INFLUENCE OF THE VOLUME FRACTION OF THE CARBONYL IRON PARTICLES ON THE MECHANICAL PROPERTIES OF THE MAGNETORHEOLOGICAL ELASTOMERS

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Abstract

Magnetorheological materials belong to the group of the so called intelligent materials. Their rheological properties can be changed in a large range using an external magnetic field. That is why they find ever growing application in modern technical equipment, among others in controlled dampers, clutches, sensors etc. In the paper, a numerical strength analysis of a magnetorheological material was presented. The influence of the volume fraction of carbonyl iron particles (the share of the carbonyl iron particles varied from 1.5 to 33.0 vol. %.) on the mechanical properties of the material were investigated, in particular on the Young's modulus variation. Experimental tests were carried out for specimens made of pur e PU 70/30 elastomer with iron particles. They included uniaxial compression tests. In the former case, specimens were in a shape of a cylinder with a diameter of 20 mm and a height of 25-30 mm. The results of experimental tests carried out in order to determine the parameters necessary to build the numerical model were included in the paper. In the paper, an algorithm developed for determining the parameters for modelling the structure was presented. A fragm ent of the structure, containing several particles of iron and some quantity of elastomer, corresponding to the assumed volume fractions, was subjected to numerical analysis.

Keywords: *smart materials, magnetorheological elastomer (MRE), finite element method (FEM)*

1. Introduction

Magnetorheological (MR) materials are known as smart materials that have rheological properties that can be changed under a magnetic field. MR materials can be classified into two groups: MR fluids and MR elastomers [1]. Magnetorheological elastomers are materials that have polarisable particles arranged in chains in polymer media such as silicon rubbers and natural rubbers. The physical phenomena seen in MR elastomers are very similar to those in MR fluids. However, the particle chains within the elastomer composite are intended to operate in the preyield regime, whereas MR fluids typically operate within a postyield continuous shear or flow regime [2]. To fabricate MR elastomers, a strong magnetic field is needed. The typical curing magnetic field strength is approximately 8×10^6 A/m [3]. Chain formation results from the anisotropic magnetic forces among the particles. When individual particles are exposed to an applied magnetic field, magnetic dipole moments pointing along the magnetic field are induced in the particles. Pairs of particles form head-to-tail chains. When the elastomer is cured, the particles are locked into place and when a shear force is applied to the material, additional work is needed to overcome the dipole interactions in the elastomer. The amount of additional work rises monotonically with the increase of the magnetic field, resulting in a field-dependent shear modulus [4].

In the paper, a numerical analysis of a magnetorheological elastomer is presented. The influence of the volume fraction of carbonyl iron particles on the mechanical properties of the material were investigated, in particular on the Young modulus values. The presented experimental tests were carried out for specimens made of pure PU 70/30 elastomer with iron particles. They included uniaxial compression tests. Specimens were in a shape of a cylinder with a diameter of 20 mm and a height of 25 mm. The results of experimental tests carried out in order to determine the parameters necessary to build the numerical model were included in the paper. In the paper, an algorithm developed for determining the parameters for modelling the structure was presented. A fragment of the structure, containing several particles of iron and some quantity of elastomer, corresponding to the assumed volume fractions, was subjected to numerical analysis.

2. Experimental results

The experimental researches were carried out in the Department of Mechanics and Applied Computer Science of Military University of Technology. The quasi static uniaxial compression load was applied to the cylindrical samples, which had the diameter of 20 mm and height of 25 mm. The pure elastomer PU 70/30, as well as with iron particles were tested. The volume fraction of the carbonyl iron was: 0%, 8.3%, 11.5% respectively. The distribution of the particles in the sample was homogenous or was shaped into chains along the external magnetic field applied during the elastomer curing process. The chains were inclined at an angle of 45 degrees to the cylinder rotation axis. The compression test was carried out to the displacement of 12.5 mm of the top surface of the sample with the velocity of 10 mm/min. The example of the specimen is presented in Fig. 1.

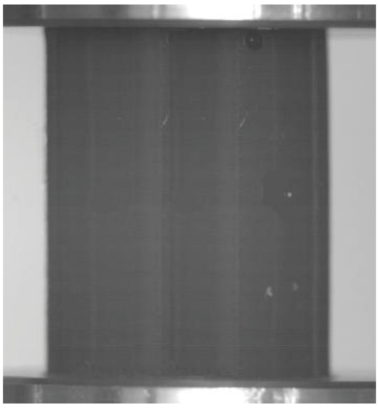

Fig. 1. Example of MRE specimen during compression test

The exemplary results for the pure elastomer and with 11.5% vol. of iron particles are shown in Fig. 2 and 3.

3. Macrostructural numerical analyses

The experimental researches results were used to the determination of the material properties for the FE modelling.

The Mooney – Rivlin material model [5] was applied to the numerical analysis of the hyperelastic behaviour of the elastomer. In that model the strain energy density function **W** is a linear combination of two invariants of the left Cauchy-Green deformation tensor [6]. This function can be assumed as:

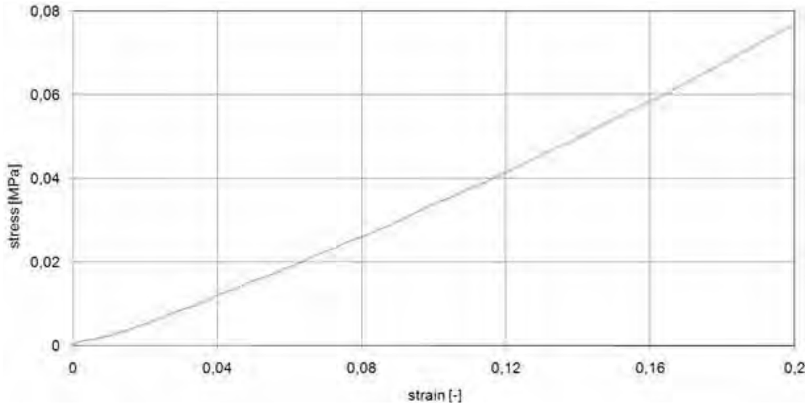

Fig. 2. Experimental results for pure elastomer

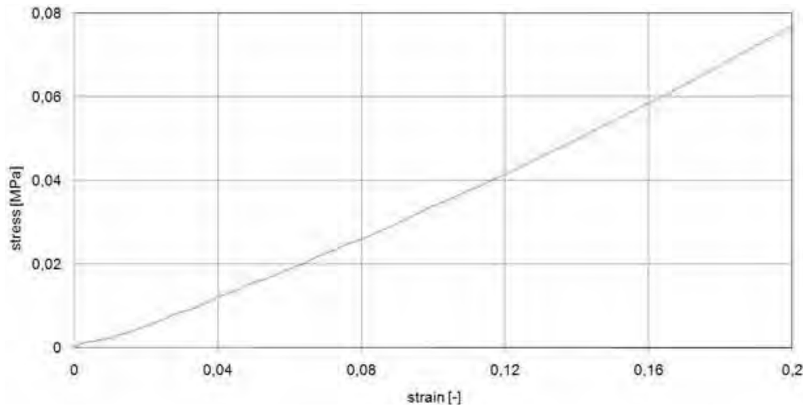

Fig. 3. Experimental results for elastomer with 11.5% vol. iron particles

$$W = \sum_{i+j=1}^{n} C_{ij} (I_1 - 3)^i (I_2 - 3)^j , \tag{1}$$

were C_{ij} are empirically determined material constants, I_1 and I_2 are the first and the second invariant of the deviatoric component of the left Cauchy-Green deformation tensor described as follows:

$$I_1 = \lambda_1^2 + \lambda_2^2 + \lambda_3^2 , \tag{2a}$$

$$I_2 = \lambda_1^2 \lambda_2^2 + \lambda_2^2 \lambda_3^2 + \lambda_3^2 \lambda_1^2 , \tag{2b}$$

were λ_1, λ_2, λ_3 are the elongations of the element in directions shown in Fig. 4.

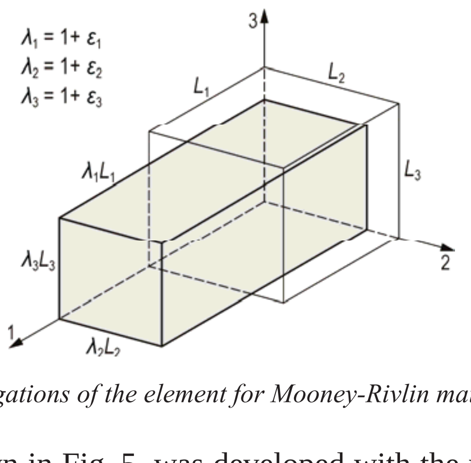

Fig. 4. Elongations of the element for Mooney-Rivlin material model

The numerical model, shown in Fig. 5, was developed with the use of solid elements Hex8 [5] and the Mooney-Rivlin material model described above. A static numerical analysis was carried out with the use of MSC Marc computer code. A compression was performed with two rigid plates - stationary and moving one (displacement of 20% sample height). The parameters for the Mooney-Rivlin material model were calculated with the use of MSC Mentat application and are presented in Tab. 1.

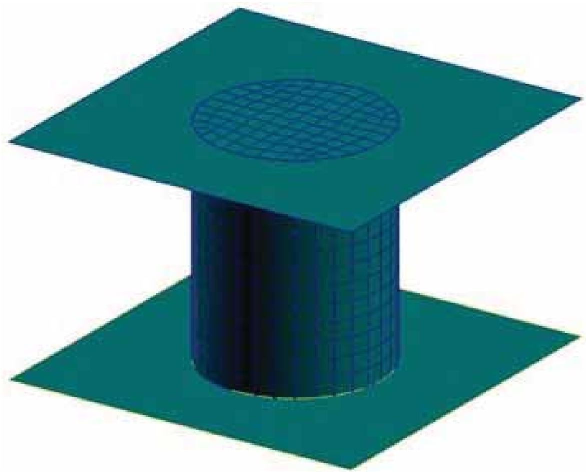

Fig. 5. FE model of elastomer sample

Tab. 1. Mooney-Rivlin constants for FE model

	Quantity	Symbol	Value
Pure elastomer	Constants	C_{10}	28380
		C_{01}	-2968.7
Elastomer with 11,5% vol. iron particles	Constants	C_{10}	19450
		C_{01}	-9780

The results of the numerical analysis with the comparison to the experiment are presented in Fig. 6 and 7. The very high correspondence between experimental and numerical analyses is clearly visible.

4. Microstructural numerical analyses

To assess the micromechanical interactions between the iron particles and the elastomer during the compression test the microstructural numerical model was developed. The microstructure of the MR elastomer cured in the external magnetic field of 400 and 600 mT intensity is presented in Fig. 8.

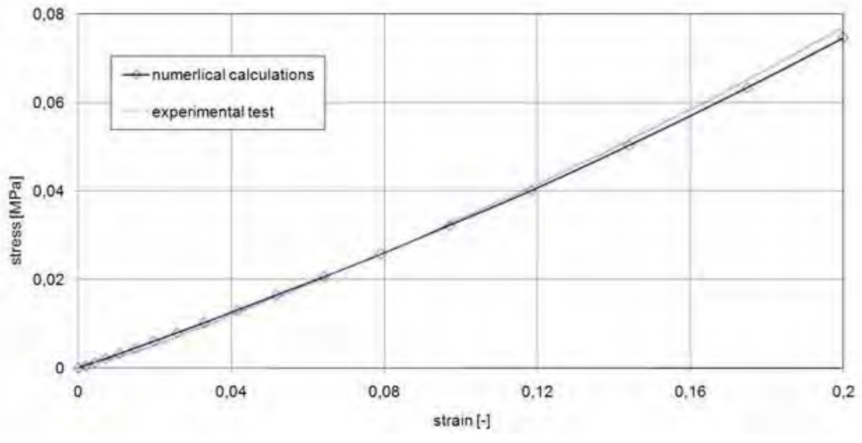

Fig. 6. Numerical calculations and experimental results for pure elastomer

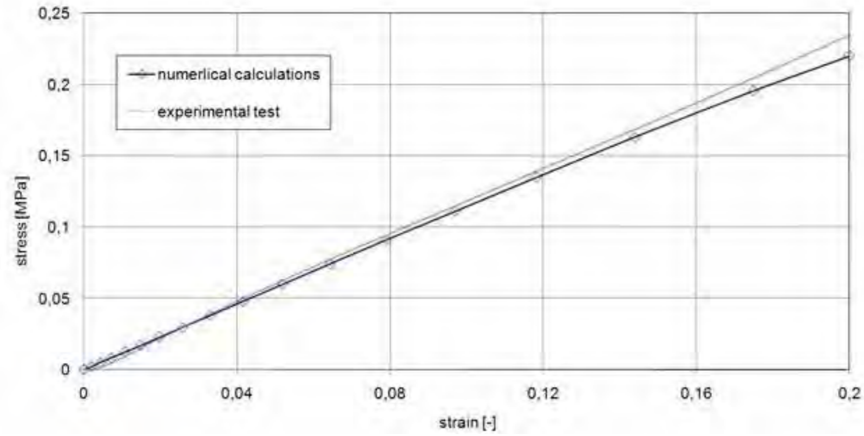

Fig. 7. Numerical calculations and experimental results for 11.5% vol. iron particles

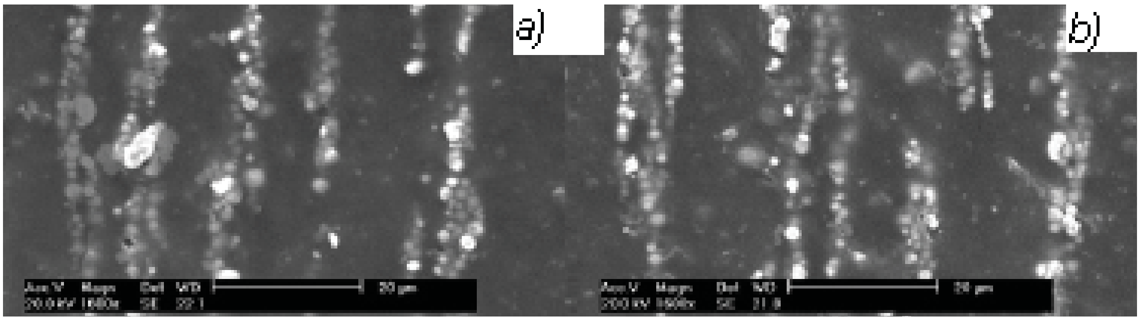

Fig. 8. SEM images of MREs prepared under magnetic flux density of (a) 400 mT, (b) 600 mT [7]

The FE model representing the iron particles chain built on the basis of the solid elements is presented in Fig. 9. Because of the large difference in the Young modulus values for elastomer and iron the material model for the particles was assumed as rigid.

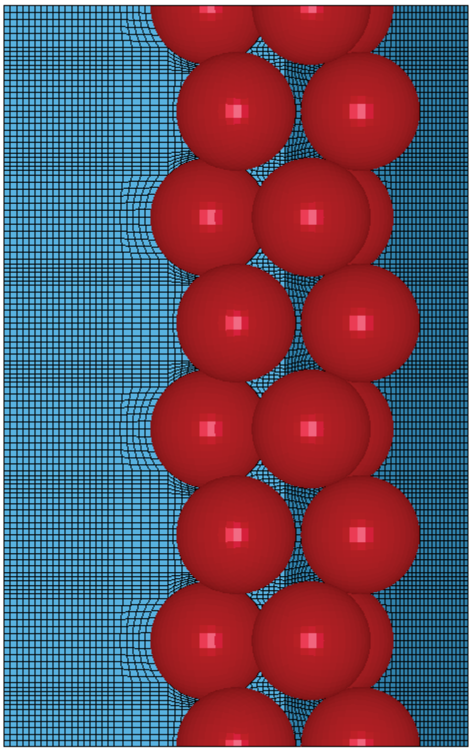

Fig. 9. FE model representing iron particles chain

The results are presented as stress distribution in the elastomer in Fig. 10. It is clearly visible that the highest stress value is reached in the elastomer near the top of the iron sphere. Also any other mechanisms appearing in such a microstructure can be evaluated.

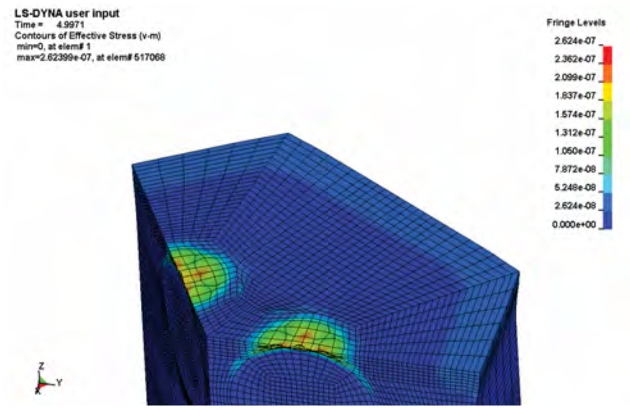

Fig. 10. FE Results of MRE microstructure numerical model analysis for compressive load consideration

5. Conclusions

In the paper the experimental and numerical researches of the MR elastomer were presented. The compression test was carried out in both cases. The numerical model was based on the usage of the Mooney – Rivlin material model application for the hyperelastic material behaviour description. The global numerical analysis of the magnetorheological elastomer strength properties was verified and the high correspondence between FE and experimental tests was achieved. It can be concluded that the applied research method is correct.

In the paper the method of the microstructural modelling of MR elastomer internal structure was also presented. This method allows assessing the influence of the single iron particle on the behaviour of surrounding elastomer (e.g. stress distribution).

Acknowledgements

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