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Experimental Analysis of Mechanical Behavior under the Effect of Temperature Frequency

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Abstract**—**Finding the mechanical properties of magnetorheological elastomers (MREs) is fundamental to create smart materials and devices with desired properties and functionalities. The MREs properties, in shear mode, have been extensively investigated, but these have been less exploited with frequency-temperature dependence. In this article, we studied the performance of MREs with frequency-temperature dependence. The elastic modulus, loss modulus and loss factor of MREs were studied under different temperature values; different values of the magnetic field and different values of the frequency. The results found showed the interest of these active materials in different industrial sectors.

Keywords**—**Magnetorheological elastomer, mechanical behavior, frequency, temperature.

I. Introduction

POLYMER composite materials are materials with high mechanical performance, which can be shaped as desired by the designer and have unlimited potential. Polymer composite materials are developing today in practically all fields and are at the origin of tremendous challenges in various high-tech achievements, among them we distinguish MREs which are, generally, prepared by dispersing magnetic particles in a non-magnetic elastomeric matrix [1]-[6].

Until now, some research has been carried out on the MRE performances as a function of temperature. Zhang et al. [7] evaluated the mechanical properties of MREs based on a mixed rubber matrix (cis-polybutadiene rubber and natural rubber). The results showed that the temperature-dependent moduli exhibited different characteristics for MREs with different rubber matrices. Lejon and Kari [8] carried out different measurements to study the influence of temperature, dynamic deformation amplitude, magnetic field intensity and frequency on the dynamic shear modulus of magneto-sensitive elastomers. The measurements indicated that the temperature was the most influential on the parameters especially when the temperature reached the transition phase of the material. Wan et al. [9] found that the transition temperature of MREs appeared at about 50 °C, and the storage modulus initially decreased with increasing temperature, reaching its minimum value at 50 °C, and then began to increase with additional increase in temperature. Rouabah et al. [10] in their work determined through experimental analysis the mechanical properties of a magnetorheological elastomer (MMRE) by a Dynamic Mechanical Analyzer (DMA). Borin et al. [11] discussed the effect of repetitive quasi-static magnetization of a MRE on its magnetic response. Typical components of this material, namely soft silicone rubber and carbonyl iron powder are used to produce magnetically sensitive composite samples. Moreno-Mateos et al. [12] proposed a comprehensive study on the influence of magnetic boundary conditions and demonstrated the importance of considering them in the overall material structure modeling strategy. Zhang et al. [13] numerically analyzed the swelling of MREs for sheet metal. The velocity and stress distribution of the sheet metal under different magnetic intensities were compared and analyzed. Selvaraj [14] studied an alternative vibration damper fabricated by MRE. In this work, Gorshkov et al. [15] studied the physical driving mechanisms whose control makes it possible to act in real time on all the band gaps formed in 3D metamaterials based on magnetoelastomers. Khebli et al. [16] studied the stability of MRE structures by the finite element method and Ritz.

However, previous studies focused on the performance of MREs as a function of temperature and mainly concern the effect of temperature on the properties of the polymer matrix, and little attention is paid to the effect of temperature on magnetomechanical properties. In addition, the magnetomechanical properties of MREs are closely related to the arrangement of internal particles [17], and its changes can directly reflect the differences in the microscopic arrangement of internal particles. Wen et al. [18] studied the influence of temperature on magneto-mechanical performances, which is useful for their practical application and mechanism analysis. Previous studies focus on the performance of MREs as a function of temperature for values lower than 60 °C, at different values of magnetic field intensity. By utilizing the Finite Element Method (FEM) and the Ritz approach, Aguib et al. [19] predicted the fundamental frequencies and loss factors of sandwich plates consisting of two aluminum skins and an MRE core at different external magnetic fields. Settet et al. [20] proposed an analytical model of an MRE sandwich beam to predict the static behavior with MRE.

In this work, we studied the performance of MREs with frequency-temperature dependence. The elastic modulus, loss modulus and loss factor of the MRE were studied under different temperature values; different values of the magnetic field and different values of the frequency.

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II. EXPERIMENTAL STUDY

A. Elaboration of the Magnetorheological Elastomer

The studied elastomer is prepared by mixture of silicone oil, RTV141A polymer, and 30% of iron particles of total mixture, the mixture obtained is mixed for about 15 minutes to obtain an elastomer paste with good homogenization. In order to develop an MRE, this paste is injected into an aluminum mold and subjected to a magnetic field. The constituents in mass fraction of the elastomer produced are given in Table I. The different steps for preparing the MRE are given in Fig 1.

TABLE I
CONSTITUENTS OF THE MRE

$m_{\text{silicone oil}}$ (g)	$m_{RTV(A)}$(g)	$m_{RTV(B)}$(g)	M_{Iron}(g)
1.064	1.0385	0.104	7.559

B. Experimental Characterization

The dynamic mechanical characterization tests (Fig. 2) were carried out on elastomer samples of 30 mm length, 20 mm width and 2 mm thickness. The applied test magnetic fields were parallel to the direction of the thickness of the MRE specimen, resulting in chains of iron particles oriented also in the direction of the thickness of the MRE specimen.

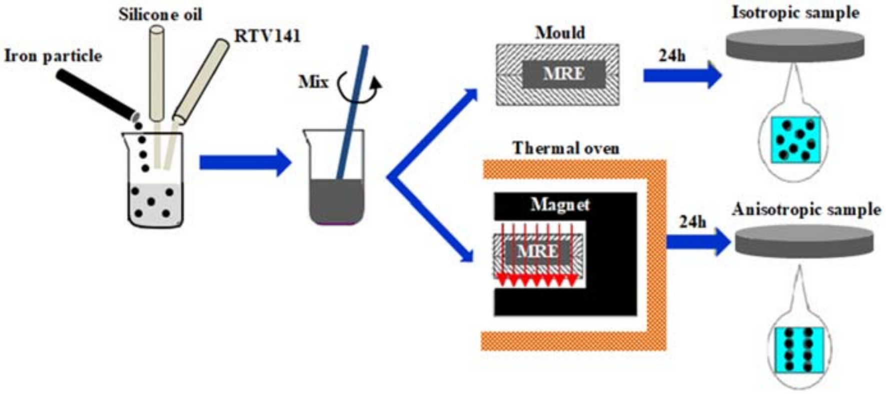

Fig. 1 Preparation steps for MRE

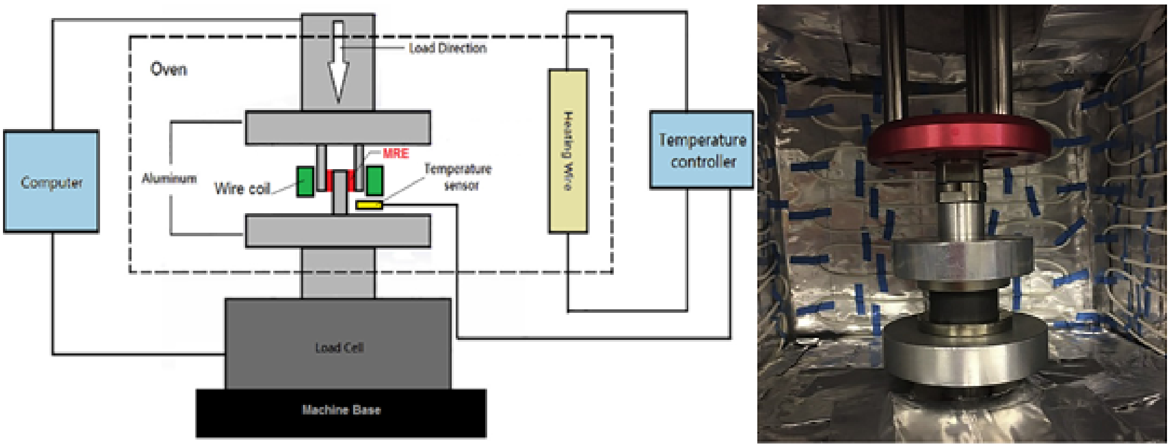

Fig. 2 Dynamic mechanical characterization of MRE

III. RESULTS AND DISCUSSION

A. Influence of Temperature

The results of the DMA tests carried out for samples of anisotropic MREs subject to variable temperatures and magnetic fields are represented by Figs. 3-5, the latter represents the dependence on the magnetic field of the elasticity modulus in shear G', the loss modulus G" and the loss factor η (η=G"/G') under different temperature values. Fig. 3 represents the temperature dependence of the elastic modulus G', Fig. 4 represents the temperature dependence of the loss modulus G" and Fig. 5 represents the temperature dependence of the loss factor η.

Figs. 3 and 4 showed that the moduli G’ and G’’ of the MRE decreased with increasing temperature. When the temperature was 25 °C, the moduli G’ and G’’ were 1.6743 MPa and 0.2788 MPa, respectively. For a temperature value of 100 °C, the moduli G' and G" respectively reached the values of 1.3321 MPa and 0.1117 MPa, i.e. with a reduction of 20% and 60% respectively.

We also note that the variation of the moduli G' and G" as a function of the magnetic field intensity becomes linear in the range from 0.25T to 0.5T with low gradients compared to the nonlinear range from 0T to 0 .25T.

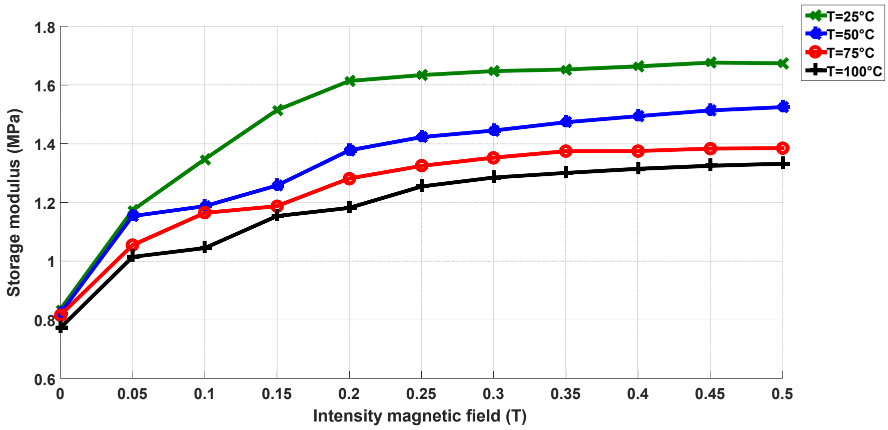

Fig. 3 Different Influence of temperature on the storage modulus

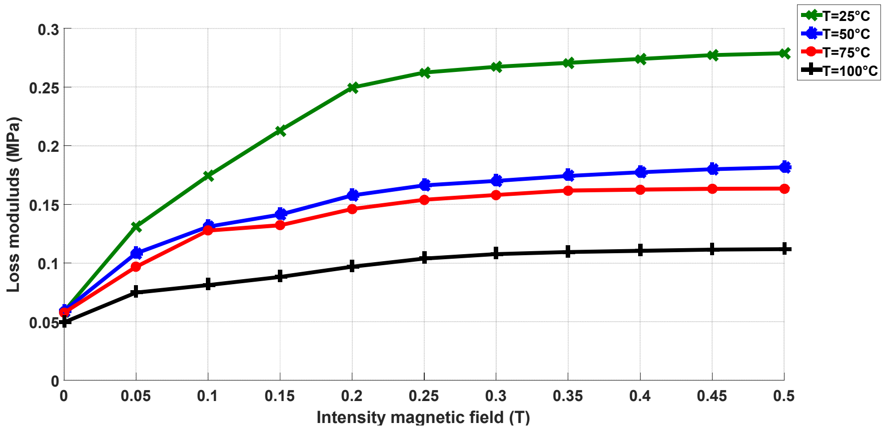

Fig. 4 Influence of temperature on loss modulus

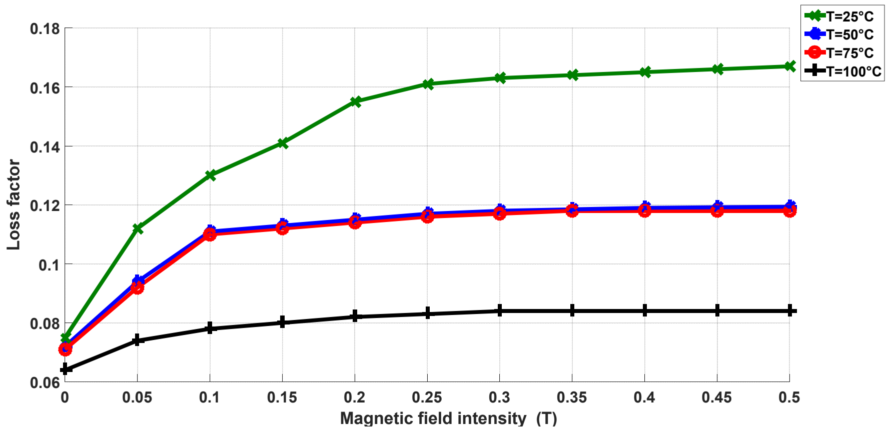

Fig. 5 Influence of temperature on the loss factor

Fig. 5 shows the variation of the loss factor as a function of the magnetic field intensity with different temperature values. It is observed that the loss factor decreased significantly with increasing temperature. For the magnetic field intensity value of 0.5T, the loss factor has a value of 0.275 for a temperature of 25 °C, and a value of 0.125 for a temperature of 100 °C. Of these two results, we therefore note a reduction in the loss factor of 50%. We also notice that the loss factor varies in a non-linear manner for low magnetic field intensities ($B < 0.2T$), then beyond this value the curves converge towards a constant value, this means that the magnetic field reached a saturation value and the elastomer paste has entered the phase of complete crosslinking.

B. Influence of Temperature - Frequency

Figs. 6 and 7 show the temperature-frequency dependence of the shear elastic modulus G', the loss modulus G" and the loss factor under the influence of 0.5T magnetic field

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intensity. It can be seen that the elasticity and loss moduli increase with increasing frequency. For a temperature of 25 °C, and with frequencies of 20 Hz and 80 Hz, the elastic modulus increases practically by 20% and the loss modulus increases practically by 15%. On the other hand, for a temperature value of 100 °C, we notice a slight increase in the elastic modulus, and a 10% increase in the loss modulus.

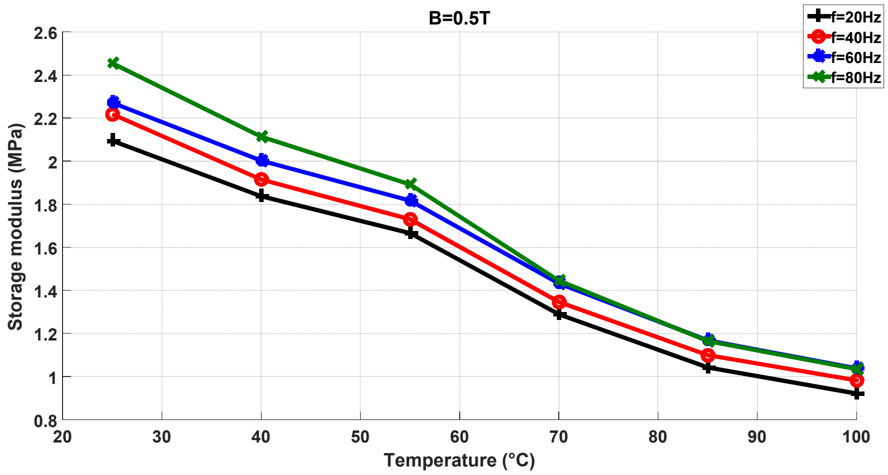

Fig. 6 Influence of temperature – frequency on the storage modulus

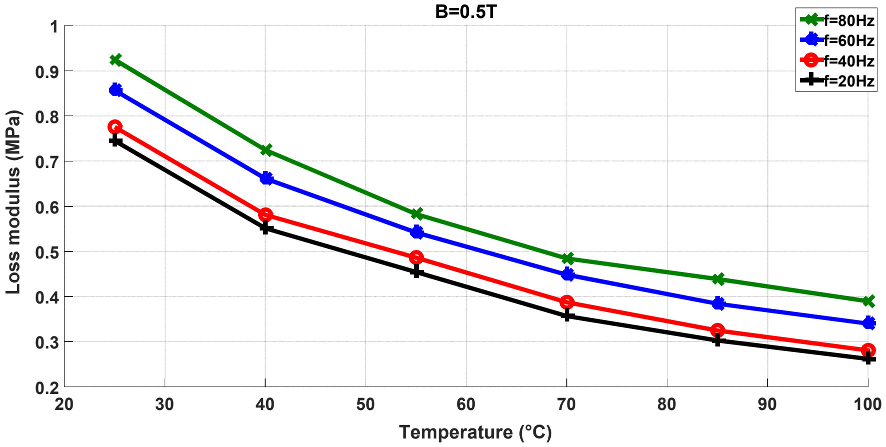

Fig. 7 Influence of temperature – frequency on the loss modulus

IV. CONCLUSION

Recent MRE composite materials are currently sought-after materials for several industries. Their advantages include a combination of light weight with efficient use of material leading to improved mechanical properties and adjustable by a magnetic field, particularly storage modulus, loss modulus and loss factor; these three properties have a direct impact on the rigidity. The latter is due to the increase in the interaction force between the ferromagnetic particles.

In this study, the influence of temperature as well as the frequency-temperature dependence on the mechanical properties of the MRE were studied, it was observed that the increase in temperature decreases the mechanical properties, such as the storage modulus, the loss modulus and the loss factor. On the other hand, increasing the frequency increases these latter properties

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