

MANUFACTURE AND TESTING OF MAGNETOSTRICTIVE COMPOSITES

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Abstract: Among used in today's engineering materials, the more attention is attached to active materials, defined most often as SMART. Smart Magnetic Materials (SMM) play a big part in this numerous group of materials, from which chosen are an object of described hereafter investigations. One type of SMM are Giant Magnetostrictive Materials (GMM) which can be represented by i.e. Terfenol-D. The biggest difficulty with mechanical application of GMM is its brittleness, as well as appearing of eddy currents near frequencies of work and high price. These disadvantages tend scientists to search new solutions in a form of composite materials with giant magnetostriction (GMMc). The purpose of this paper was to manufacture magnetically polarized (anisotropic) magnetostrictive composites (GMMc) and to investigate their magnetomechanical properties. The materials were based on an epoxy resin matrix and Terfenol-D particles which were added with different volume fraction. A manufacturing procedure was developed to create specimens with magnetic field-oriented microstructure. GMMc with various volume fraction of Terfenol-D particles were subjected to quasi-static investigation of their properties with the use of a dedicated test stand. The results revealed that selected properties of magnetostrictive composites differ markedly depending on the value of used prestress and intensity of magnetic field.

Key words: magnetostrictive, composites, GMM, SMART materials.

1. Introduction

Giant magnetostrictive materials (GMM) are materials whose selected properties can be changed by an external magnetic field. They belong to a wider material group known as Smart Magnetic Materials (SMM) and some of them are the alloys composed mainly of terbium (Tb), dysprosium (Dy) and pure iron [1]. Materials with giant magnetostriction may change the magnetic energy into mechanical one and vice versa. Due to such properties the materials could be used as

sensors or actuators. The GMMs obtain much larger strains (even up to 70 times) than the traditional magnetostrictive materials, and for obtaining that effect, the relatively low magnetic field intensity H is required. Very important feature of those materials is their wide working temperature range, as well as their low inertia (small area of hysteresis loop), which allows for their application in various conditions. Possibility of predicting the mechanical and magnetic properties of such materials as the Terfenol-D caused that they find all the wider application in various engineering

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domains [7].

The solid magnetostrictive materials, despite their numerous advantages, have several disadvantages which make their wider industrial application difficult. First of all, their significant drawback is high brittleness, resulting in the low tensile strength. The other limitations are the eddy currents of significant value, which restrict the effective working frequency of devices to several kilohertz. Important parameter is also the price of Terfenol-D, which is kept at the level of 2 \$/1 g. The above limitations are generating the need for finding new solutions. One of them is magnetostrictive composites (GMMc). The main object of the research are composites based on epoxy resins, where the magnetically active filling usually have the form of powder [4, 5].

2. Objectives

The main goal of this paper was to show the manufacturing process of magnetostrictive composites with different volume fraction of Terfenol-D powder and to examine their magnetomechanical properties. For that purpose, the manufacturing procedure was developed which made it possible to produce magnetically polarized GMMc with epoxy matrix. Their properties were tested on a dedicated test stand, described in detail in authors' previous publications [3, 6].

3. Manufacture of Magnetostrictive Composites

The properties of magnetostrictive composites depend mainly on volume fraction of particles of magnetostrictive materials in the matrix and particle alignment. In this chapter components of composites are discussed and the manufacturing processes are described for the selected compositions.

3.1. Matrix

The most popular material used as GMMc matrix is an epoxy resin. Since this material is not recyclable, there is no possibility of reprocessing once the matrix is cured. That is why an EPOLAM 2015 epoxy resin was selected as matrix. The material as well as the hardener which is necessary in the manufacturing process, was purchased in the form of liquid. The most important properties of the resin are: low viscosity, good behavior in a humid environment (composites resistant to water), and also good mechanical and thermal properties (see Table 1).

EPOLAM 2015 properties [9], at glass transition temperature 80 °C Table 1

Unit	Value
Brookfield's viscosity [MPa*s]	30
Density [g/cm ³]	1,06 – 1,10
Tensile strength [MPa]	105
Charpy's Toughness [kJ/m ²]	30

3.2. Magnetic Particles

If maximum magnetostrictive effect is to be obtained, magnetic particles should have high magnetic permeability and saturation magnetization. Also the size, shape and volume fraction of the particles strongly affect the properties of the whole composite. The highest magnetostrictive effect is achieved for magnetic particles several dozen micrometres in size. Terfenol-D powder from the Gansu Tianxing Rare Earth Functional Materials Co., Ltd., with particle size of about 5-300µm (Figure 1), was selected as magnetic filler. Performed examinations revealed that particles have a porous surface and irregular shape (Figure 2).

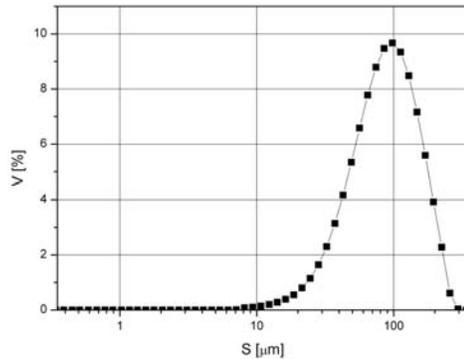


Fig. 1. *Terfenol-D powder particles size distribution*

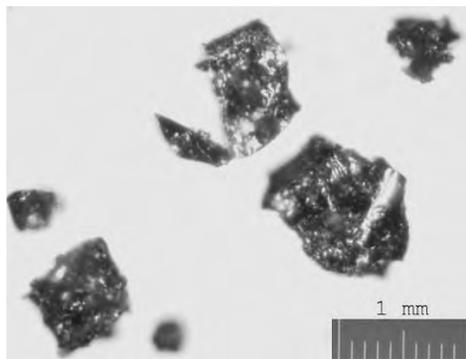


Fig. 2. *Shape and size of Terfenol-D particles*

3.4. Composition of Test Samples

To achieve maximum magnetostriction effect in a GMMC, the proportions of individual components must be carefully selected, especially the content of magnetic particles should be as high as possible. The limit value, known as the critical particle volume concentration (CPVC) can be calculated. For Terfenol-D powder, it amounts to 48%. Various contents of magnetic particles were tested and two different values of volume fraction of Terfenol-D powder were set 35% and 45%. What is more, three additional types of composite, with higher volume fraction, which exceed the value of critical particle

volume concentration also were produced. For those samples special manufacturing process was prepared.

3.5. Manufacturing Process

The manufacture of magnetostrictive composites consisted of several operations (Figure 3). At the first stage (A), a hardener was added into the epoxy resin. When the ingredients were well mixed (D), the measured quantity of the Terfenol-D powder was also added to the container. Then, (F) the whole mixture was mixed, until homogenization of all ingredients was reached. In the next step, container with a mixture was closed in the vacuum chamber for the deaeration process, (G) which took about 10 minutes, until whole air was sucked out. After vacuum process prepared mixture was poured over to the containers of cylindrical shape (H). The containers were subjected to initial polarization (I) and again deaerated, from the air that could get into the mixture during the pouring process. When the whole air was sucked out the specimens were subjected to subsequent polarization (J), which prevented sedimentation of the powder particles during the resin binding process.

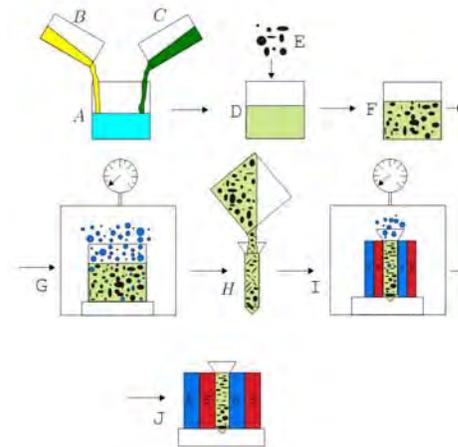


Fig. 2. *Manufacturing procedure of composite specimen*

In order to obtain samples with higher volume fraction of Terfenol-D particles additional operations have been made. The specimens were subjected to magnetic polarization perpendicularly and parallel to the principal specimen axis. For this purpose, the specimens were inserted between permanent magnets and into the coil (Figure 4a and 4b).

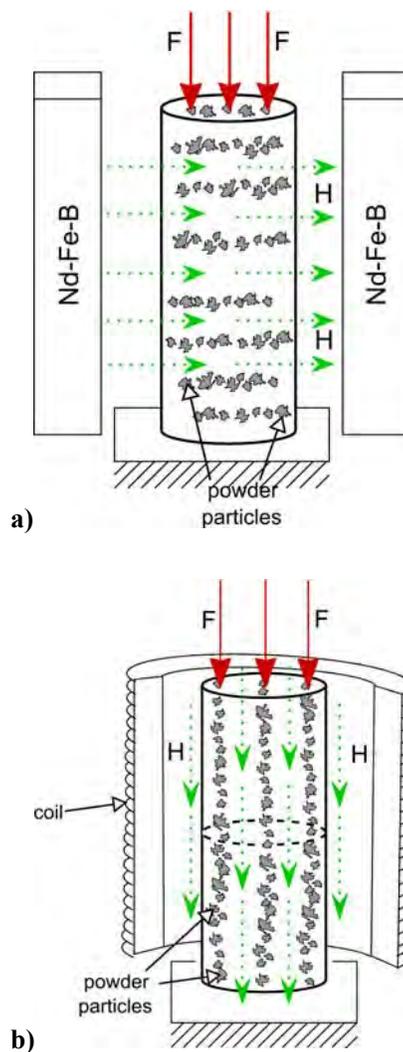


Fig. 4. Specimen with polarization field H during resin curing: a) perpendicular polarization, b) parallel polarization

The magnetic field used for the preliminary magnetization amounted to 150kA/m. Then the specimens were placed in an MTS hydraulic pulsator where the excess of resin was squeezed out, whereby a material with an increased volume fraction of Terfenol-D particles was obtained. The specimens were left in the strength tester for 4 hours to allow the resin to set. Then they were put into a furnace and annealed at temperature of 80°C for 24 hours until the matrix fully hardened. The GMMs produced in this way contained 70% of Terfenol-D powder in their volume.

The composite in the shape of cylindrical rods of a 70 mm length and 10 mm in diameter, were obtained. To avoid inhomogeneities in the material, especially on the top and bottom of specimens, both ends of the specimens were reduced and their surfaces aligned. The final length of the sample was 50 mm.

4. Testing methods

Magnetostrictive composites were examined on a dedicated test stand (see Figure 6), described in detail in [6]. The magnetostriction of the produced GMMc was investigated and compared with that of solid Terfenol-D.

The measurement was performed at room temperature (22°C). Prestress σ_0 was precisely applied and maintained by means of the MTS. Magnetic field strength during the tests was adjusted by adjusting the intensity of the current flowing in the coil. An adjustable power supply was used for this purpose. The range of magnetic field, dependent on the magnetic circuit parameters, was 0-168 kA/m. In order to check whether there was parity effect, the measurement was made for both positive and negative values of magnetic field strength H . The latter was measured using a Hall probe placed in the coil.

Then strain $\Delta\lambda$, being the result of the time-varying strength of the magnetic field acting along the principle axis of the tested specimen, was measured using optical fibre sensors (fibre Bragg grating (FBG)) glued to the composite sample. In this way the influence (directly proportional to the change in the length of Bragg wave) of the electromagnetic field on the magnitude of the measured physical quantity (strain) was eliminated [8]. FBG sensors of the bare fibre type, which could be installed directly on the surface of the sample along its principal axis, were used for the measurements.

An IPHT (Jena) measuring system was used as the signal processing unit (SPU). The strain change was measured with a sampling rate of up to 5Hz (quasi static measurement). The FBG based measuring method is described in detail in [2].

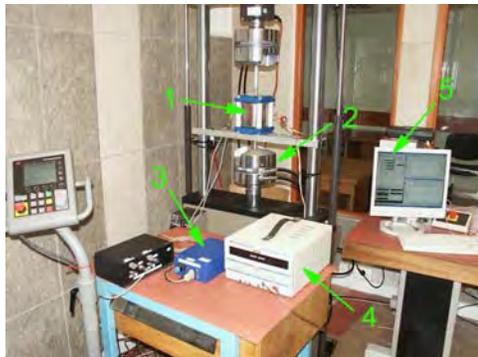


Fig. 6. Test stand: 1 - coil with sample, 2 - MTS, 3 - FBG measurement unit, 4 - power pack, 5 - PC with data acquisition.

5. Results and Discussions

Due to the fact that best results of magnetostriction were obtained only for three types of composites which containing high volume fraction of Terfenol-D particles, results only for this group of specimens will be shown in this section.

In order to determine the

magnetomechanical properties of the GMMc, the values of magnetostriction $\Delta\lambda_{\max}$ obtained for maximum magnetic field strength $H=168$ kA/m were compared.

The test results for the composite materials and solid Terfenol-D, under a prestress of $\sigma_0=1$ MPa were compared (Figure 7). It appears that the best results were obtained for the specimen polarized perpendicularly to the principal axis. The magnetostriction of this GMM is lower by 280ppm (which amounts to 30%) than that of the solid material.

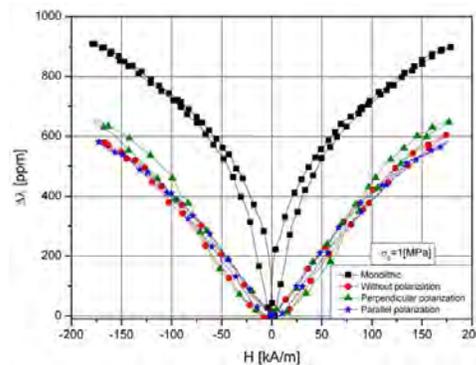


Fig. 7. A comparison of magnetostriction values $\Delta\lambda_{\max}$ for the composite materials with 70% volume fraction of Terfenol-D particles and solid Terfenol - D, under a prestress $\sigma_0=1$ MPa.

Figure 8 shows a comparison of the test results for the GMM composites and solid Terfenol-D at a higher prestress $\sigma_0=7$ MPa. In comparison with the previous diagram, one can notice that the magnetostriction of the GMM increases with the prestress, but to a lesser extent than in the case of solid Terfenol-D. At 7MPa it is lower by 700ppm (which amounts to 45%) than that of the solid material. But also in this case, the best result was obtained for the material with perpendicular polarization.

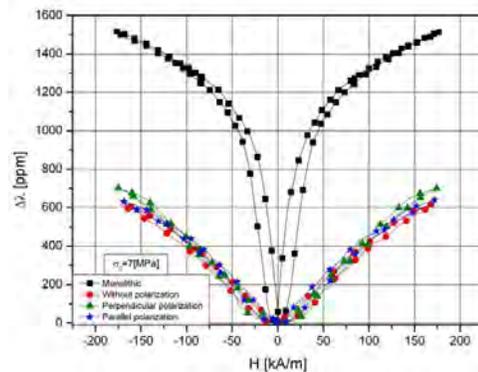


Fig. 3. A comparison of magnetostriction values $\Delta\lambda_{max}$ for the composite materials with 70% volume fraction of Terfenol-D particles and solid Terfenol - D, under a prestress $\sigma_0 = 7MPa$.

6. Conclusions

GMM composites with different volume fraction of Terfenol-D particles were manufactured and their magnetomechanical properties were tested. Effect of magnetostriction was observed, as a change in material length occurring under the influence of external magnetic field. The results revealed that, the higher, the volume fraction of magnetostrictive material in matrix was, the better results of length change were obtained.

Acknowledgements

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