VARIOUS APPROACHES TO MAGNETORHEOLOGICAL ELASTOMERS STRUCTURES FE MODELLING

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Abstract

Magnetorheological elastomers (MREs) are the materials with rheological properties which can be rapidly and reversibly changed in a continuous way by the applied magnetic field. They are the solid analogues of magnetorheological fluids (MRFs) consisting of magnetically permeable particles (such as iron) added to a viscoelastic polymeric material prior to crosslinking.

In the paper different approaches to numerical modelling of the magnetorheological elastomers (MREs) structures are presented. The methods of the MRE micro- and macrostructural FE simulations are taken into consideration.

The first approach is connected with the microstructural behaviour of the iron particles situated in the pure elastomer and subjected to the mechanical or magnetic load. The second approach is related to global material properties consideration and macrostructural behaviour modelling.

The paper shows that there are many ways of such new materials structure behaviour modelling. All the FE analyses always need to be verified with the experiments as well as for macro- and micro scale material reactions, properties and phenomena describing.

Keywords*: magnetorheological elastomer, FE modelling, multistage modelling, micro scale, macro scale*

1. Introduction

Interest in magnetorheological elastomers (MREs) has recently increased due to their prospective applications in smart systems. They are solid analogues of magnetorheological fluids in which the fluid component is replaced by the crosslinked material such as rubber or gel. They both consist of micron sized magnetically permeable particles in a nonmagnetic matrix material. Iron powder is used as the most common magnetic material with a high purity. In the case of MREs the magnetically permeable particles are added to the viscoelastic polymeric material prior to cross-linking [1, 2]. In a manner similar to the case of MRFs the particles tend to align themselves in the direction of the magnetic field [3-5]. But in MREs after the matrix curing process, the ferromagnetic particles are fixed in their positions and form chain-like structures. Magnetorheological (MR) materials change their rheological properties continuously, rapidly, and reversibly under the influence of the applied magnetic field [6, 7].

In the paper different approaches to numerical modelling of the magnetorheological elastomers (MRE) structures are presented. The methods of the MRE micro- and macrostructural FE simulations are taken into consideration.

The first approach is connected with the microstructural behaviour of the iron particles situated in the pure elastomer and subjected to the mechanical or magnetic load. The second approach is related to global material properties consideration and macrostructural behaviour modelling.

The paper shows, that there are many ways of such new materials structure behaviour modelling. All the FE analyses always need to be verified with the experiments, as well as for macro- and micro scale material reactions, properties and phenomena describing.

2. Applications of magnetorheological elastomers

Applications of MR elastomers include automotive bushings and engine mounts, where significant changes in spring constant due to the applied magnetic field can be used to control stiffness and damping properties dynamically. Some examples of the MRE applications are presented in Fig. 1.

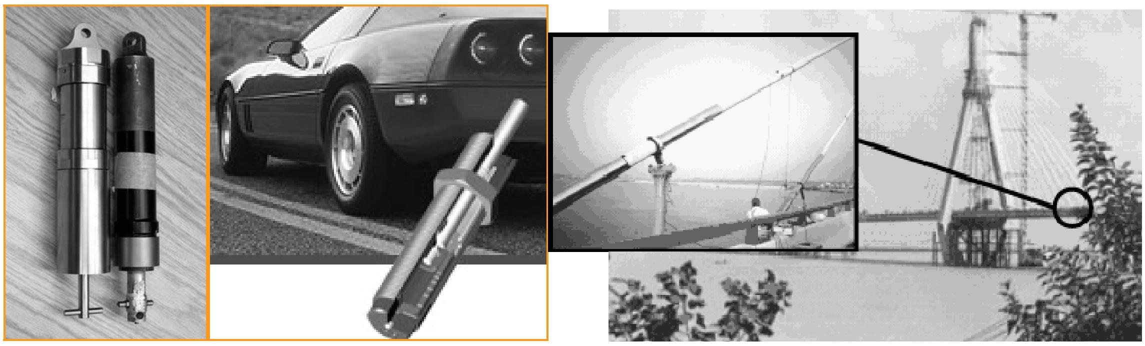

Fig. 1. Examples of MRE applications

3. MRE microstructure description and modelling

Different elastomers and magnetic particles can be used for fabrication of MREs. The strong external magnetic field is applied during the polymer curing process. The field induces dipole moments within the particles which relax into minimum energy states. The particle chains with collinear dipole moments are formed and the curing of the polymeric host material locks the chains in place. The particles can form separate chains, three-dimensional structures consisting of individual chains or more complex structures in which the particles have multiple interaction points [9]. The obtained microstructures determine the magnetorheological properties of the composites.

In Fig. 2 the typical microstructure of the MRE cured under the magnetic field of 300 mT, filled with carbonyl iron particles of 11.5 and 33 vol. % is presented.

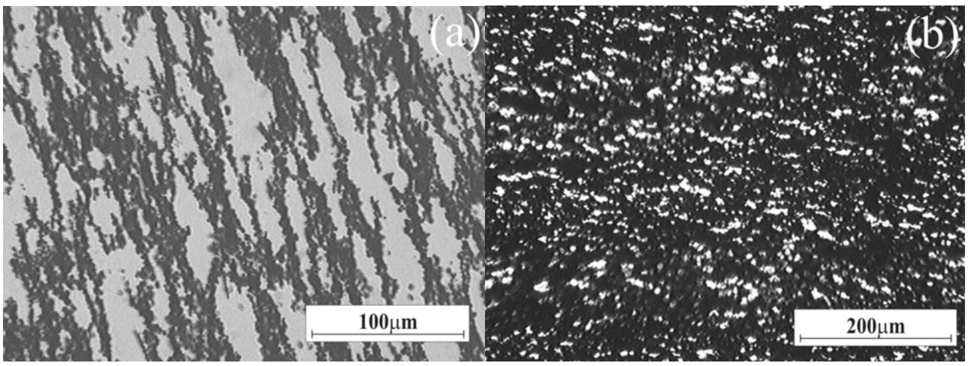

Fig. 2. Microstructure of PU cured under magnetic field of 300 mT, filled with carbonyl-iron particles: (a) 11.5 vol. %, (b) 33 vol. % [8]

The FE models were developed to assess the microstructural behaviour of the MRE. The most important thing in such approach is to choose the proper dimensions of the analyzed structure and to describe what mechanisms are the most important to research. The developed model was built of spheres representing the iron particles which were surrounded by the elastomer. The model is presented in Fig. 3 [10].

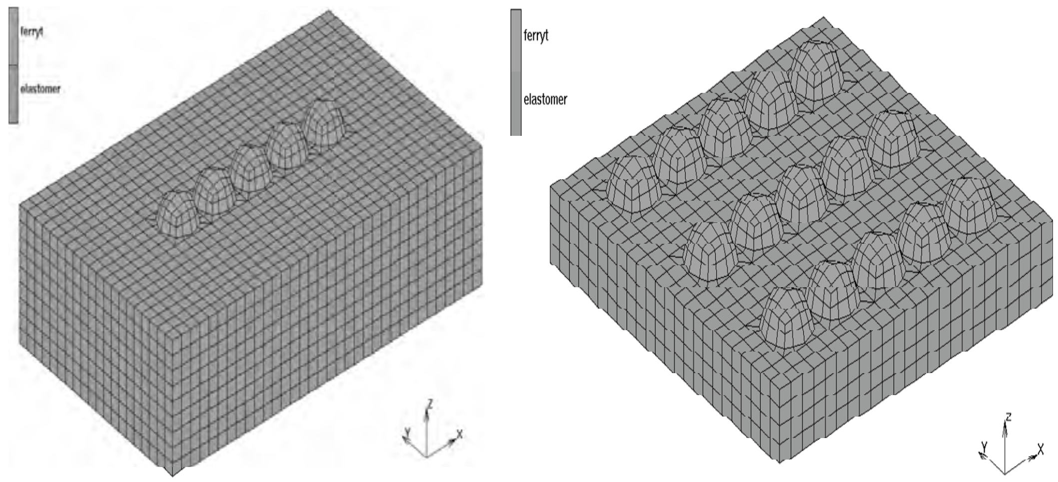

Fig. 3. Numerical model of MRE microstructure made of solid elements

The load coming from the magnetic force was realized by applying a concentrated force at the middle of the sphere. Additionally, this node was connected by link elements with its surrounding nodes. The applied boundary conditions were shown in Fig. 4.

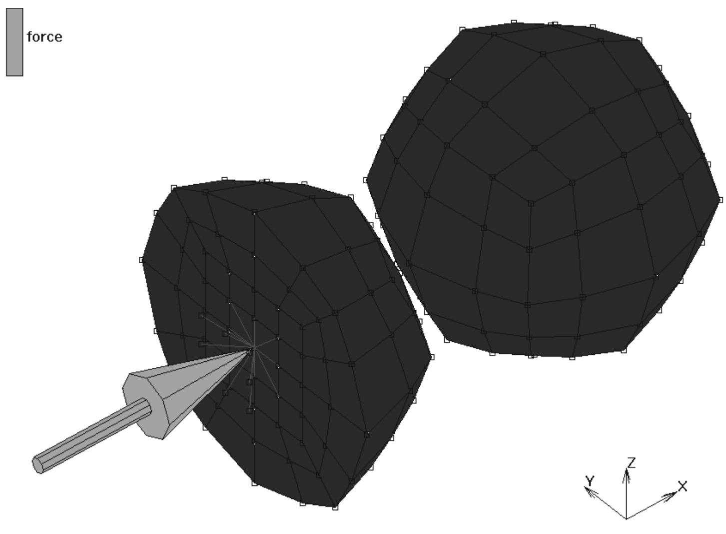

Fig. 4. Applied force simulating magnetic field influence

The example results obtained during the static analysis carried out with MSC.Patran/Marc computer code in the form of stress fringes were presented in Fig. 5. On the basis of such analysis results it is allowed to describe the stress distribution in the elastomer around the iron particle after the magnetic load. Also any other mechanisms appearing in such a microstructure can be evaluated.

Such results can be verified by the experiments with the usage of elasto-optics methods.

The other model was developed to assess the micromechanical interactions between the iron and the elastomer during the compression test. The FE model representing the iron particles chain built on the basis of the solid elements is presented in Fig. 6.

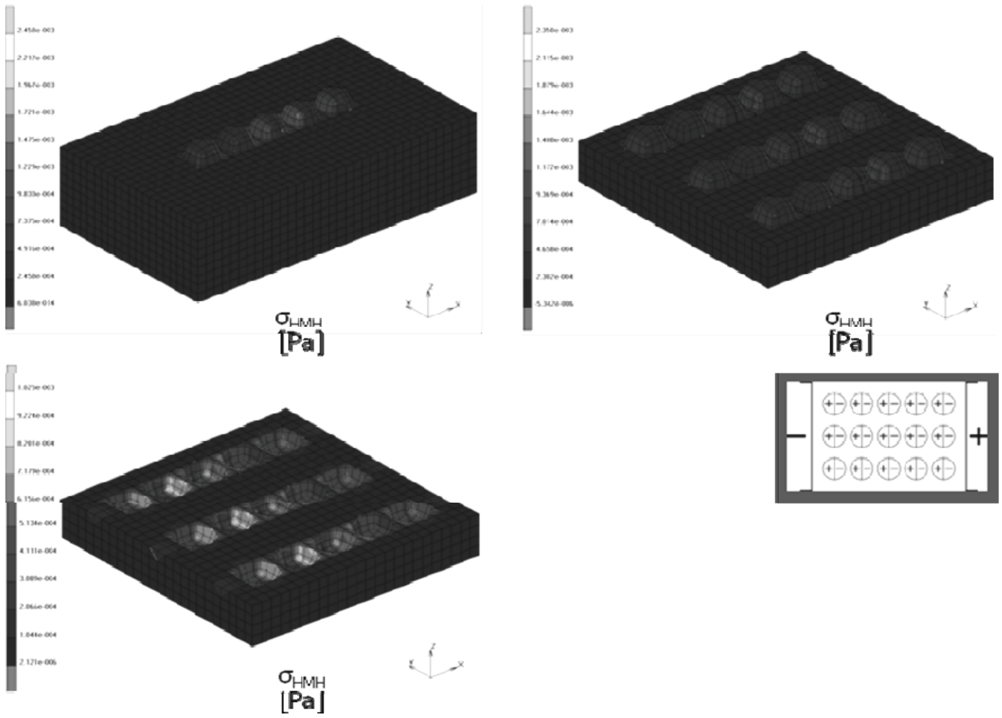

Fig. 5. Results of MRE microstructure numerical model analysis for magnetic load consideration

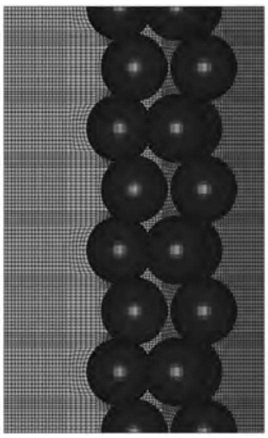

Fig. 6. FE model representing iron particles chain

The results are presented as stress distribution in the elastomer in Fig. 7. It is clearly visible that the highest stress value is reached in the elastomer near the top of the iron sphere.

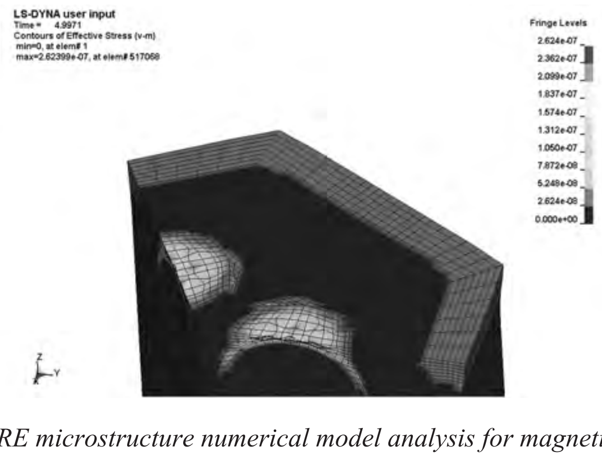

Fig. 7. Results of MRE microstructure numerical model analysis for magnetic load consideration

4. MRE macrostructure description and modelling

The macrostructural model was based on the assumption that MRE behaves like the 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 which took place for example in the three point bending experiment.

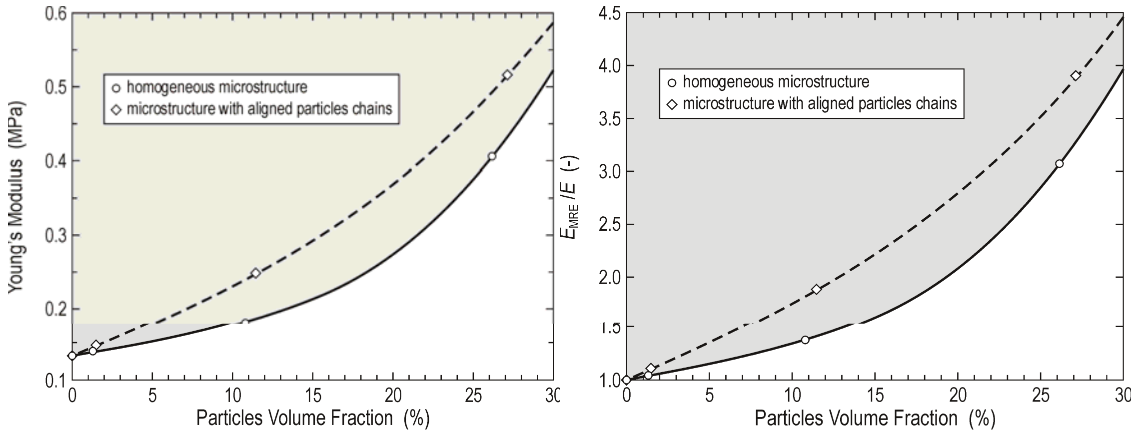

Fig. 8. Influence of the iron vol ume fraction on the Young's modulus of the magneorheologica l elastomer (a) ; Increase of the Young's modulus value in comparison with a pure elastomer (b)

The three point bending experiment of the MRE in the magnetic field was numerically verified. For the purpose of the FE modelling the previous experimental results for researching the Young modulus vs. the particles volume fraction were used. They are presented in Fig. 8.

The FE analysis consisted of the two stages: the first one was to initially deflect a cylindrical sample (ř=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. 9.

A numerical analysis was carried out for the MRE sample with 11.5 vol. % Fe and the iron chains parallel to the sample axis. The considered magnetic fields were 0.1, 0.3, 0.5. 0.7 and 1T. The number of Fe dipoles in 1 mm^3 was about 273058.

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

The results of the analysis are presented also in Fig. 9.

The applied method of numerical modelling of magnetorheological elastomers for small deformations was concluded to be correct. The considered material model was the orthotropic one with the material properties of MRE on the direction along the iron chains and - of a pure elastomer - for the other directions. Such a way of FE modelling resulted in about 0.15% of correspondence between the numerical and experimental analyses.

5. Conclusions

In the paper the various approaches to numerical modelling of the magnetorheological elastomers (MRE) structures were presented. The methods of the MRE micro- and macrostructural FE simulations were taken into consideration.

The different behaviours and phenomena appeared in each analysis and can be described due to the micro- and macromechanical properties of the researched MRE structure. The selection of the method must be based on the aims that have to be reached: for example, when the single iron particle reaction to the magnetic field is important, the micro scale model is necessary to be used.

The paper shows that there are many ways of such new materials structure behaviour modelling. All the FE analyses always need to be verified with the experiments, as well as for macro- and micro scale material reactions, properties and phenomena describing.

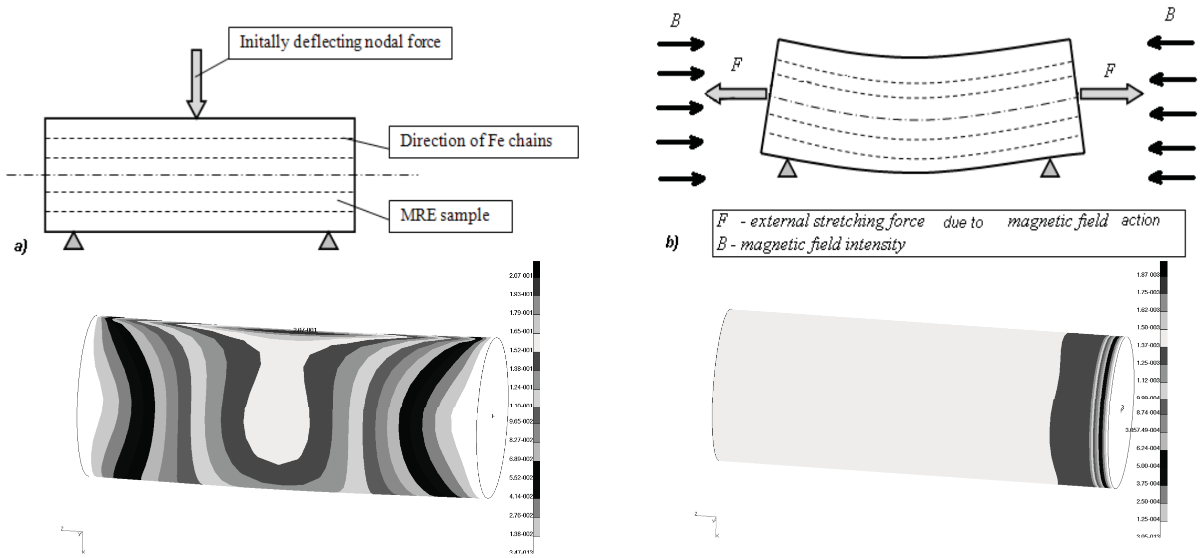

Fig. 9. Stages of MR E numerical analysis: initial bending (a), magnetic fie ld influence consideration (b) and respective deformation fringes above

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