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Dynamical Properties of Magnetorheological Elastomers with Iron Particles

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Abstract: The dependence of dynamical moduli and loss factor of magnetorheological elastomers (MRE) on the external magnetic field intensity and on the frequency of applied cyclic shear deformation was studied. Isotropic samples of MRE were made of the silicon rubber matrix filled by iron or carbonyl iron micro-particles. The magnetic field produced by an electromagnet was applied in course of cyclic loading of double-shear samples of MRE under controlled shear strain. Dynamical moduli and the loss angle were determined as the function of the magnetic field intensity and of the frequency of cyclic deformation in shear. The dynamic stiffness of MRE depends on magnetic flux density and increases with increasing testing frequency. The loss factor of MRE samples is tunable with the magnetic flux density and depends also on the testing frequency.

Keywords: Magnetorheological Elastomers (MRE); Carbonyl Iron Filler; Dynamical Properties.

1 Introduction

The variety of different rubber dampers is used in engineering applications to isolate structures from unwanted vibrations. Smart elastomeric composites are increasingly being used as damping elements in the vibration absorbers [1]. The magneto-sensitive (MSE) or magnetorheological (MRE) elastomers are such smart composites which consist of magnetically polarizable particles dispersed in a cross-linked elastomeric matrix. The particles have micron size and they should be of the material with high magnetic saturation. These composites inherit main properties of the rubber matrix such as large deformations, stress softening effect, amplitude and frequency dependency, reduction of stiffness at cyclic loading and viscoelastic time-dependent features. MRE composites, however, have further interesting properties, entailed by the particles that can be controlled by the application of the external magnetic field. Deformation of the MRE composite in the presence of the magnetic field causes field dependent elastic modulus which rises monotonically with applied magnetic field. The percentage of maximum increase in modulus in the presence of the magnetic field is reported to be between 30-60 % of the zero-field modulus [2]. The MR effect includes also increased damping similarly to the case of MR fluids. The loss factor of MREs in dynamic compression at low frequencies was found to increase by about 30 % in magnetic field [3]. MREs are thus candidates for active vibration control of structural systems. To maximize the magnetic permeability of the composite, the filler particles in the MRE should be aligned in the direction of the applied magnetic field [1]. The particles alignment is effected by an external magnetic field applied during the cross-linking of the MRE, the particles form columnar structures and become locked in place upon final cure. It is stated that to obtain the maximal MR effect while retaining the mechanical properties of the composite the optimum filler fraction should not exceed 30 vol % [4]. The matrix materials commonly used for MREs are natural rubber, silicon rubbers, vulcanized rubbers filled by carbon black or by silica. The MR effect is increased by choosing the material of particles with high permeability and high saturation magnetization. Iron or carbonyl iron spherical particles with a diameter of 1-10 μm are commonly used [4]. Engineering applications of MREs are in general very recent and involve, for example, tuned vibration absorbers, stiffness-tunable mounts and suspensions and automotive bushings. In particular, vibration isolators made of MS rubber are shown to be more effective than traditional rubber isolators [5–7].

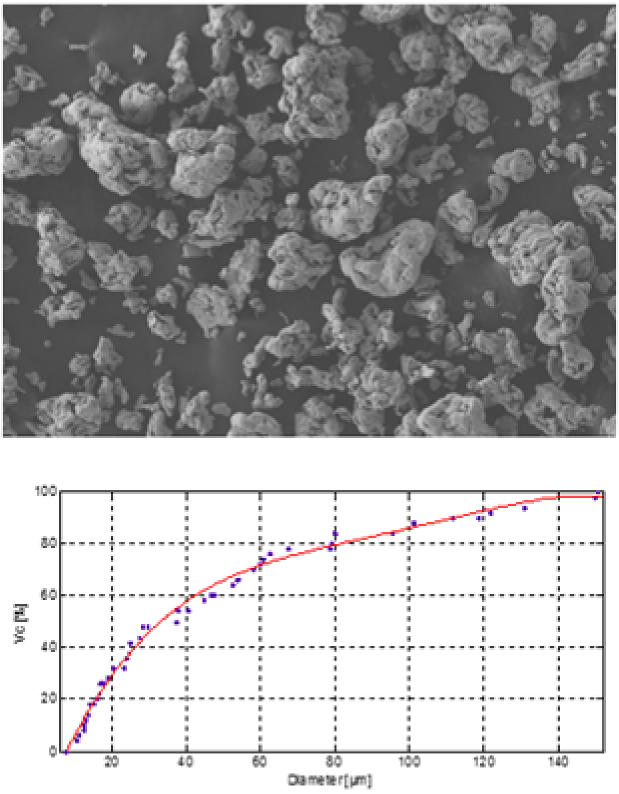

Fig. 1: Iron particles. SEM image and size distribution.

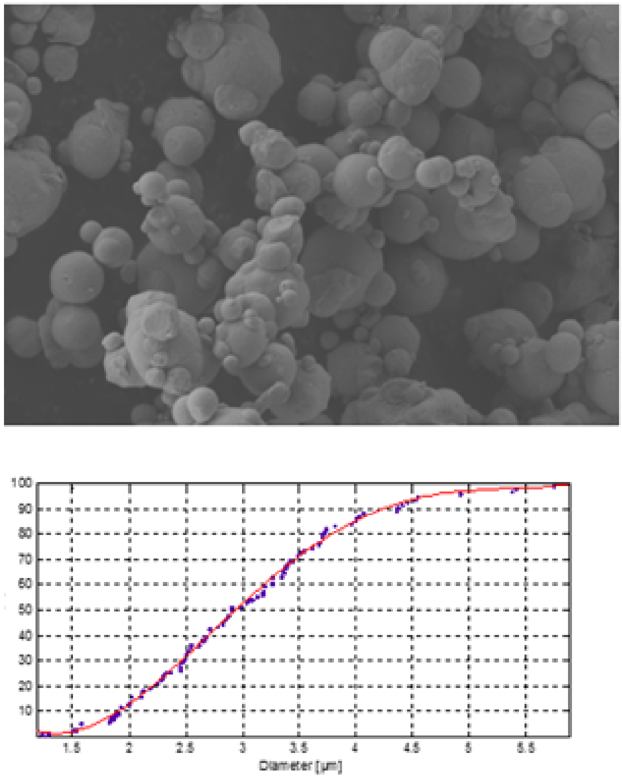

Fig. 2: Carbonyl iron particles. SEM image and size distribution.

2 Experimental

The raw particle size of the filler and particle distribution were examined by Scanning electron microscope. The results are on Fig. 1 and Fig. 2. The iron particles are larger and of irregular shape in comparison with carbonyl iron particles which are smaller and globular. The matrix material is silicone rubber compound mixed of ZA 22 gum and RZA 22 catalyst in the ratio of 1:1. Iron or carbonyl iron micro-particles of 30 vol % were interfused with silicone oil and then mixed in the silicon rubber mixture. The mixing and polymerization process were carried out at room temperature with settling duration for 1 h.

Polymerization was carried out without the presence of a magnetic field. MRE samples are therefore isotropic. Samples were cut into rectangular shape with dimension $20 \times 20 \times 5$ mm and glued together with aluminium strips to form the double-shear specimen on Fig. 3. Activator IA845 provided by Gumex was applied in the surface of the elastomer, in order to improve the attachment of the elastomer to aluminium.

The shear tests of the double-shear specimens were carried out on Instron Electropuls. The samples were loaded in the gap in the core of the electromagnet on Fig. 4. The SEM pictures of the MRE microstructure are on Fig. 5 and 6.

The amplitude of the cyclic load was 0.5 mm and the frequency changed in steps from 1 to 10 Hz. The samples were firs tested without an applied magnetic field to obtain the basic dynamical composite properties, namely storage and loss moduli and the loss angle. Then the electromagnet current was switched on and the sample was cyclically loaded again under the magnetic field with the magnetic flux density 0.5 T.

The dynamic moduli and the loss angle were calculated by means of Fourier analysis of measured signal of response force compared with the harmonic signal of strain loading [8].

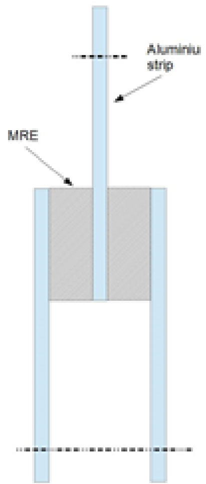

Fig. 3: Double shear sample.

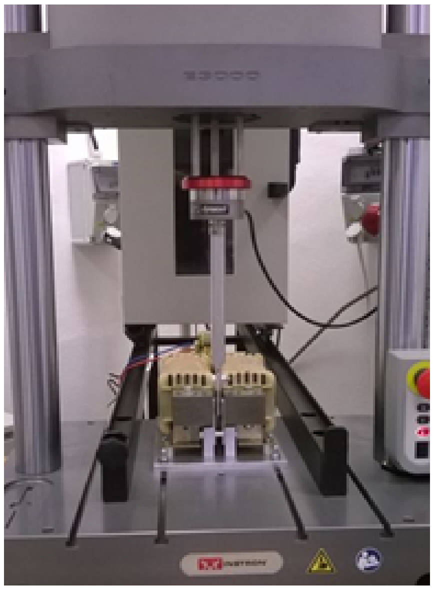

Fig. 4: Cyclic loading of samples in magnetic field.

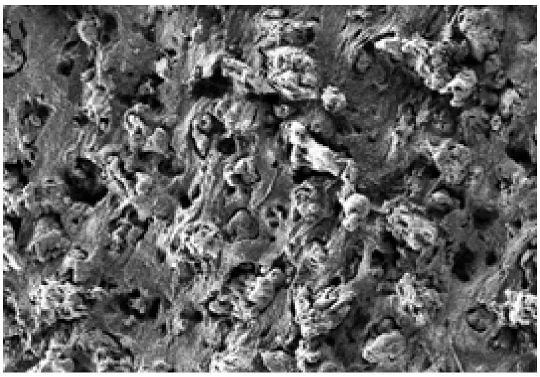

Fig. 5: MRE with standard iron particles.

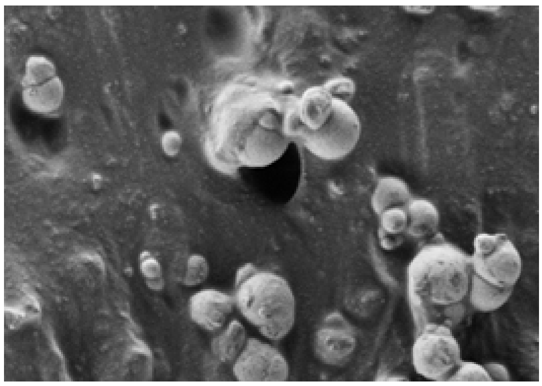

Fig. 6: MRE with carbonyl iron particles.

3 Results and Discussion

The iron particles on Fig. 1 were by-product of plasma experiments. They are of irregular size and the particle size distribution with range varies from 20-100 μm. The MR effect in the MRE samples with these particles was very low because their big size and bad adhesion with matrix. The globular carbonyl iron particles on Fig. 2 provided by Sigma-Aldrich were smaller 2-5 μm and the adhesion between the matrix and the particles have been much better. The DMA of silicone rubber specimens showed that the behaviour of the silicone rubber is very similar to natural rubber which exhibits no hysteresis. The behaviour of samples with embedded particles is completely different – they showed a clear hysteresis and damping in cyclic loading even without the external magnetic field.

The dynamical testing of MRE double-shear samples in the magnetic field showed clearly the MR effect and the increase of the damping capability of MRE due to the magnetic field. The measured loss angle values of MRE samples without and with the magnetic field are presented in the Fig. 7. The difference between the zero-field loss factor and the loss factor with magnetic field 0.5 T was around 10 % in the samples with carbonyl iron particles. The loss modulus is also increasing by 10 % approximately as can be seen on Fig. 8. The storage modulus of MRE samples was only slightly influenced by the magnetic field.

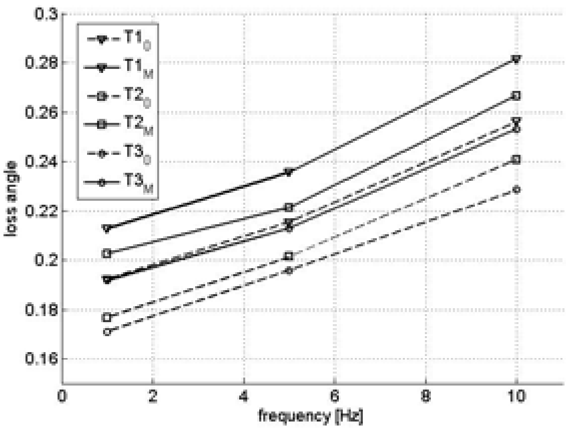

Fig. 7: Loss angle for 0 and 0.5 Tesla.

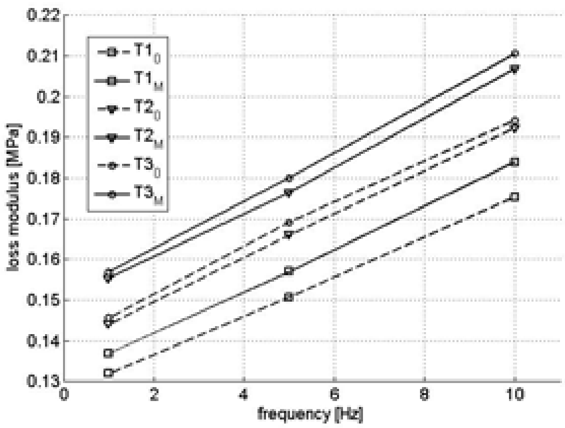

Fig. 8: Loss modulus for 0 and 0.5 Tesla.

4 Conclusion

This study investigated dynamical properties of magnetorheological elastomers as tunable damping elements. The dynamical moduli and the loss factor were measured by DMA. An loading device was developed for testing the MRE double-shear samples.

The dynamical properties namely the loss factor changed with the applied magnetic field. Results showed that MREs can be used as active damping elements in shear loading.

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