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EXPERIMENTAL METHOD OF MAGNETIC PERMEABILITY EVALUATION OF MAGNETORHEOLOGICAL COMPOSITES

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Abstract

The paper presents method of measuring the magnetic properties such as magnetic permeability and determination of the hysteresis B – H loop of magnetorheological composites. Magnetorheological composites are composition in which polarizable magnetic particles are dispersed in the soft elastomer mould. Magnetorheological composites have a big potential, which can be used in the aviation sector or in the motorization. Defining the magnetic properties of magnetorheological composites is essential; it allows determining the possibility of use of such materials and also gives opportunity to adapt materials characteristics to the needs of design.

In the Institute of Aviation during the project "Butterfly wing", the specialized test stand for testing of magnetic composite materials has been designed and manufactured. Construction of the test stand is based on electromagnet yoke, which allow generating magnetic field with a value above 1.5 T at low coercion value. Tests on the test stand were preceded by a simulation in the Maxwell Ansys environment.

The article presents subsequent stages of magnetorheological materials testing, starting with electromagnet yoke characterization relative to the air gap to determining relation between magnetic induction B, and magnetizing current I, determining the correction factor of the electromagnet and ending on the measurement of magnetic B – H hysteresis loop of tested composite materials.

Keywords: *experimental method, magnetorheological composites, investigations, magnetic permeability*

1. Introduction

Magnetic field is described by two vectors: magnetic field strength ***H*** and flux density ***B***. The relationship between the flux density ***B*** and the magnetic field strength ***H*** can be defined by the fact that the relative permeability μ_r is not a constant but a function of the magnetic field intensity thereby giving magnetic flux density as: $B = \mu 0 \mu r H$, where μ_0 is free space permeability. Depending on the relative permeability μr, the substances are divided into three groups:

- diamagnetic, μ_r is insignificantly less than 1,
- paramagnetic, μ_r is insignificantly greater than 1,
- and ferromagnetic, μ_r is significantly greater than 1.

Diamagnetic materials spontaneously do not exhibit magnetic properties. Placement of diamagnetic in an external magnetic field generates in the material a magnetic field directed opposite to the external magnetic field.

In general paramagnetic opposed to diamagnetic, orients its dipole along a line of external magnetic field. Structures domain, within the material, tend to be set along external magnetic field line, but the degree of structure orientation is expressed by means of the susceptibility or permeability, which corresponds to the question of the orientation degree of internal dipoles, low susceptibility or permeability indicate a low structure orientation.

In the case of ferromagnetic materials a relationship between the values vectors ***H*** and ***B*** it is not, unlike the other group of substances, or a linear or even unequivocal. If in non-magnetized ferromagnetic sample we will generate a magnetic field of field strength value ***H***, and then we lower the field strength by zero to – ***H*** (by changing the field phrase to the opposite), and again increase by the value of zero to the value of ***H***, we obtain a closed curve called magnetic hysteresis loop or B-H curve. Due to the width of the magnetic hysteresis loop of ferromagnetic materials it can be distinguish hard magnetic materials with a high coercive force and a soft magnetic materials with a low coercivity [3, 12, 15].

Magnetorheological (MR) materials belong to the group of smart materials. Their rheological properties are susceptible to the existing magnetic field. First magnetic materials – magnetorheological fluids were developed by Rabinov in 1948 [8, 9]. Currently the following types are distinguished among the magnetorheological materials: MR fluids (MRF), MR foam, MR gel, MR paste, MR composite.

MR elastomers are constant MRF analogs and they can be the solutions to MRF inconveniences, the sedimentation. MR elastomers are composites, in which the magnetic particles are scattered (dispersed) inside the elastomer matrix. Usually very soft elastomers, such as masticated silicones or soft polyurethanes are used as the polymer matrix. In the majority, they are being filled with up to 30% magnetic particles volumetrically. This is the cause of the significant deterioration of their mechanical properties – in case of silicone elastomers, the mechanical properties are already impaired. In MRE based on soft silicones and polyurethanes a considerable magnetic efficiency can be observed, however it is achieved at poor mechanical properties, as a result it prevents them from being real engineering solutions [4].

Magnetorheological composites have a big potential, which can be used in the transport [1]. One of the solutions, which can includes the MR composite is the patent [16] concerning the inflexibility regulations of the suspension elements by implementing a rigidity-adjusted sleeve.

Similar solution was used in eliminating the vibrations of brake discs [14]. Thyssen Krupp AG Company has developed a steering wheel column with an adaptive system of energy absorption in case of a crash in which magnetorheological composite is applied in one of the elements [5].

General Motors has developed a system, which absorbs energy during the crash [2]. It can be installed inside headrests, seats, dashboard, and doors or over drivers and passengers' heads. This patented solution is composed of a rigid base and elastic cover. In between them, there are the cylindrical elements made of magnetorheological composite and the coil is reeled on them. The whole system is equipped with the sensors and a control system.

Such materials are suitable for engineering solutions, such as building smart vibroisolators or variable shape structures (morphing structures) used in aeronautical engineering. Morphing structures enable the change of aerodynamic properties of the lift and steering surfaces during the flight, increasing the efficiency of the flight [11].

In order to get MR composites with good mechanical properties, works are being conducted on MR composites based on retreading natural India rubbers. These composites are being filled with great amount of magnetic particles, as well. They are being filled with up to 50 % magnetic particles volumetrically. In case of composites based on natural India rubber, it does not cause a rapid decrease of its mechanical properties.

2. Magnetorheological composites

The fabricated magnetorheological composites consisted of the two main components: first carbon iron powder HS, produced by BASF, was used for fabrication of the samples. It has a spherical shape and average diameter 1.8-2.3 μm. This type is pure iron particles (>99%). As a second component a natural rubber (NR) type SVR 3L produced by Brenntag was used.

Using a laboratory mill the NR masterbatch was obtained containing no carbon iron particles. Then, using a mixer the masterbatch was mixed with appropriate quantities of ferromagnetic filler.

The vulcanization of the compound was performed using a laboratory press. Plates were vulcanized at 145°C, at a pressure of 17 MPa. The obtained plates were cut into discs with a diameter of 20 mm.

The morphological studies of vulcanizes were performed using a scanning electron microscope (SEM, Gemini LEO 1530). Micrograph of the sample is shown in Fig. 1, where we can observe carbonyl iron particles (CIP) suspended in the polymer matrix.

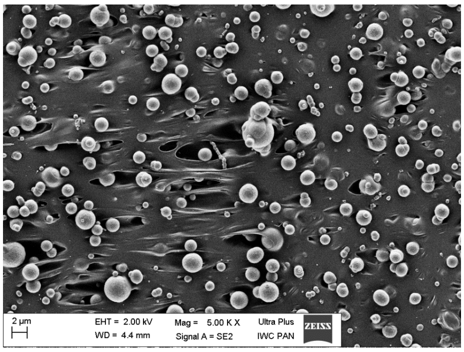

Fig. 1. SEM microstructure of MR composite revealed on a surface of sample containing CIP HS

3. Measuring method of magnetic properties of MRE composites

Methods by which can be examined magnetic properties are defined by a set of standards developed by organizations related to materials engineering and electrical engineering. The measurements of values that characterize magnetic field i.e. magnetic flux, magnetic induction and intensity of the magnetic field, and the measurements of the magnetic materials properties are usually performed by electrical methods.

The Standards provide several methods for determining the magnetic properties of the tested materials. Depending on the shape and type, the following magnetic circuits can be distinguished by [6, 7, 10, 13, 15]:

- systems for closed frame and ring samples examining i.e. oscilloscope method, ballistic method or Epstein frame,
- open systems, a straight sample is put inside the magnetizing coil,
- systems for examining the samples in closed magnetic circuits, a sample is just the part of the circuit i.e. yoke electromagnet.

The basic magnetic properties of magnetorheological composites were determined using test stand developed in the Institute of Aviation. Due to the expected paramagnetic properties of MRE composites, it was necessary to perform a test stand that allowed generating high magnetic field to determine the degree of saturation of the tested MRE materials.

From the test stand solutions describe above, choice was a closed magnetic circuit based on an electromagnet yoke. Such system preparation requires precise mechanical and electromagnetic calculations however, it is possible to obtain high magnetic field.

Test stand consists of several parts, which include electromagnet yoke, magnetic induction gauge and PC with LabView data control and measurement application (Fig. 2).

The electromagnet yoke made from Armco steel, a technically pure iron – 99.99% Fe, 0.01% impurities, and two coils connected in series, in order to maintain the uniform current value flowing through both windings, as a result the magnetic flux sum up (Fig. 3).

In order to examine the MRE material samples a full mathematical description was prepare based on which tested material properties are determined. Before tests, in order to compare the actual results with theoretical reflections 2D and 3D simulations were prepared in the Maxwell ANSYS environment. Firstly electromagnet calibration was performed. Electromagnet calibration consists in determination of the relation between magnetic induction B, and magnetizing current I. The tests were performed for air gaps' sizes: 1.2 mm, 5 mm, 3 mm and 10 mm. The results of the experiment are coincide with the results obtained in the simulation (Fig. 4). Electromagnet calibration determine linearity of $\mathbf{B} = f(\mathbf{I})$ characteristics.

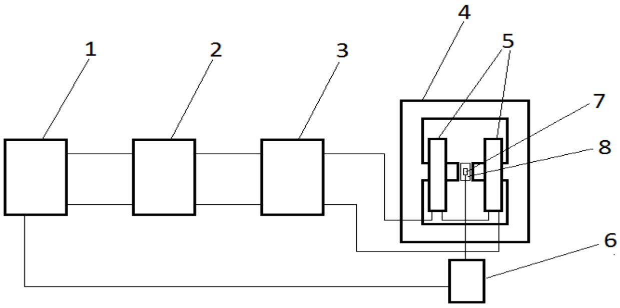

Fig. 2. Test stand scheme: 1 – PC with data control -measurement application, 2 – power supply, 3 – electromagnetic relay, 4 – yoke, 5 – coils, 6 –gaussmeter , 7 – measuring probe, 8 – measuring gap

Fig. 3. Electromagnet yoke

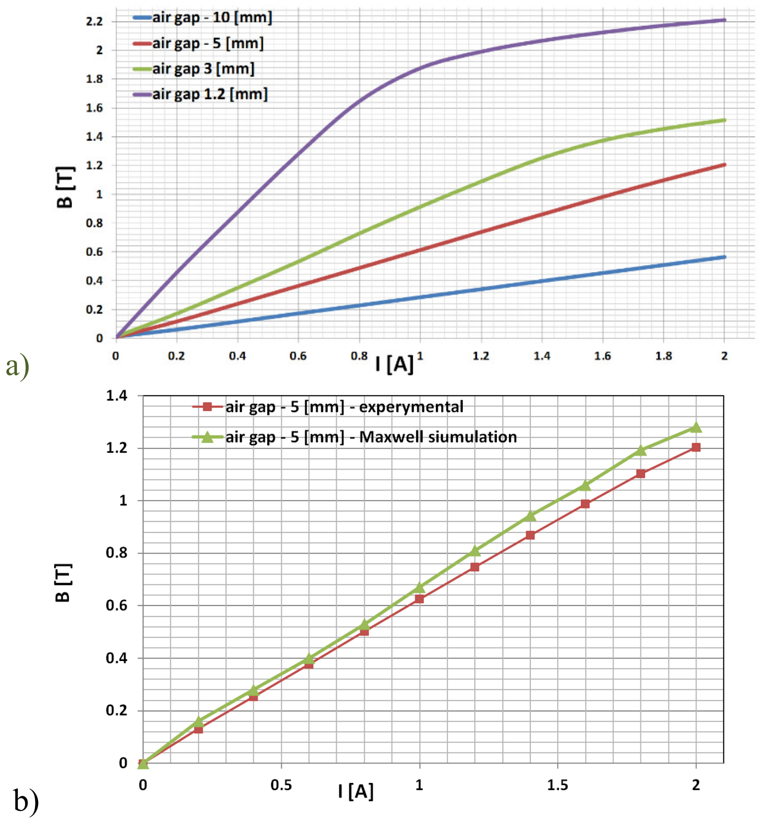

Fig. 4. The electromagnet calibration: a) experimental for different air gap; b) compare with Maxwell simulation

The next stage of the analysis was to set correction factor. This factor is necessary to determine, because the yoke of device is made of a soft magnetic material, which causes losses related to the remagnetization of the whole system. Correction factor is determined before each MRE material test for the air gap.

4. Research and results

Tests were performed for two magnetorheological composite samples, each of a different thickness. The following tests were performed in order to determine the hysteresis curve of the material, respectively, the first sample having a thickness of 0.8 mm and a second sample having a thickness of 0.9 mm. Composite sample with the Hall Effect probe were placed inside the air gap (Fig. 5).

Fig. 5. Magnetic induction measurement on the working station with the magnetorheological elastomer

The result of the measurements performed in a described way, a **B** as a function of **H** curve was obtained, which is shown in Fig. 6 and 7.

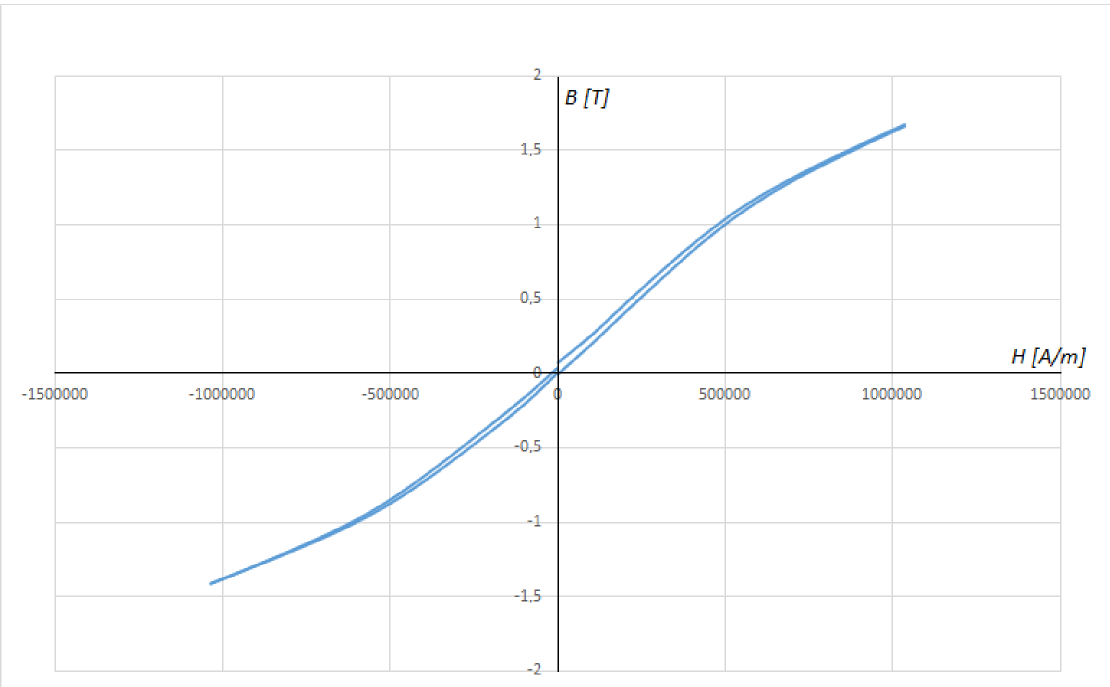

Fig. 6. B-H curve for sample having a thickness 0.8 mm

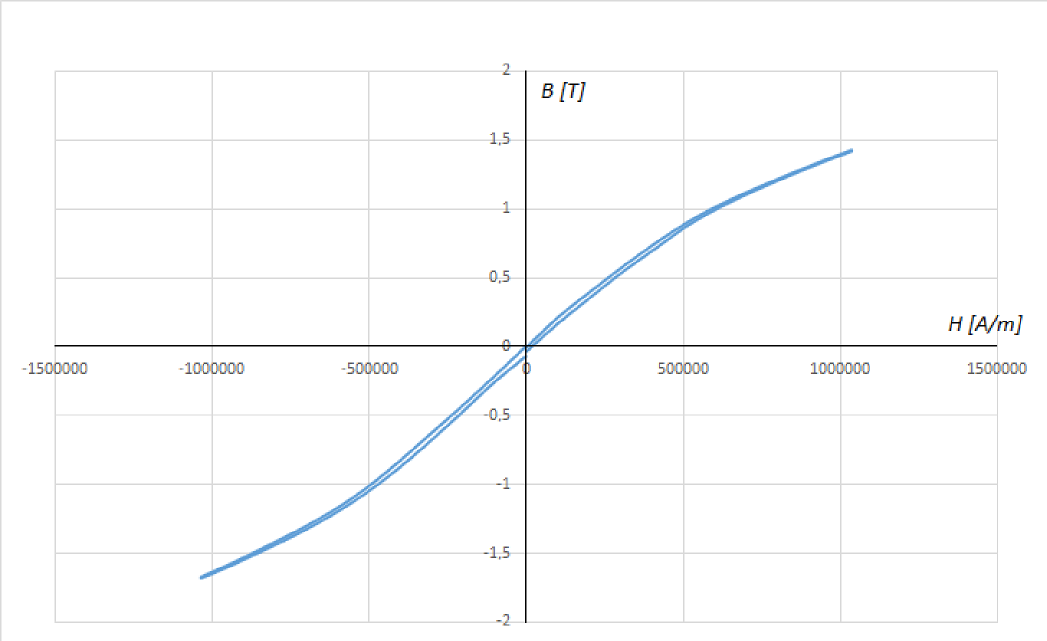

Fig. 7. B-H curve for sample having a thickness 0.9 mm

5. Conclusions

Magnetic properties of MR composites have been studied by some researches but a study on its magnetic hysteresis curve is the new investigation. Hysteresis curve of the MRE fabricated with carbon iron particles dispersed in natural rubber was studied in the magnetic field 0-2T. For magnetic characterization, a new experimental set up for magnetorheological materials was conceived and constructed. Due to the interaction between carbon iron particles, we can find magnetic hysteresis curve.

The obtained results of experiment confirm the characteristics of paramagnetic material, which is perfectly shown in the graphs (Fig. 6 and 7). The difference in material thickness does not affect significantly to changes in the characteristics. The proposed test bench fulfil the criteria for determining the magnetic properties of the MR composites.

MR composites based on natural India rubber are used in the car or aviation industry. Works are being conducted in FORD and General Motors. New solutions, which regard implementing magnetorheological composite for transport applications, are constantly being patented/licensed.

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