= \sigma_{Viscoelastic} + \sigma_{Hysteresis} \\ \sigma_{Viscoelastic} &= E(f,\varepsilon_0,B,\varepsilon_p)\varepsilon(t) + \eta(f,\varepsilon_0,B,\varepsilon_p)\dot{\varepsilon}(t) \\ \sigma_{Hysteresis} &= \alpha(f,\varepsilon_0,B,\varepsilon_p)\varepsilon^2(t) + \beta(f,\varepsilon_0,B,\varepsilon_p)\varepsilon^3(t)\end{aligned} \quad (1)$$

3- Discussion and Results

The accuracy of the proposed model has been validated in Figure 2, where the predicted response of the MRE has been compared to the corresponding experimental results subject



(a)



(b)

Fig. 2. Comparisons of the stress-strain hysteresis traits estimated by the proposed model with the experimental records subject to different levels of pre-strain and excitation conditions. (a) At a strain of 4%, pre-strain of 21%, frequency of 5 Hz, and magnetic flux density of 100 mT, and (b) At a strain of 16%, pre-strain of 0%, frequency of 1 Hz, and magnetic flux density of 200 mT

to different levels of pre-strain and excitation conditions. As shown in Figure 2, the model accurately predicted the hysteresis response of the MREs at different levels of pre-strain. It is important to note that the accuracy of the model was maintained under other loading conditions and field intensities. To evaluate the accuracy of the proposed model compared to the experimental data, the fitness index has been introduced as:

$$\%fitnessvalue = \left[1 - \frac{norm\left(\tau_{Model} - \tau_{Exp}\right)}{norm\left(\tau_{Exp} - mean\left(\tau_{Exp}\right)\right)}\right] \times 100 \quad (2)$$

Where *norm* is the normal mean function and τ_{Model} and τ_{Exp} denote the estimated tension and the corresponding experimental values, respectively. Results showed a compatibility of over 90% between the proposed model and the experiments for all loading conditions and field intensities, which illustrates the capability of the model to approximate MRE characteristics in practical applications.

4- Conclusions

In this study, the impact of static pre-strain on the tensile and compressive storage and loss moduli and the stress-strain hysteresis traits of isotropic MREs in dynamic tension-compression testing was investigated and in the next step, a comprehensive nonlinear viscoelastic model considering the impact of static pre-strain, aimed at predicting the stress-strain relationship and dynamic moduli of MREs under various loading conditions was proposed. Three of the most important findings from this research are summarized as follows:

• Applying static pre-strain increases the values of tensile and compressive storage and loss moduli at all strains, frequencies, and magnetic flux densities.

• The maximum relative MR effect of 288.32% has been achieved at a strain of 4%, a frequency of 7 Hz, and without the application of static pre-strain.

• The proposed nonlinear model has a relatively accurate response (with compatibility of over 90%) for all loading conditions and can be used to approximate MRE characteristics in practical applications.

References

[1] T.J. Fiske, H.S. Gokturk, D.M. Kalyon, Percolation in magnetic composites, Journal of Materials Science, 32 (1997) 5551-5560.

[2] L. Chen, X.L. Gong, W.H. Li, Microstructures and viscoelastic properties of anisotropic magnetorheological elastomers, Smart materials and structures, 16(6) (2007) 2645.

[3] J.D. Carlson, M.R. Jolly, MR fluid, foam and elastomer devices, mechatronics, 10(4-5) (2000) 555-569.

[4] A.K. Bastola, M. Hossain, A review on magneto-mechanical characterizations of magnetorheological elastomers, Composites Part B: Engineering, 200 (2020) 108348.

[5] R. Brown, Physical testing of rubber, Springer Science & Business Media, 2006.

[6] H. Vatandoost, M. Norouzi, S.M.S. Alehashem, S.K. Smoukov, A novel phenomenological model for dynamic behavior of magnetorheological elastomers in tension–compression mode, Smart Materials, and Structures, 26(6) (2017) 065011.

HOW TO CITE THIS ARTICLE

A. M. Alimardan, M. Norouzi, M. Ghatee, M. B. Nazari, M. H. Izadifard, A. H. Yaghoobi, Investigating the Effect of Static Pre-Strain on Tension-Compression Mode Properties of Isotropic Magnetorheological Elastomers , Amirkabir J. Mech Eng., 55(10) (2024) 261-264.

DOI: 10.22060/mej.2024.22544.7642