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INVESTIGATION ON LAMINATED MAGNETOELECTRIC COMPOSITE

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Summary: *In this paper, a novel magnetoelectric laminated composite system consisting of a one layer of longitudinally polarized piezoelectric material sandwiched between two layers of transversally magnetized Terfenol-D magnetostrictive composite was presented. Terfenol-D composites were fabricated by embedding and aligning Terfenol-D particles with a size distribution of 5-300 μm in a Epolam 2015 epoxy matrix with volume fraction 0.7. Their quasistatic and dynamic magnetic and magnetomechanical properties were measured as functions of magnetic field. The PZT material was a commercially available material which was supplied by Smart Material company. The P1 type of micro fiber composite (MFC) was chosen. Behavior of this hybrid material in a variety of external magnetic field directions was investigated. Based on the obtained results, it was found that the prepared composite material exhibits magneto-electric effect in the case of work in a variable magnetic field.*

1 INTRODUCTION

Currently, the research on new materials exhibiting cross effects, coupled by the mechanical and magnetic fields are directed to combine these materials with other materials which exhibiting completely different properties. The most promising of these additional materials tend to be those which are characterizes by an electric properties. Usually in the literature a combination of these two kind of materials is known as hybrid material. They can be characterized by the capability to work under the influence of various external factors. Most of these new materials based on polymer matrices. Polymer-based magnetoelectric (ME) materials are one of the most interesting, challenging and innovative materials and thus these materials are in a field of interest of many research centers.

Due to the unique properties of these materials, it is believed that in the near future, the gap between basic research materials and real applications will be filled. Materials exhibiting magneto-electric effect are sort of bridge connecting the magnetic and electrical properties [1-3]. The interest in the effect of ME is increasing due to its potential applications in areas such as data storage, multi-state memory, sensors, actuators, transformers, gyros, microwave devices, optical waves, diodes, and other [4-8]. In order to positively match the technological requirements of these and other applications, a strong ME effect at room temperature has been obtained from multiferroic (MF) composites, which is generally obtained by combining piezoelectric and magnetostrictive components [9].

In this paper a study on the magnetostrictive-piezoelectric composite materials with different configuration in a variety of external magnetic field directions was presented.

2 MATERIAL

In this chapter, materials that were used to form a hybrid composite which exhibiting the effect of ME were shown. The main properties that allowed us to use these materials in such kind of structures were presented.

2.1 Piezoelectric material

The principle of work of piezoelectric materials is well known and it based on displacement of electric charges under mechanical deformation. This physical phenomenon works also in opposite way it mean that change in the electric charge causing mechanical deformation of this kind of material. At present, material such as PMN-PT single crystals exhibit the best coupling coefficient in d_{33} mode. This coefficient qualifies the efficiency of energy conversion between electric and mechanical. Unfortunately these type of piezoelectric materials is expensive and highly brittle. Thus for our investigations we choose PZT oxide ceramics, which also exhibit a good coupling coefficients.

PZTs can work along several modes, each of them have can be characterized by its own coupling coefficient. In case of bulk PZT materials we can distinguish two modes such as d_{33} and d_{31}. We are talking about first one of these modes d_{33} when the strain of material and its polarization are in the same direction. The second mode d_{31} is define when the strain and polarization of the material are orthogonal. Similar comparison can be done for a thin discs or layers made of PZT. However in case of thin disc we can define d_t and d_p modes. If the strain is normal to the plane of the piezoelectric disc the d_t mode is defined and when the strain is in the radial direction the d_p mode is defined. Scheme of each of modes is shown in Figure 1.

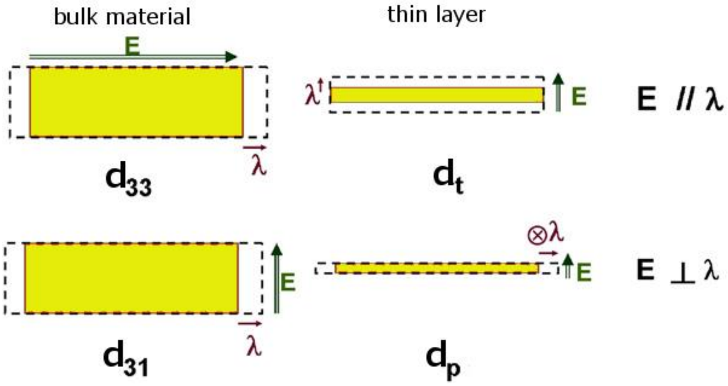


Figure 1: Scheme of modes for bulk PZT material and thin layer [10].

For our investigation we decided to use commercially available material which was supplied by Smart Material company. The P1 type of micro fiber composite (MFC) was chosen. This type of material is made up of PZT-5 microfibers (130 × 150 μm^2), encased between two Kevlar/Kapton sheets and polarized along their length. The P1 type MFCs are utilizing the d_{33} effect for actuation and elongate up to 1800 ppm if operated at the maximum voltage rate of -500 V to +1500 V. The P1 type MFCs might be used as a very sensitive strain sensors.

2.2 Magnetostrictive material

Magnetostriction as the phenomenon could also be defined as a change in material dimensions caused by a change in its magnetic state. Most often, the magnetostrictive materials change their dimensions as a result of a change in magnetic field applied to them, as well as change their magnetic properties under the force applied to them.

In this study, the magnetostrictive composite (also referred to as GMMc) was used. It was made by combining the epoxy resin and the GMM material (Terfenol-D) powder. At first, the epoxy resin Epolam 2015 (from Axons Technologies company) was mixed with the curing agent. Next, the appropriate amount of Terfenol-D powder (Gansu Tianxing Rare Earth Functional Materials Co., Ltd.) was added, with particle size of about 5-300μm.

The manufacturing procedure consisted in intensive mixing of all the ingredients until their complete homogenization. The mixture was then vacuum vented, poured into the dedicated cylindrical containers and subjected to initial polarization. After that, the material was once again vented in the vacuum chamber to eliminate the air introduced during the mixing stage.

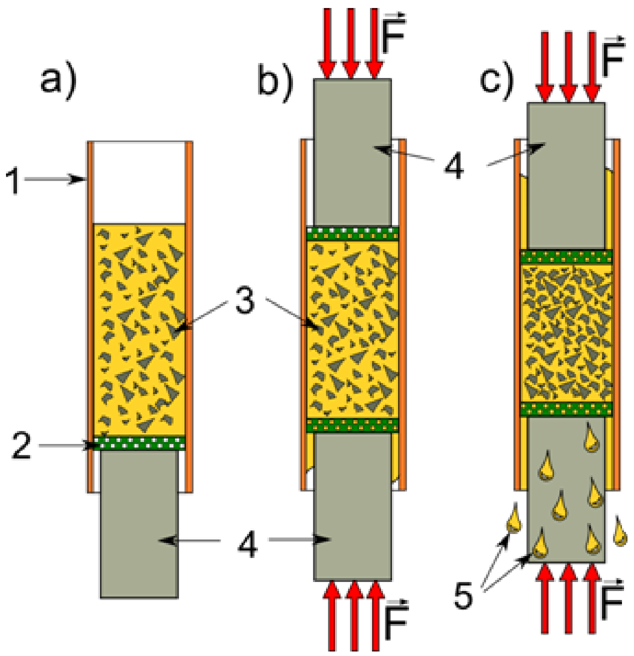
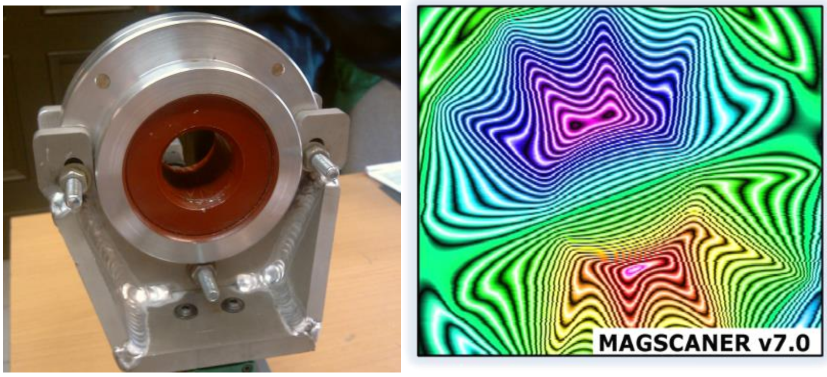


Figure 2: Methodology for preparing composite samples with a high volume fraction of Terfenol-D particles, where: 1 - container, 2 - filter, 3 - mixture, 4 - aluminum rods, 5 - excess resin.

Additionally in order to prepare magnetostrictive composite with distinguish amount of Terfenol-D particles it was necessary to remove excess resin, which was in the mixture after the initial procedure. For this purpose, pre-prepared mixture was poured into a container, one end of which was secured by a filter with high density and an aluminum rod (Fig. 2). Containers thus prepared were placed between the grips of a hydraulic testing machine MTS, wherein the second end of the container was protected in the same way as the first (Fig. 2b). Then the mixture which was in a container, was subjected to compression by means of aluminum rods. Squeezing of the mixture should allow to empty the containers of excess of the resin, which was made possible thanks to the half-permeable filters that allowed the free flow of resin, and prevented the escape of particles from the powder containers (Fig. 2c). In order to ensure uniform value of Terfenol-D volume fraction in the composite, each sample was subjected to the same pressure. Thus prepared samples were left in the testing machine for 8 hours, until initial resin curing process was over. Then, after the time allowed for initial binding, prepared sample was removed from the testing machine and placed for 24 hours in a furnace in order to achieve full bonded matrix and then it was removed from the container.

3 EXPERIMENTAL RESULTS

As a source of magnetic field (Fig. 3a) so called Halbach array was used. In this array, the magnetic field has strictly defined direction, what can be clearly seen in Figure 3b, where a map of magnetic field distribution around the Halbach array was presented. The value of the magnetic field inside the Halbach array was on the level of 1 T. Due to its characteristics Halbach array allows to easily change the direction of the magnetic field vector around the object in its interior, while ensuring the constancy of the value of this field.



a b

Figure 3: a) Image of Halbach array, b) Map of magnetic field distribution around Halbach array.

The hybrid material consisted of two main components, the first of which was the piezoelectric material in the form of a thin layer patch, and the second was a magnetostrictive composite, which was based on the powder of giant magnetostrictive material which is Terfenol-D The construction of hybrid material needs to allow to place it inside of the Halbach array. View of the material sample is shown in Fig. 4. In order to perform the strain measurements it was decided to use strain gauges, which were placed in a such way that allow to measure strain in many directions.

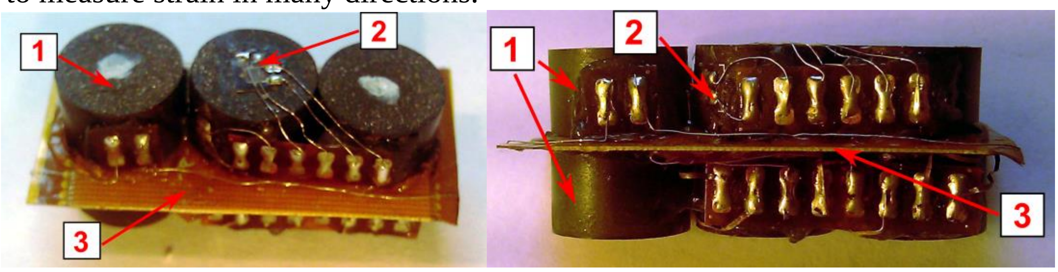


Figure 4: View of the new type of magnetostrictive-piezoelectric sample, where: 1 – magnetostrictive composite, 2 – strain gauges, 3 – piezoelectric material.

Next, prepared sample was placed in an aluminum housing (Fig. 5), which was used to provide the appropriate pre-stress to the hybrid material. Additionally the housing needs to provide to fix constant position relative to the Halbach array.

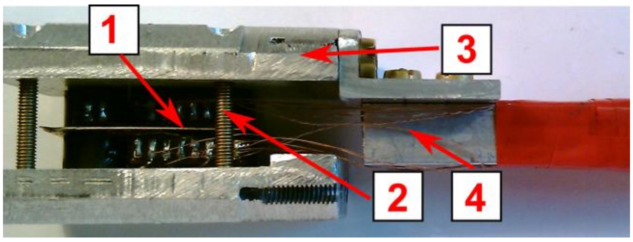


Figure 5: New type of hybrid composite placed inside aluminum housing, where: 1 – sample, 2 – screws, 3 – aluminum housing, 4 – signal wires.

In order to test the effect of the rate of change of the magnetic field vector on the response of the material, the study was conducted in two stages. In first step the quasi-static examination was performed. During this test the Halbach array was turning and stopping in desired positions. At first the zero position of the array was determined. In a zero position the direction of field lines was perpendicular to the sample surface. After determination of zero position a Halbach array started to rotate around the sample. The rotation increments was 15 degrees at 20 second intervals. This allowed the determination of the response signal from the strain sensor taking into account fact that change of magnetic field might have influence on the obtained result.

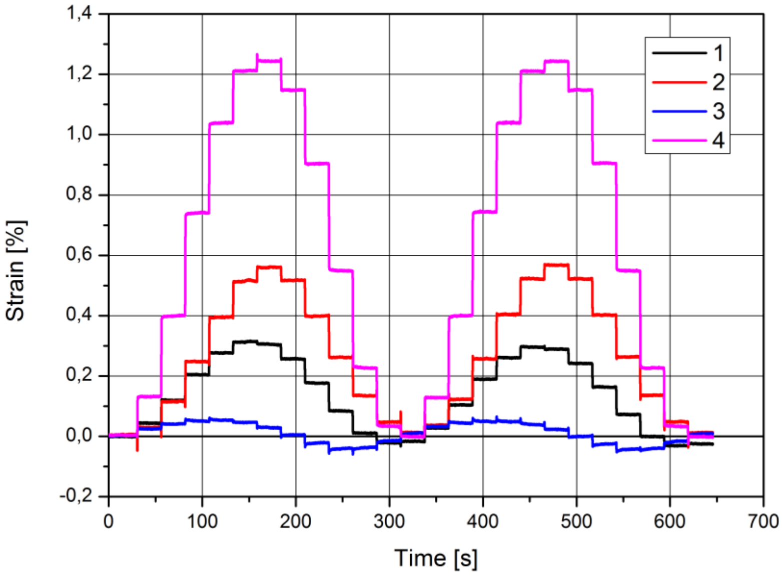


Figure 6: Change in a signal from strain gauges during quasi-static measurements.

During the measurement the Halbach array performed one full turn. The measurement results are shown in Fig. 6 and 7. Fig. 6 shows the results obtained for the strain sensors placed between the piezoelectric and magnetostrictive material, so it can be assumed that the deformation of both materials was similar. It is clearly visible that the greatest deformation of the material was obtained when the magnetic field vector was acting on the side of the sample.

Additionally, Fig. 7 shows the induction of a voltage signal on the piezoelectric material. It is clearly seen that during the whole measurement there were no changes in the value of electrical voltage. The lack of voltage changes was connected with the low rate of change of the magnetic field vector.

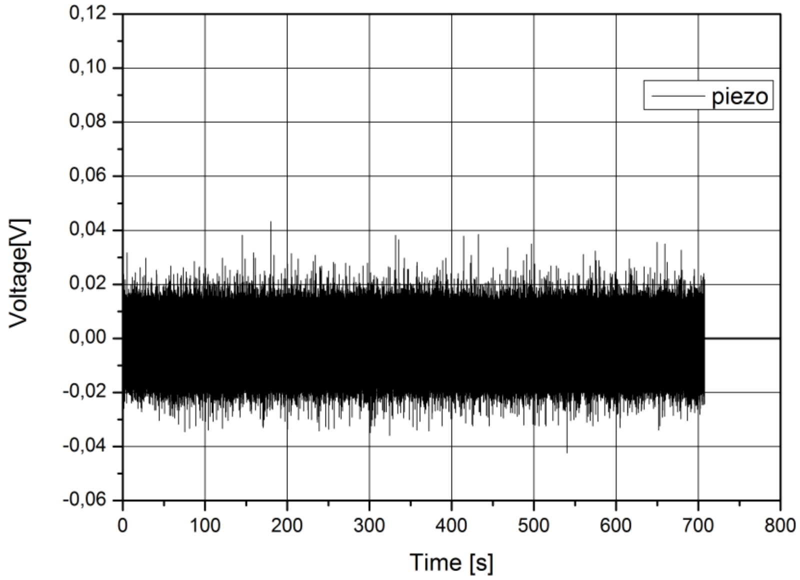


Figure 7: Voltage signal from the piezoelectric material during quasi-static measurements.

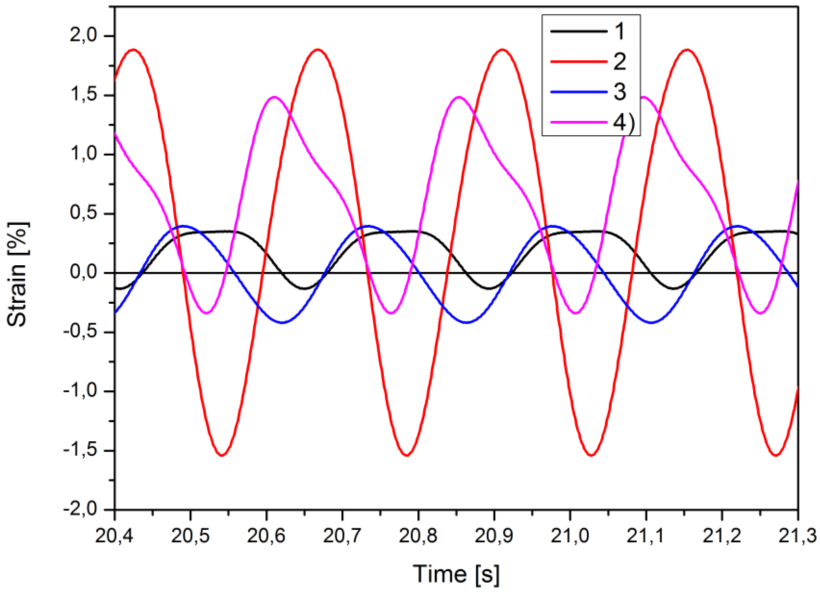


Figure 8: Change in a signal from strain gauges during cyclic measurements.

Further studies have been made for cyclic changes in the direction of the magnetic field vector. The measurement consisted in rotating the Halbach array around the sample with varying frequency. In Figures 8 and 9 are shown the results obtained from the measurements of the changes of direction of the magnetic field at frequency of 5 Hz.

Similarly as before for the measurement of quasi-static firstly the deformation of the material under the influence of an applied magnetic field has been presented (Fig. 8). The obtained results show the sinusoidal nature of the changes, which was to be expected. Just like it happened in the case of quasi-static measurements in the case of cyclic one, the maximum deformation of the material obtained when a magnetic field vector applied to the material was acting from the side of the sample.

In Figure 9 the signal received from the piezoelectric material was shown. In a contrast to the quasi-static measurement during the cyclic measurements there was noticed a change of voltage value of the piezoelectric material. The voltage obtained from the piezoelectric material at the frequency of changes in the direction of the magnetic field of 5 Hz was 0.2 V. On the basis of these results, we can conclude that, the rate of change of direction of the magnetic field vector, affects the voltage value obtained from the piezoelectric part of the hybrid material. Additionally it can be said that with the increase of the frequency of these changes the ME effect should also increase.

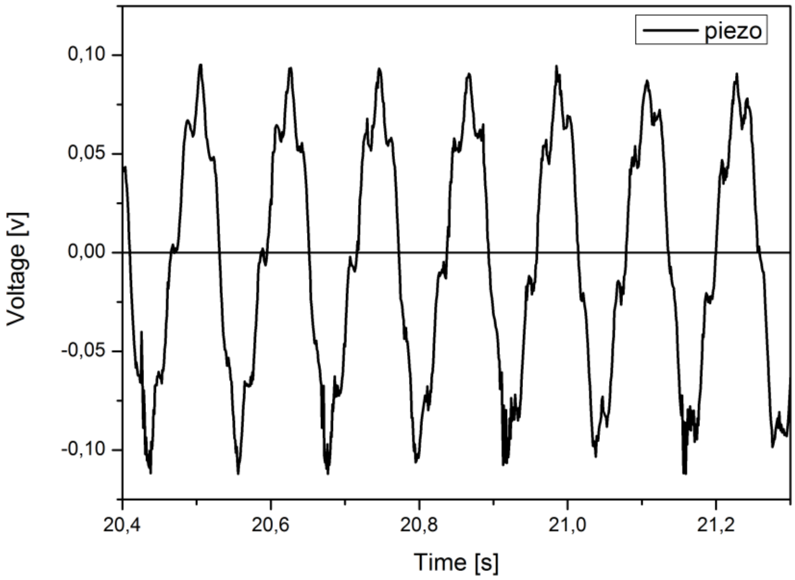


Figure 9: Voltage signal from the piezoelectric material during cyclic measurements.

4 CONCLUSIONS

The paper presents the results of research on the developed hybrid composite material. Using a simple arrangement, the operating principle of produced composite material was presented.

Based on the obtained results, it was found that the prepared composite material exhibits magneto-electric effect in the case of work in a variable magnetic field.

Additionally, results have shown that the influence on the voltage value of the piezoelectric material has the rate of magnetic field vector direction changes and polarization of magnetostrictive and piezoelectric elements.

The results can be the base for further research over the properties of this new group of SMART materials.

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