INTRODUCTION TO N-BODY SIMULATION OF MAGNETORHEOLOGICAL ELASTOMER (MRE) MICROSTRUCTURE FORMING PROCESS

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Abstract

Magnetorheological elastomers (MREs) are the materials with rheological properties which can be changed in a continuous way, rapidly and reversibly 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 the introduction to the n-body simulation of the MRE microstructure forming process is presented. First, the basics of the n-body problem are presented as the planar three-body problem. It is well known, that the planar three-body problem is the problem describing the motion of three point masses in the plane under their mutual Newtonian gravitation.

In the paper it is shown how that problem will be applied to the simulation of the phenomena that appeared when the external magnetic field is applied to the chaotically mixed iron particles in the liquid elastomer. Also the physical model of the interactions occurred in such structures are described.

The assumptions shown in the paper will be then used for the development of the computer program which calculates the interactions between iron dipoles and describes the movement of the particles in the liquid elastomer under the magnetic field.

Keywords*: magnetorheological elastomer, n-body problem, magnetic interactions, smart materials, forming process*

1. Introduction

Magnetorheological materials are intelligent or “smart” materials which can respond to changes in the environment. The mechanical properties of MR materials can be reversibly changed and controlled almost instantaneously by altering an externally applied magnetic field. The functionality is based on the interaction between the magnetic particles which are distributed in a non magnetic material. The interest in such kind of materials shows a huge growth. Different types of MR materials are MR fluids, foams, elastomers and gels. The best known and best investigated materials are the MR fluids (MRF). But MRFs still have clear weaknesses which makes the investigation in MR elastomers so important.

Experimental experience and applications have shown that MR materials are much more efficient then analogous electrorheological materials as high voltages are required to get latter working effectively.

Magnetorheological elastomers (MREs) are multi-phase, multi-functional composite materials. Magnetic particles are suspended in a non-magnetic elastomer solid. Functionality is based on the interaction between the particles when applying a magnetic field. The particles try to align in chains in the direction of the magnetic field. These materials have rheological properties that can be changed continuously, rapidly and reversibly by an applied magnetic field. Mainly stiffness and shape are changeable.

Microstructure–property relationships of urethane magnetorheological elastomers added to a 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.

The microstructure of the MRE cured under the magnetic field is presented in Fig. 1.

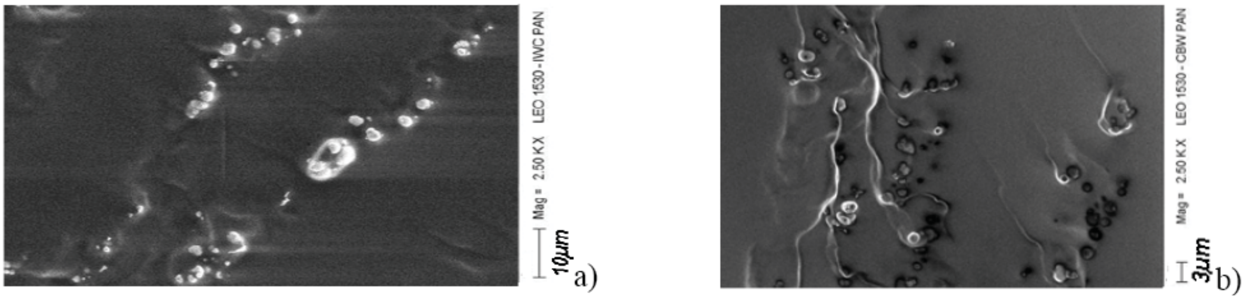

Fig. 1. SEM images of MRE obtained from PU 80/20 filled with 11.5 vol. % of carbonyl-iron particles, cured under magnetic field of a) 100 mT, b) 300 mT [6]

2. Three– body problem

The three – body problem presented below will be applied to the MRE microstructure forming process simulation which is consider to be the similar n-body problem with assumptions presented in chapter 3 of this paper.

The planar three – body problem is the problem of describing the motion of three point masses in the plane under their mutual Newtonian gravitation. It is a popular application of numerical integration of systems of ordinary differential equations since most solutions are too complex to be described in terms of known functions.

In addition, the three – body problem is a classical problem with a long history and many applications. Nevertheless, the sometimes complicated interplay of the three bodies can often be described in terms of two body interactions and is therefore qualitatively simple to understand. About 100 years ago the French academy of Sciences set out a prize for the solution of the problem which was awarded to Sundman for a series solution convergent at all times [7].

3. Physical basics of MRE microstructure forming process simulation

The interactions between two iron particles (dipoles) are described with three forces vectors: magnetic, gravity, viscosity and uplift pressure. Fig. 2 presents those forces for two interacting dipoles. In the further simulation those forces will be consider for each two dipoles in the model.

The most important force to consider is a magnetic force which appears when the external magnetic field is implemented to the iron particles. Those particles change into dipoles and

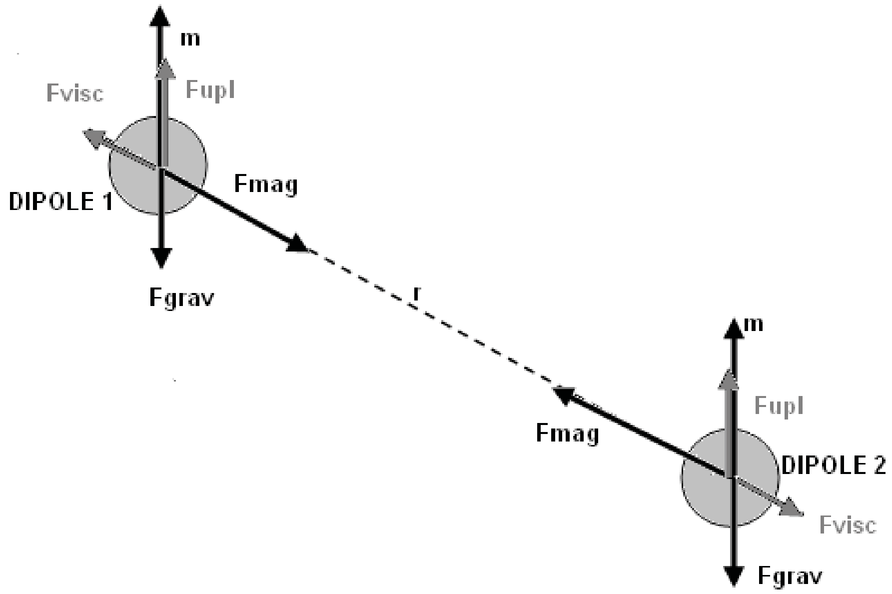

Fig. 2. Forces appeared in system of two dipoles interacting in magnetic field

magnetic force starts to act. The force is described with the equation (1) and is directed along the line connected the centres of two interacting dipoles (see Fig. 2):

$$F_{mag} = (3\mu_0/4)\cdot m^2\cdot(5\cos^2\alpha-1)\cdot(1/r^4), \quad (1)$$

where:

α - the angle between the external magnetic field and the dipoles chain axes,

$\mu_0=4\pi\cdot 10^{-7}$H/m - a magnetic permeability of a void,

r - the distance between two interacting dipoles,

m - magnetic momentum, considered in accordance to the volume iron share, magnetic field intensity and always directed along the magnetic field lines (the chart describing the magnetic momentum value vs. the magnetic field intensity is presented in Fig. 3).

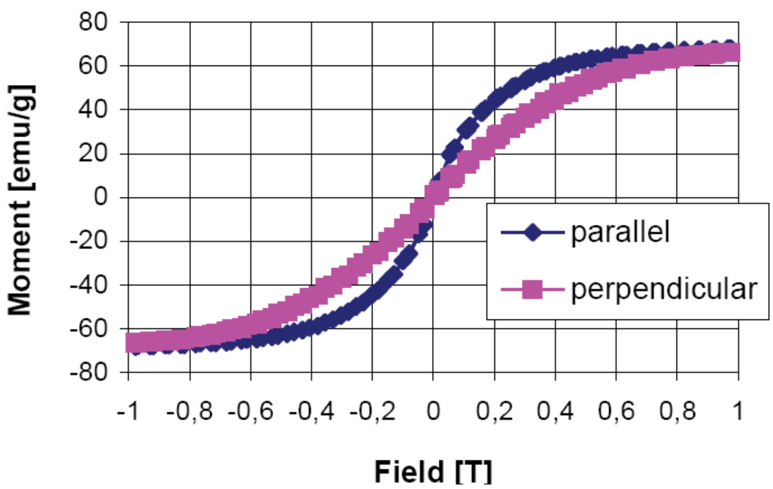

Fig. 3. Magnetic properties of MREs with 11.5vol.% Fe, cured undermagnetic field strength of 0.3T [8]

The other forces are:

- the gravity force described with equation (2):

$$F_{grav}=m_{Fe}\cdot g, \quad (2)$$

where:
m_{Fe} - mass of iron particle,
g - gravity acceleration,
- the uplift pressure described with equation (3) as:

$$F_{upl}=\rho_{elast}\cdot g\cdot V_{Fe}, \tag{3}$$

where:
ρ_{elast} - density of elastomer in which an iron particle is situated,
V_{Fe} - volume of an iron particle,
- the viscosity force connected with the movement resistance a liquid elastomer to an iron particle and is described with the equation (4), in accordance to Stokes rule:

$$F_{visc}=6a\cdot\mu\cdot v, \tag{4}$$

where:
a - is a radius of an iron particle,
μ - viscosity of a liquid elastomer,
v - velocity of an iron particle.

The time dependence of the viscosity of elastomer during the cross-linking is presented in Fig. 4.

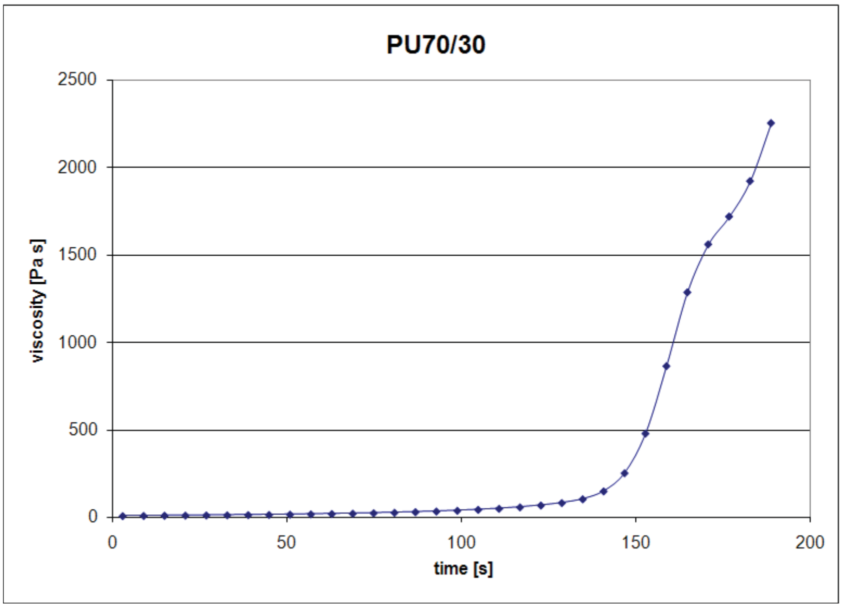

Fig. 4. Time dependence of elastomer viscosity during cross-linking

4. Conclusions

In the paper the introduction to the n-body simulation of the MRE microstructure forming process was presented. First, the basics of the n-body problem were presented as the planar three-body problem.

In the paper it was shown how that problem will be applied to the simulation of the phenomena that appeared when the external magnetic field is applied to the chaotically mixed iron particles in the liquid elastomer. Also the physical model of the interactions occurred in such structures were described.

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