Rheological properties magnetically elastic material samples under extreme compression modes

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Abstract. The magnetoelastic material samples in compression tests are investigated. The studied materials rheological properties are carried out on an automated testing machine. Compressive moduli changes diagrams depending on deformation values up to limiting extreme values are plotted. Transition ranges from linear to nonlinear, longitudinal compression moduli, depending on the specimen compression degree, were fixed. Repeated tests on specimens showed a decrease in the compression moduli by several times. In revealing the rheological properties the investigated materials shape memory effect is demonstrated.

1 Introduction

The investigated materials belong to the composite magnetically elastic materials group actively developed for application in various technical products fields. These materials are promising for practical applications due to the inherent unique properties and parameters inherent in their creation combination. In order to identify new physical and mechanical properties, technical parameters and further the created materials improvement, complex tests are carried out in different modes both dynamic and static [1-7]. A works cycle is devoted to magnetoelastic materials rheological properties determination. Magnetoelastic elastomers studies with elastic characteristics control during their deformation are presented in [8-16]. The magnetoelastic material ability to hold its shape under loading was investigated in [17-20]. It was shown that the studied magnetoelastic material has a magnetostriction effect. The investigated materials application area can be active, controlled vibration dampers, when it is possible to lead away from the arising resonance frequencies in the used technical device. This process essence is to expand the damping range not by anti-phase damping vibrations or vibrations, but by changing the support elastic and rigid characteristics, to displace or lead away the resonant vibrations in the region of low or high frequencies relative to the vibration absorbing object working.

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frequency modes [21]. These magnetically active elastomers deformation and strength properties under compression with an additional external magnetic field imposition were investigated. The filler microparticles restructuring effect in external magnetic fields, established earlier by atomic force microscopy, on these composites complex properties was discussed [22–23].

2 Test machine and test method used

An automated testing machine LFM-L-10 (Walter+Bai AG, Switzerland) was used to perform compression tests on magnetically elastic specimens. This tabletop machine allows for static compression, tensile, and bend loading. The testing machine using convenience is the test specimens successive, gradual loading compression method by the moving upper plate at the required speed, while the lower plate is stationary. Compression is possible from minimum loads 50 N to a maximum 10 kH. When testing, the specimens are placed at the lower stationary plate center. When the test specimen is compressed by the upper moving platen, the machine automatically records, at a given frequency, the measured compression forces depending on the test specimen deformation amount. The measured compressive forces are characterized by elasticity modulus means. The longitudinal elasticity moduli in compression are measured in MPa and are determined from the dependence: \( F / A \epsilon \), where \( F \) is the force, on the tested product, obtained in compression (Newton); \( A \) is the cross-sectional area for testing (mm\(^2\)); \( \epsilon \) is the compression deformation (mm). The recorded diagrams show changes in compression moduli graphs (on the vertical axis in MPa) as the strain amount function, as the original length percentage, i.e. before the test (on the horizontal axis Epsilon in %). The obtained graphs allow to analyze the compressive moduli characteristics peculiarities depending on the material compression values, to establish linear and non-linear moduli change characteristics during the sample compression with a given compression rate. The method used shows the compression moduli change ranges from initial loads to loads causing the studied material irreversible fractures, and also establishes the characteristics at which the studied materials self-recovery (shape memory) is possible.

3 Rheological properties studies in different test series

The tested magnetically elastic material specimens were made on the basis SIEL elastomeric matrix (PDMS) with isotropic carbonyl iron particles fillers with sizes 2-5 μm and 80% mass concentration. Figure 1(a) shows the test specimen mounted on the stage before the compression start. The specimen had dimensions: diameter 30 mm and height 15 mm. Figure 1b) shows the specimen during compression on the test machine (pressure plate lowered and gradually loading the specimen). Figure 1c) shows the final compression moment: the specimen is deformed and goes beyond the limit dimensions of the upper compression plate.
In all the following specimens tests up to 60% compression ratio, the unit recorded low compression moduli located in the linear values range well below 1 MPa. Figure 2 shows a diagram of the change in compression moduli during the first specimen deformation at a compression ratio greater than 60%. In this and the following diagrams, the change in compression moduli is shown as a red curve. Fig. 2 shows that in compression ranges above 60%, the compression moduli value begins to increase as it moves into the nonlinear region. Near 80%, the compression moduli approach values equal to 1 MPa, then there is a non-linear rise to 16-18 MPa in the range exceeding 90%.
Fig. 2. The sample compression moduli change in the nonlinear region.

Then the same sample was tested again. After the first test, the specimen partially recovered its shape and had an approximate size 37 mm diameter and 11 mm height. The re-deformation process is shown in Fig. 3a) at the deformation initial moment, Fig. 3b) during compression and Fig. 3c) at the ultimate deformation final moment; the specimen extends beyond the ultimate dimensions of the upper compression plate.

Fig. 3. The sample re-deformation process.
Repeated the sample compression shows a decrease in compression modulus at the same compression ratio. For example, in the first test at 85% compression, the compression modulus was in the range up to 2 MPa; in the second test, the compression modulus decreased by half and was in the range 1 MPa. Increasing the compressive load resulted in a further increase in the difference in compression modulus between the 1st and 2nd test. For example, near 93% the specimen compression, the compression modulus in the first test was in the range up to 15 MPa and in the second test in the range 6-7 MPa. Thus, at repeated compression there was a decrease in the compression modulus relative to the first test almost 2 times.

In the final experiments, the sample that had been tested for compression in the previous tests was investigated. The sample had the original dimensions: diameter 30 mm and height 27 mm. After the earlier tests, the specimen was deformed and received dimensions: diameter 39 mm and height 21 mm. Fig. 5 shows the specimen re-deformation process in the other, perpendicular direction, on the previously tested specimen from the previous experiments. Figure 5(a) represents the initial compression stage. Fig. 5(b) represents the final compression stage.
Fig. 5. Process the sample re-deformation in the other, perpendicular direction (from previous experiments).

Fig. 6 shows a diagram in compression moduli change in this test.

![Diagram](image)

**4 Summary**

It was shown that when testing specimens starting from 70% there is a non-linear compression moduli growth. The same size specimens repeated tests showed a decrease in compression moduli, e.g. in the 80% range by several times. Increasing Epsilon compression ranges (%) starting from areas close to 90% and above 90% show a dramatic non-linear increase in compression moduli.

After extreme loading in ranges up to 45 MPa, all the test specimens returned to their original shape with insignificantly altered dimensions. The test specimens shape recovery after such significant extreme deformations, (when the specimens dimensions changed significantly from the cylinder shape to the plate shape and the reverse reversal), showed the materials under investigation shape memory. The demonstrated “material intelligence” effect or the ability to self-repair in revealing the rheological properties under extreme compression modes can be used in various technical products.
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