NUMERICAL SIMULATION OF THE BEAM MADE OF MAGNETORHEOLOGICAL ELASTOMER BENDING IN THE MAGNETIC FIELD

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Abstract

Magnetorheological elastomers (MREs) belong to the group of so-called smart materials, which respond to an external stimulus by changing their viscoelastic properties. Magnetorheological (MR) material can be fluid, gel or solid like material, such as elastomer. The mechanical properties of the MR materials change when subjected to an external magnetic field. The MREs are interesting candidates for the active stiffness and vibration control of structural systems.

In the paper the verification process of the applied FE modelling method is presented. The verification is based on the three point bending experiment. The results of that experiment were used to evaluation of the correction on numerical model and analysis.

The model was based on the assumption that MRE behaves like an orthotropic material with the material properties of MRE on the direction along the iron chains - and of a pure elastomer - on the other directions. Such an assumption can be made for the small deformations of a sample, what took place in the considered experiment.

The FE modelling method was considered to be correct.

On the base of the verified method a FE element model of the MRE beam bending was developed. Such MRE beams are used as "smart" switches that react under the changeable magnetic field.

Keywords*: magnetorheological elastomer, smart materials, numerical modelling, magnetic field influence*

1. Introduction

Magnetorheological elastomers (MREs) belong to the group of so-called smart materials, which respond to an external stimulus by changing their viscoelastic properties. Magnetorheological (MR) material can be fluid, gel or solid like material, such as elastomer. The mechanical properties of the MR materials change when subjected to an external magnetic field. The MREs are interesting candidates for the active stiffness and vibration control of structural systems. MR materials typically consist of micron-sized magnetic particles suspended in a non-magnetic matrix. The magnetic interactions between particles in these composites depend on the magnetization orientation of each particle and on their spatial relationship, coupling the magnetic and strain fields in these materials and giving rise to a number of interesting magnetomechanical phenomena. MR materials include MR fluids, foams, gels and elastomers [1]

MR elastomers (MRE) are composites where magnetic particles are suspended in a non-magnetic solid or gel-like matrix. The particles inside the elastomer can be homogeneously distributed or they can be grouped (e.g. into chain-like 16 columnar structures). To produce an aligned particle structure, the magnetic field is applied to the polymer composite during crosslinking so that the columnar structures can form and become locked in place upon the final cure. This kind of processing imparts special anisotropic properties to the viscoelastic materials. Only recently has the field responsiveness of the viscoelastic properties of these elastomers been explored [2-4].

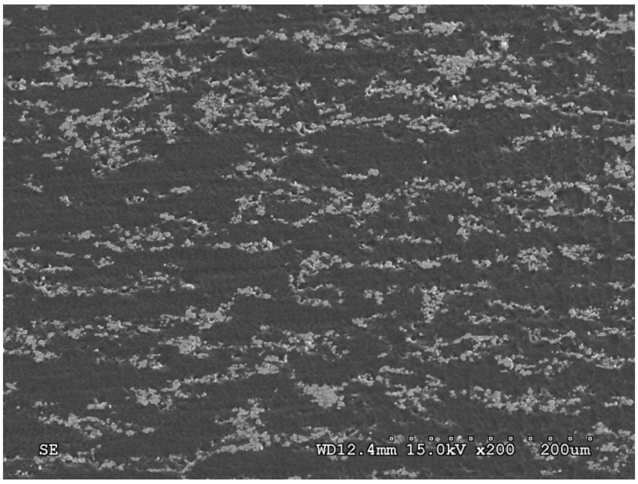

Fig. 1. SEM image of MRE microstructure with 11.5% of iron particles volume frac tion cured under magnetic field of 300 mT

2. Experimental results

The experiments have been conducted to evaluate the magnetorheological material response to the applied magnetic field. An electromagnet has been used to produce the magnetic field. The field strength has been constantly monitored using the Hall-probe method. The cylindrical samples (ø=8 mm, h=18 mm) have been used for the experiments. The experimental setup is shown in Fig. 2.

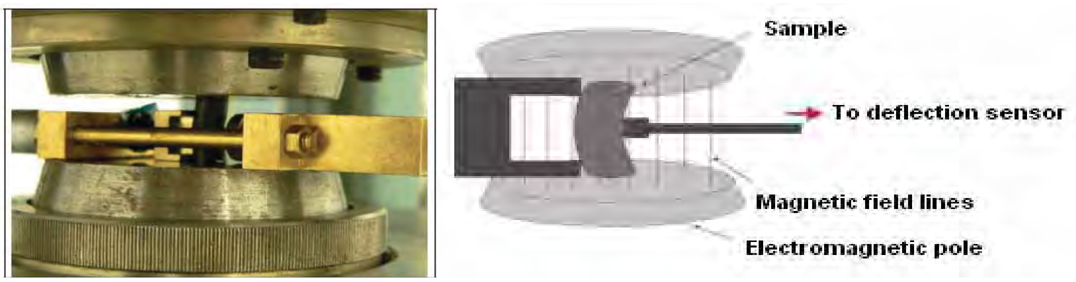

Fig. 2. The experiment setup for MRE examination in the magnetic field [6].

The experiment objective was to measure the response of samples to a deflection under the magnetic field. The samples were placed parallel to the magnetic field lines and deflected before the application of a magnetic field. A deflection, which is analogous to a three point bending, was applied to change the orientation of the particles chains in the material. After the application of the magnetic field the samples tend to straighten which was measured by a deflection sensor. The magnetic field within the range of 0-0.9 T has been applied. The samples response became stronger with rising intensity of the field in all the cases. A deflection value was changing depending on the content of iron in a sample. The highest deflection was observed for samples with 11.5 vol. % of iron particles. The lower deflection of samples with 33 vol. % Fe may be caused by a higher stiffness of samples with a greater amount of particles [5].

3. Numerical model description and verification

A numerical model was developed to verify the results the experiment described above. The model was based on the assumption that MRE behaves like an orthotropic material with the material properties of MRE on the direction along the iron chains - and of a pure elastomer - on the other directions. Such an assumption can be made for the small deformations of a sample, what took place in the considered experiment.

The FE analysis consisted of the two stages: the first one was to initially deflect a cylindrical sample (ø=8 mm, h=18 mm) by a nodal force to the deflection value taken from the experiment described before. Then the deflected sample was stretched by the external force simulating the influence of the mass forces appearing in the iron chains under the magnetic field. A scheme of the numerical experiment stages is presented in Fig. 3.

A static FE analysis was accomplished with MSC.Patran/Marc computer code.

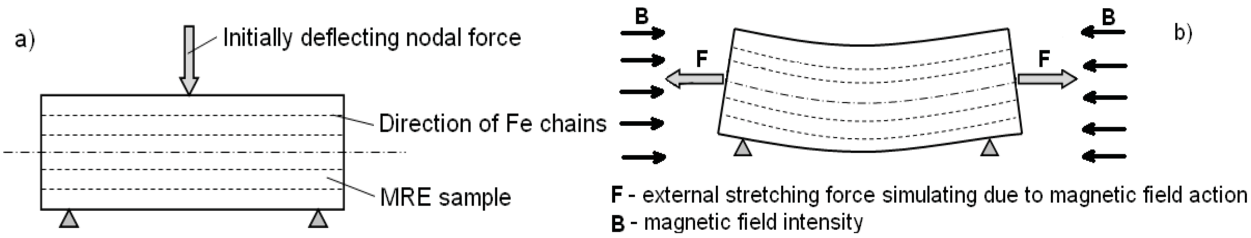

Fig. 3. Stages of FE analysis: initial bending (a), magnetic field action consideration (b)

The external stretching force, which simulated the action of magnetic field on Fe chains, was calculated according to the equation describing a dipole interaction force in iron chains along the sample axes. The equation is as follows [5]:

$$F_0 = \left(\frac{3\mu_0}{4\pi}\right) \cdot (m^2) \cdot (5\cos^2\alpha - 1) \cdot \left(\frac{1}{r^4}\right), \tag{1}$$

where: α - angle between the external magnetic field and the dipoles chain axes, $\mu_0=4\pi 10^{-7}$ H/m – a magnetic permeability of a void, r = 12 μm – the distance between two interacting dipoles, m – magnetic momentum of MRE, considered in accordance to the volume iron share and magnetic field intensity (taken from previous researches). The resulted value describes the force per 1 gram of the elastomer – iron composite. For FE analysis the force F_0 value was multiply by the value of the sample mass, what is given with the equation (2):

$$M = V \cdot (U \cdot \rho_{Fe} + (1 - U)\rho_{elastomer}), \tag{2}$$

where:
V - MRE volume,
U - volume share of iron particles in elastomer,
ρ_{Fe} = 7874 kg/m^2 - iron density,
$\rho_{elastomer}$ = 1030 kg/m^3 - pure elastomer density.

The results of the applied modelling method of magnetorheological elastomers for small deformations agree with experiments. The considered material model was orthotropic with the material properties of MRE in the direction along the iron chains and – of a pure elastomer – for the other directions. The FE modelling resulted in about 0.15% of correspondence between the numerical and experimental analyses.

4. MRE beam bending numerical analysis

After the analysis method verification the numerical model of MRE beam with the dimensions 10x4x25 mm was developed. Such MRE beams are used as “smart” switches that react under the changeable magnetic field. The model and its boundary conditions are presented in Fig. 4. The solid eight-nodal elements were applied.

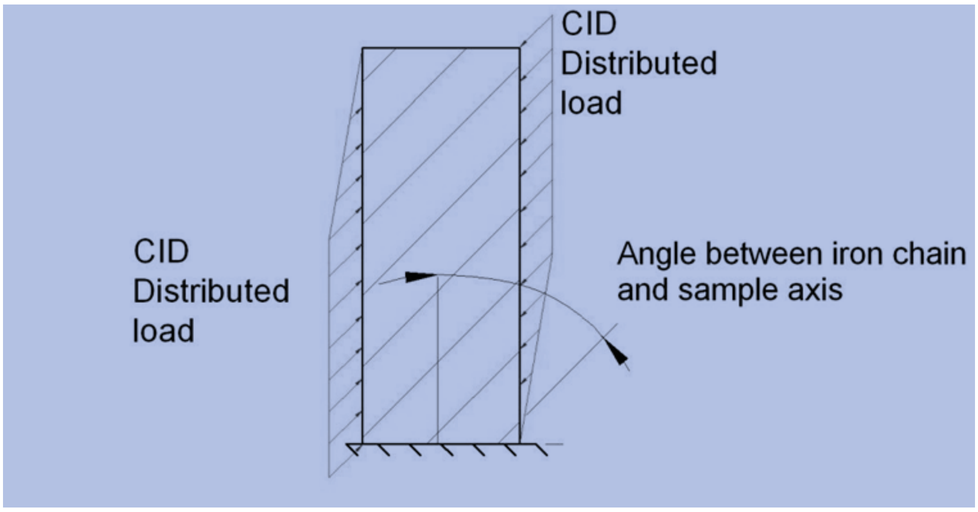

Fig. 4. Scheme of numerical model and applied boundary conditions

The MRE sample with the iron particles volume fraction of 33% and iron chains aligned along the angle of 45 degrees to the beam axes was analyzed. The material model was the orthotropic one with the material properties of MRE on the direction along the iron chains (Young modulus $E_{MRE} = 0.65$ MPa, Poisson ratio $\nu = 0.46$) - and of a pure elastomer - on the other directions (Young modulus $E_{MRE} = 0.61$ MPa, Poisson ratio $\nu = 0.46$). Such an assumption can be made for the small deformations of a sample which took place in the analyzed experiment.

During the FE analysis the MRE beam was subjected to the external distributed load resulted from the interactions between the iron particles under the magnetic field of 300 mT. On the base of the analytical calculations the force value per beam volume unit was determine and applied to the sample walls. The force value was 225 mN.

The results are presented in Fig. 5 as the beam deformations and total displacements. The final deformation of the beam was 2.07 mm

Such analysis can be used for assessing the MRE beam behaviour acting under changing magnetic field, what gives a simple and quick method of such structures modelling.

5. Conclusions

In the paper the verification process of the applied FE modelling method was presented. The verification was based on the three point bending experiment. The results of that experiment were uses to check the correction on numerical model and analysis.

The model was based on the assumption that MRE behaves like an orthotropic material with the material properties of MRE on the direction along the iron chains - and of a pure elastomer - on the other directions. Such an assumption can be made for the small deformations of a sample, what took place in the considered experiment.

The FE modelling method was considered to be correct.

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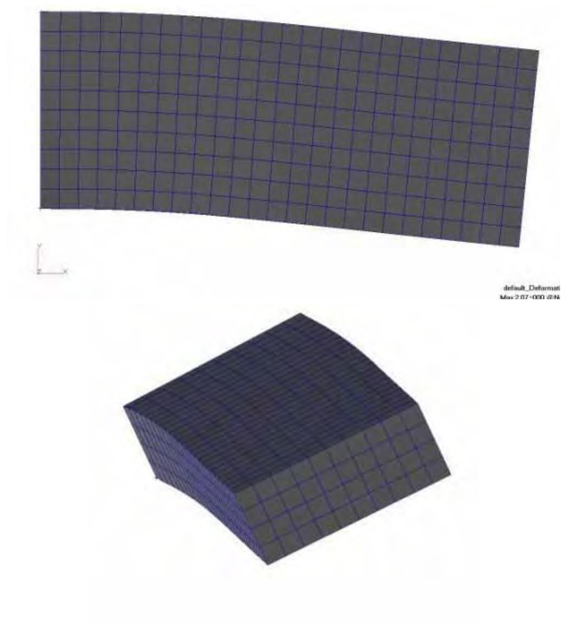
a)



b)

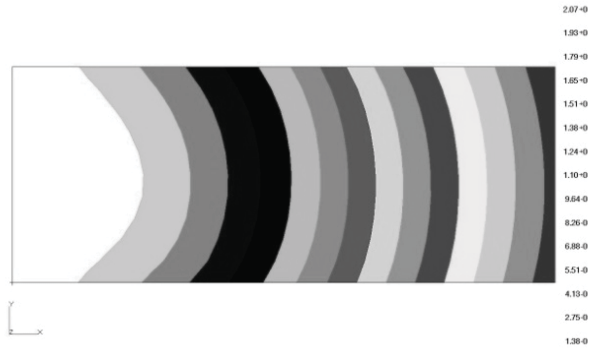


Fig. 5. FE analysis of MRE beam bending results: a) deformations, b) total displacements

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Acknowledgments

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