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The fabrication and the identification of damping properties of magnetorheological composites for energy dissipation

Damian Bodniewicz, Jerzy Kaleta, Daniel Lewandowski*

Wroclaw University of Science and Technology, Department of Mechanics, Material Science and Engineering, Smoluchowskiego 25, 50-370 Wroclaw, Poland

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ABSTRACT

The paper presents experimentally characterises properties of magnetorheological composites (MRC) in terms of their application as the energy dissipating materials. Composite specimens saturated with various contents of magnetorheological fluid, the matrix of which was polyurethane material, were prepared. The obtained composites were tested in conditions of cyclic shearing in order to determine the parameters of damping. A focus was on influence of the following parameters: a share of magnetorheological fluid in MRC, value of the magnetic field intensity H, as well as the magnitude γ and frequency f of strain. The study results have been presented in the form of hysteresis loops in the $\tau(\gamma)$ stress-strain system. As the quantity representing energy dissipated by the composites the ΔW area of those loops was assumed.

1. Introduction

Magnetorheological materials are a kind of smart material. It means that in response to an input signal expressed in the determined physical field (electrical, magnetic, thermal), such a material changes its properties expressed in another field (e.g. mechanical). One of the representatives of this class of material is magnetorheological fluid, MRF, in its simplest form composed of carrier fluid (e.g. kerosene, mineral, synthetic, semi-synthetic, or silicone oil, water and others) and ferromagnetic active particles (e.g. carbonyl iron powder). This magnetic content constitutes from 20% to 50% of the fluid volume. The rheological properties of MR fluids change under the influence of an external magnetic field and play the role of the input signal. The phenomenon is observable as the transformation of a fluid into a material resembling a solid body. This particular behaviour of an MR fluid is the result of ”scheduling” the magnetic particles appearing inside a magnetorheological fluid which form groups – chains. The higher the value of a given magnetic field, the higher the value of the force necessary to break the structural chains (yield point – τ_0) [1]. The phenomenon described above occurs in a very short time (several milliseconds) and is reversible if active particles made of magnetically soft materials are used.

Due to the drawbacks resulting from the use of an MR fluid, new solutions are being sought. The composite materials that combine the characteristics of solid and liquid materials are created. A promising solution is the connection of MR fluids and an open cell matrix (e.g. foams with specific structural and functional properties). The matrix is usually responsible for keeping the geometry and filling specific places with the fluid. The MR fluid inside the pores works as the magneto-mechanically active content responsible for the change of the composite structure properties under the influence of a magnetic field. This is the material known as Magnetorheological Composite. The types of matrices and ferroactive part connections is infinite [2–5]. Some of them are very unusual, but at the same time very promising, e.g. metal foam [6–8] or elastomer [9,10].

Apart from being sensitive to a magnetic field, the necessary component of MRC is the matrix which determines its properties. It is usually made of a porous structure polymer that is composed of a network of interconnected cell walls and edges. In this type of composite the matrix walls are covered with a thin layer of MRF and the rest of the space is filled with air. The use of a porous material, such as the MRC matrix, simultaneously solves many problems related to the application of magnetorheological fluids in engineering, e.g. the issue of maintaining a magnetically active fluid in a defined space, limiting the phenomenon of dissipated particles sedimentation, and also the high cost of manufacturing an MR fluid (reduction of the necessary fluid volume).

Thanks to the freedom of shaping the geometrical dimensions of MRC, a large number of new applications are appearing. A good example could be magnetorheological friction dampers [11,12], which reduce the consumption of the active fluid causing the particle sedimentation phenomenon to be significantly limited. It is converted to achieve a higher safety of their application and to eliminate the need for initial work cycles. Subsequent applications are impact energy

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* Corresponding author.
E-mail address: daniel.lewandowski@pwr.edu.pl (D. Lewandowski).

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absorbing elements, such as car headrests [13,14], the protectors of particular body parts of passengers, the internal lining of work and sports safety helmets, as well as other potential future applications (active bulletproof vests) [13,15,16]. The last of these applications has recently been the object of significant interest in civil engineering and also used in damping vibrations in civil structures [7,17].

1.1. Scope of the work

The magneto-mechanical properties of magnetorheological composites are very interesting. Due to their properties they are predisposed to be included into active damping systems, however, it is first necessary to identify their behaviour with respect to both their specific structural and functional properties and also a magnetic field. The main goal of the work is the characterisation of the magnetorheological composite with reference to its use as an energy dissipating material. Apart from this, the authors formulated a thesis that showed that damping properties of MRC may be modified by selecting the quantity of the magnetic fluid inside the matrix. The undertaken research was the continuation of works [18,19] performed in the magnetorheological composites field. It was decided to extend the previously recorded results by using information related to the influence of magnetorheological fluid quantity on the damping parameters of a material while testing the modified MRC. In addition, an attempt to chracterise the influence of MRF additives on the process of its sedimentation was undertaken.

The following were recognised as the key activities:

- manufacturing of composite material specimens with different MRF content;
- preparation of a test stand enabling the determination of MRC damping properties in the conditions of variable mechanical and magnetic parameters;
- determination of the mechanical characteristics of the tested material specimens in the conditions of the change of the following parameters: non-dilatational strain angle γ, strain frequency f with simultaneous stimulation of a magnetic field of variable intensity H;
- comparison of the achieved functions for composites with a different content of magnetorheological fluid.

2. Selection and preparation of MRC components

During the work aimed at the determination of the composition of MRF, the authors based their actions on the example of the J. Rabinov fluid which assumed nine parts by weight of the active carbonyl iron particles and one part by weight of silicone oil (a carrier medium) falling into it [11]. On the basis of market research on available silicon oil varieties and their properties, the pure silicone polymer of 200 cP viscosity was selected as a carrier medium.

The carbonyl iron of the CC type from BASF was used as the magnetically active particles. Tests were conducted in order to determine the grain size, and they showed that the average diameter was $\phi = 2.65\,\mu\text{m}$.Test results in the form of particle size distribution are presented in Fig. 1a and b.

The last stage of composing the MR fluid was the selection of additives which help to decelerate the sedimentation process. The supplement of silicone grease was tested with respect to its influence on MR homogeneity in time. The verifications of this effect were performed for four prepared types of MR fluids with a different content of silicon additive (Table 1). The experiment lasted 50 days and was conducted on a stand constructed by the authors with the possibility of performing automatic measurements phase separation using the optical method. In Fig. 2a, such a separation of the carrier fluid and the magnetic content is shown. After some time, the glass sample tube filled with a homogeneous suspension begins to separate into two phases. The comparative results of the sedimentation process for all the prepared MR fluids is presented in Fig. 2b. The graph shows the curves of the lowering border between the carrier fluid and the magnetic particles as a function of time. The silicon grease addition has a significant influence on the slowdown of this process.

The increase in the amount of the silicone grease caused the growth of the viscosity of the MR fluid. There were some technical difficulties in the performed tests of filling a porous matrix when the grease content was higher than 20% in the weight of the MR fluid composition. As a result of these observations, the above mentioned quantity of additive was left for future research. The matrix, i.e. a porous polyurethane material in the form of a foam with open cells, was selected. It had regular pores of about 1 mm in size (Fig. 4a).

3. Preparation of MR composite specimens

The process of preparing the MR composites was divided into six stages. A series of schemes are shown in Fig. 3 to enable a clear visualisation of the whole process.

In the first part of the procedure the material for the matrix was selected and cut to the required shape and dimensions. The second step was to prepare an external surface which allowed the final specimens on the test stand or construction to be mounted. The way of mounting depends on the type and direction of loading or deformation. In this work, MRC composites were tested for shearing. The scheme of mounting the specimens, the direction of force and the magnetic field are shown in Fig. 5. To preserve parallel movement between opposite surfaces, two stiff plates (made of glass fibre reinforced composite) of a thickness of about 0.5 mm were glued, as shown in Fig. 3b. During these steps, the matrix has to be dry and unfilled because silicone oil contained in MR precludes mounting. In the third step, a filling process with the MR fluid was performed. This was done by the injection and immersion of the specimens. A needle was used to reach the inside of the composite, although the sharp end of the needle could cause the destruction of the inner structure. For this reason, it was only used a few times. The homogeneity of the filling and the distribution of MR inside the matrix was obtained by multiple sinusoidal mechanical compression (Fig. 3d). The control of the filling was done by weighing the specimens (Fig. 3e). In the last step, two single MRC pieces were connected together to create one symmetric MRC specimen (Fig. 3f).

The matrix and the fully functional composite after the saturation process by MR are presented in Fig. 4. As can be seen, some space inside the composite is filled with air. This allows to it to be deformed without the loss of fluid or the occurrence of leaking.

Four MRC specimens containing different fractions of MR inside the matrix were made (Table 2). The type of fluid was selected from the previous sedimentation experiment. Due to its low sedimentation and good injection ability, P2 was selected.

4. The experiment – cyclic tests

4.1. The test stand

The cyclic shearing tests of the produced composite specimens were performed at a test stand composed of three parts. First the mechanical part was hydraulic strength machine. The electromagnetic part allows a magnetic field of controlled intensity value H to be supplied an electromagnet connected to a supplier with the controlled value of current. The measurement system allows the acquisition and processing of measurement data including force F, displacement x and magnetic field H.

The method of preparing and installing the specimen at the measurement stand was determined by the intention to obtain a state close to pure shearing in the material. It is worth emphasising here that the way of mounting in the electromagnet gap warranted the perpendicular direction of a magnetic vector to the specimen shearing direction, which is schematically presented in Fig. 5a and b.