EXPERIMENTAL DYNAMIC CHARACTERIZATION OF MAGNETORHEOLOGICAL SILLY PUTTY

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Summary: *In the present study the dynamic behavior of a commercial silicon based magnetorheological elastomer was investigated. This material presents a non-newtonian characteristics whose response depends on the rate at which it is stressed. The damping properties under dynamic load of these materials have been studied in technical literature, while the influence of the magnetic field on the dynamic shear modulus is unknown. Hence, the aim of this paper is to test the change in dynamic shear modulus under a sinusoidal strain with amplitude of 2 and* $4\,\mathrm{mm}$*, cyclic frequency of 4 , 8 and* $12\,\mathrm{Hz}$ *and magnetic flux density of* 0 *and* $0.2\,\mathrm{T}$*. The approach adopted in this work was based on a design of experiment technique in order to evaluate the influence of the three variables involved and their interactions. The results highlights a strong dependence of the dynamic shear modulus on the strain rate while the influence of the magnetic field is weak, especially at the higher frequencies.*

Keywords: *magnetorheological elastomer, dynamic test, design of experiment*

1 Introduction

Silly Putty is a silicon based polymer filled with ferromagnetic particles, produced by Dow Corning Corporation [8] (Dow Corning 3179 dilatant compound). Silly Putty's unusual flow characteristics are mainly due to the ingredient polydimethylsiloxane (PDMS), a viscoelastic liquid. Viscoelasticity is the property of materials that exhibits both viscous and elastic characteristics depending on the deformation rate [1]. The approach adopted in this work resembles the dynamic mechanical analysis (DMA). DMA is a technique used to evaluate and characterize materials which is most useful for studying the viscoelastic behavior of polymers. A sinusoidal stress is applied and the strain in the material is measured, allowing one to determine the dynamic complex modulus. When a sample is subjected to a sinusoidal oscillating stress, it responds in a similar strain wave, provided the material stays within its elastic limits. When the material responds to the applied wave perfectly elastically, an in-phase or elastic response is seen, while a viscous fluid gives an out-of-phase response with energy absorption. Silly Putty falls in between these two behaviors. Eq. 1 describes the maximum values of strain (γ_0) and stress (τ_0) at the peak of the sinusoidal input wave, δ is the phase lag due to the excess time necessary for molecular motions and relaxations to occur.

$$\gamma = \gamma_0 \sin(\omega t); \qquad \tau = \tau_0 \sin(\omega t + \delta); \tag{1}$$

Using trigonometric relationships and recalling that $\tau_0 = G\gamma_0$, the equation of τ in (1) can be divided into an in-phase component and out-of-phase component, which gives:

$$\tau = \gamma_0 G' \sin(\omega t) + \gamma_0 G'' \cos(\omega t); \tag{2}$$

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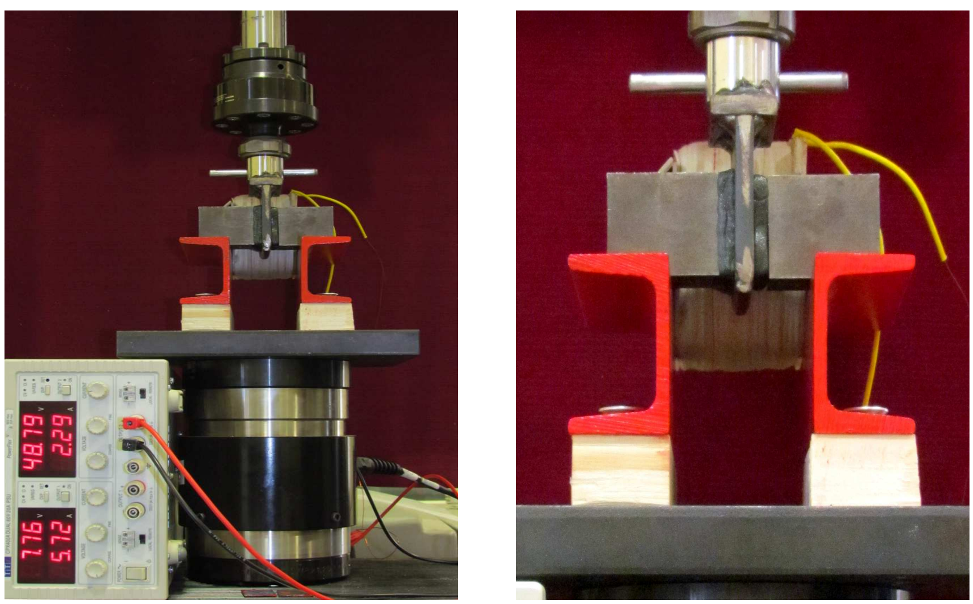
in which, G', the in-phase component associated with stiffness, is called dynamic storage modulus and represent the ability of the materials to store potential energy and release it upon deformation. G'', the out-of-phase component associated with internal friction, is called dynamic loss modulus and represent the energy dissipation in internal motion [3]. Subsequently, it can be defined the dynamic complex modulus as follows:

$$G^* = \frac{\tau_0}{\gamma_0} e^{i\delta} = \frac{\tau_0}{\gamma_0}(\cos\delta + i\sin\delta) = G' + iG'' \tag{3}$$

2 Materials and Methods

The purpose of this work is to assess whether exist an interaction between the applied magnetic field and the prescribed sinusoidal profile. The variables involved are the magnetic field intensity, which causes the formation of a chain-like ferromagnetic particles, along with the frequency and the amplitude of the sinusoidal input wave. The values chosen for the tests are magnetic field: 0 and $0.2\,\mathrm{T}$; frequency: 4, 8 and $12\,\mathrm{Hz}$; amplitude: 2 and $4\,\mathrm{mm}$. A general factorial design was adopted to run all combinations of all the factors, using Design Expert 8.0 [6]. The tests were carried out using an universal testing machine (MTS Mini Bionix 858 with 25 kN axial capability, 1(a), [7]). The testing machine provided the instantaneous force-displacement trend. By means of the MTS Flextest control software, it was possible to set up the characteristics of the input wave (the number of cycles and the sampling frequency). The magnetic field was provided by a carbon steel magnetic yoke inserted in a copper coil (1700 coils using an AWG 22 wire). The current was supplied in DC mode to the coil by a stabilized TTI power supply system. Avoiding any flux loss is a key point to reach the desired magnetic field values. Accordingly, two wood layer was placed to isolate the magnetic yoke's support 1(b).

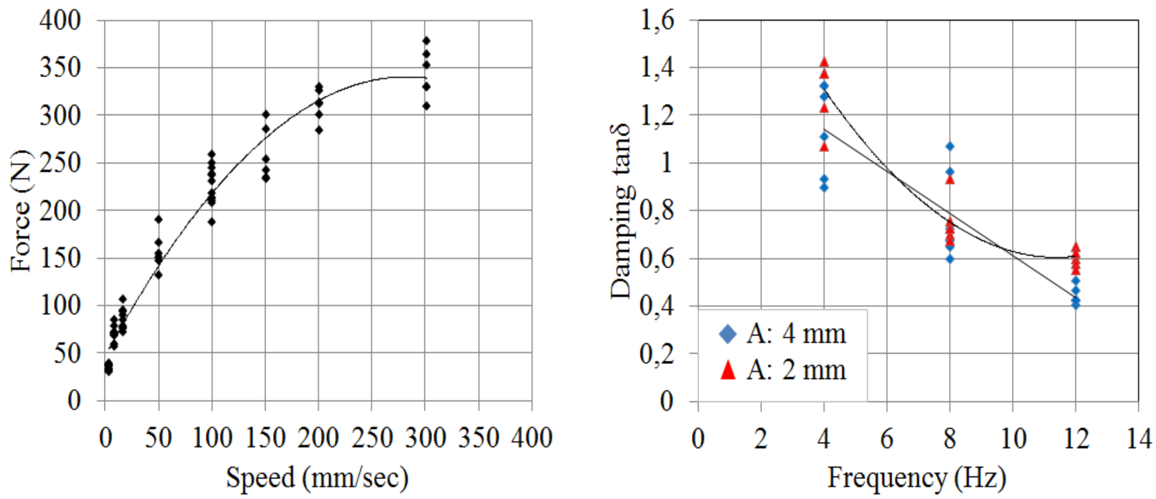


(a) (b)

Figure 1: Experimental apparatus and power supply system (a). Magnification view of the set up (b).

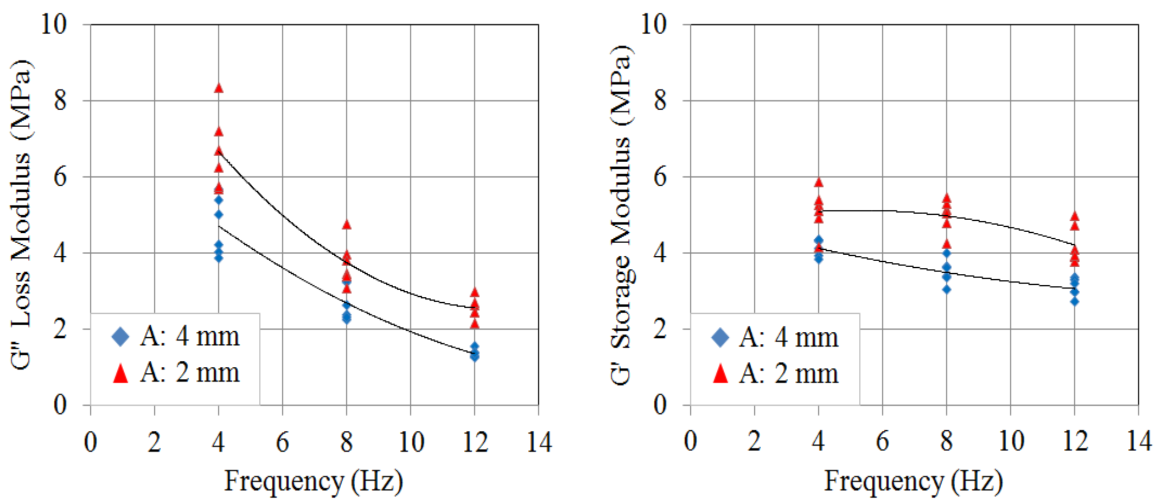
3 Results and Discussions

Figure 2(a) shows the experimental values of forces as a function of the speed deformation. The forces at speed values below 50 mm/min are retrieved from [1], in which the strain rate values were lower than those used in this work. The experimental forces increment logarithmically with the speed deformation, which is an effect of shear thinning fluids. Another name for shear thinning fluids is pseudoplastic fluids, meaning a decrease in viscosity with an increasing shear stress rate. Figure 2(b) depicts the trend of the equivalent damping calculated as $\tan\delta = \frac{G''}{G'}$. The increasing in frequency causes a stiffening of the material and accordingly the damping capacity decrease.



(a) (b)

Figure 2: Experimental results, force vs speed relationship (a). Damping function of frequency for amplitudes of 2 mm (red triangles) and 4 mm (blue diamonds) (b).



(a) (b)

Figure 3: Loss modulus G" (a) and storage modulus G' (b) as a function of frequency for amplitudes of 2 mm (red triangles) and 4 mm (blue diamonds).

Figures 3(a) and 3(b) represent the dynamic loss modulus and dynamic storage modulus as a function of frequency. The bigger is the frequency the more rigid is the material, because the time constant related to the shear rate is smaller than the time relaxation which is the time needed for molecules to relax after applying a shear stress. Consequently, the loss modulus decreases because the material responds more elastically when the frequency increases. The design of experiment technique revealed a weak influence of the magnetic field, because of the low percentage by weight of ferromagnetic particles which is 3.3%. Moreover, there is another important difference between Silly Putty and magnetorheological elastomers. Usually, during the polymerization of the magnetorheological elastomers is applied a magnetic field that aligns the ferromagnetic particles along the induction lines. Thus, the material is strongly anisotropic, stiffer along the chains direction and softer in the other directions. Conversely, Silly Putty is an isotropic material because the ferromagnetic particles are dispersed randomly in the polymeric matrix.

4 Conclusion

In the present work, the experimental dynamic characterization of the commercial Silly Putty is performed. Silly Putty is a polymer filled with ferromagnetic particles which presents viscoelastic properties. The tests consist in applying a sinusoidal stress and measuring the force response. Subsequently, along with the equivalent damping, dynamic loss modulus and dynamic storage modulus is calculated. The results highlights the pseudoplastic behavior of this material whose force response increases logarithmically with frequency. Furthermore, with an increase in frequency by a factor of 3, the damping capacity and the dynamic loss modulus decrease respectively by 57.3% and 65.7%. This is due to the stiffening of the material as the frequency increase, that decreases its ability to dissipate energy. The design of experiment technique revealed a very weak influence of the magnetic field, especially at higher frequency, where the viscoelastic component is predominant.

References

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