Self-repair of magnetically active composite sample in extreme compression test

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Abstract. A sample of a magnetically active composite with ferromagnetic fillers is studied. It is known that magnetoactive composites are of interest for use in a number of fields of science and technology. The characteristics of changes in the properties of magnetoactive composites with ferromagnetic fillers in compression tests under repeated loading are poorly studied. The study in different, wide force modes of compression to establish the conditions of self-restoration of the material shape is of practical and scientific interest for further use of the tested material. The machine on which the tests are carried out allows loading and studying the character of the sample behavior from small to extreme compression forces. The possibility of preserving the shape memory effect of the test material after a long period between the first and repeated test and under the condition of exceeding the compression force of the sample almost three times compared to the first test is determined. The dependence of the change in the magnitudes of the sample deformations on the compression load is determined. The ranges of non-linear character of variation of the sample deformations from the compression force starting practically from 60% of the value of its initial deformation are shown. The sample tested under extreme compression of up to 30 kN, as well as in the initial test, demonstrated self-recovery (shape memory effect). Thus, the effect of reversible deformation after extreme loads, which exceeded the initial ones by 3 times, was confirmed.

1 Introduction

Compression-tested elastomers belong to the class of composite polymers widely used in industrial products, including under conditions of large alternating loads.

The magnetically active material with ferromagnetic fillers created and studied under various conditions due to its unique properties demonstrated several effects that are described in the papers [1-6].

The dynamics of the properties of magnetoactive elastomers under repeated loading in different modes of compression is practically not studied. The characteristics of the modes of transition of linear change of compression forces into nonlinear ones at different strain values are not sufficiently studied. There are no studies related to the issues of self-healing

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of magnetically active elastomers under repeated and multicyclic loads for the possibility of use in industrial products.

In the present work, repeated in situ tests were performed on a magnetically active elastomer sample presented and described in [7]. The magnetically active composite sample made on the basis of a PDMS elastomeric matrix with isotropic fillers of carbonyl iron particles of 2-5 microns in size with a concentration of 80% by weight was investigated. Compression test was performed up to extreme (maximum permissible) modes of repeated loading to study the possibility of preserving the effect of self-restoration of the sample shape after deformation.

2 Test machine with capability for extreme loads and test method

The experiments used an automated testing machine LFM-50 (Walter+Bai AG, Switzerland) provided by Melitek LLC, Moscow, with a compression force up to the maximum permissible values of 50 kN. The machine is designed for compression, tensile, bending, shear or peeling tests and many other tests for different types of materials. The measurements were recorded automatically at a frequency of 20 Hz; the upper moving platen with pressure disk moved at a speed of 5 mm/min. The diameter of the upper pressure disk was F=116 mm. The diameter of the lower stationary disk was F=118 mm. The diagrams constructed in automatic mode represent plots of load variation depending on the deformation capability of the sample material.

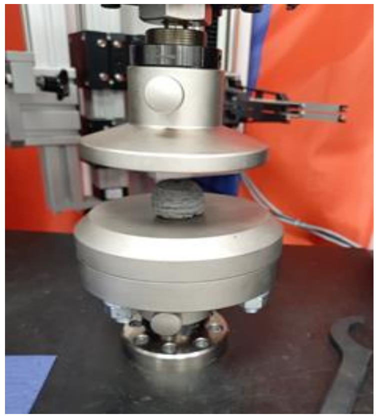
The shown research method allowed to fix the values of loads from small, initial linear modes of deformation to limiting, highly nonlinear modes, after removal of which the sample self-recovery occurred.

3 Results of repeated extreme compression tests of a magnetically active sample

Prior to the initial tests, the straight cylinder-shaped sample had dimensions of 30 mm diameter and 27-30 mm height. After a series of tests shown and described in [7] after an extreme compression load of 10 kN, the sample had the shape of a straight cylinder with a diameter of approximately 39-40 mm and a height of 18-21 mm.

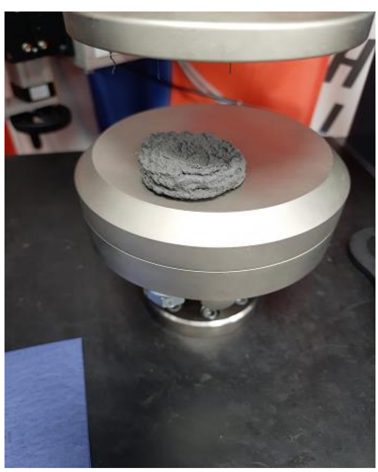
The purpose of repeated tests of the magnetically active composite sample was to verify the possibility of preserving in the test material (after one year) the effect of self-restoration of shape under the condition of increasing the extreme compression load up to 30 kN (almost 3 times).

Figure 1 (a, b, c) shows a test machine with an upper moving plate and a pressure disk and a fixed table with a mounted sample.



a

b



c

Fig. 1. (a, b, c). Machine with sample during testing: a - before the beginning of compression; b - at the moment of maximum deformation; c - after deformation removal.

Figure 2 (a, b) shows the shapes of the reconstructed sample when retested after removing the extreme load of 30 kN.

Fig. 2. (a, b). Shape of the sample after compression: a - top view; b - side view.

After extreme compression forces up to 30 kN, the sample continued to demonstrate the effect of self-restoration of shape (close to cylindrical). At the same time, the dimensions in diameter 45-52 mm and in height, approximately 10-14 mm, were preserved.

Figure 3 shows the diagram of the initial compression section P in kN as a function of strain values ε in mm for the sample.

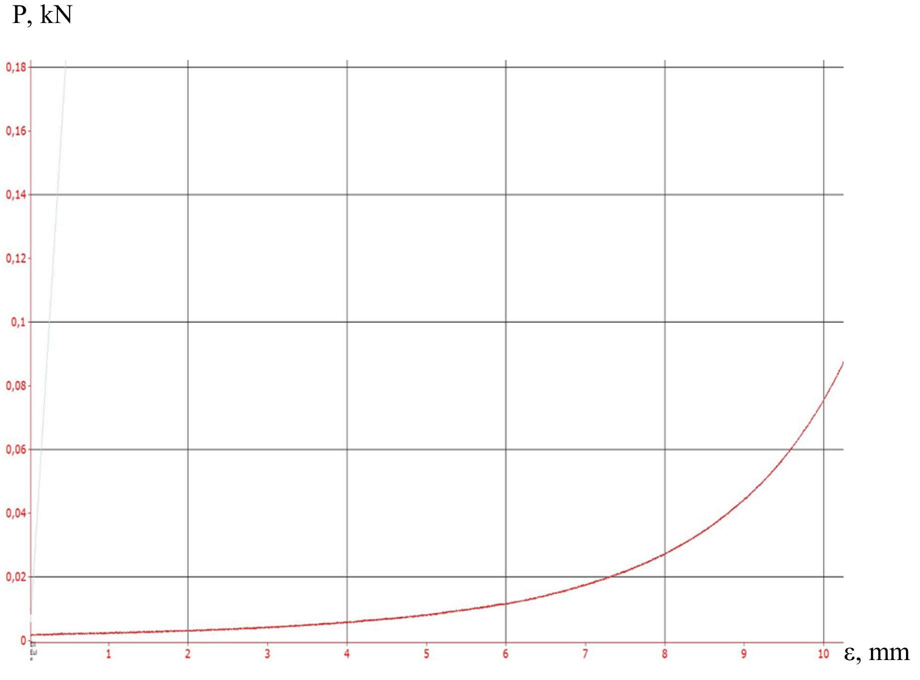
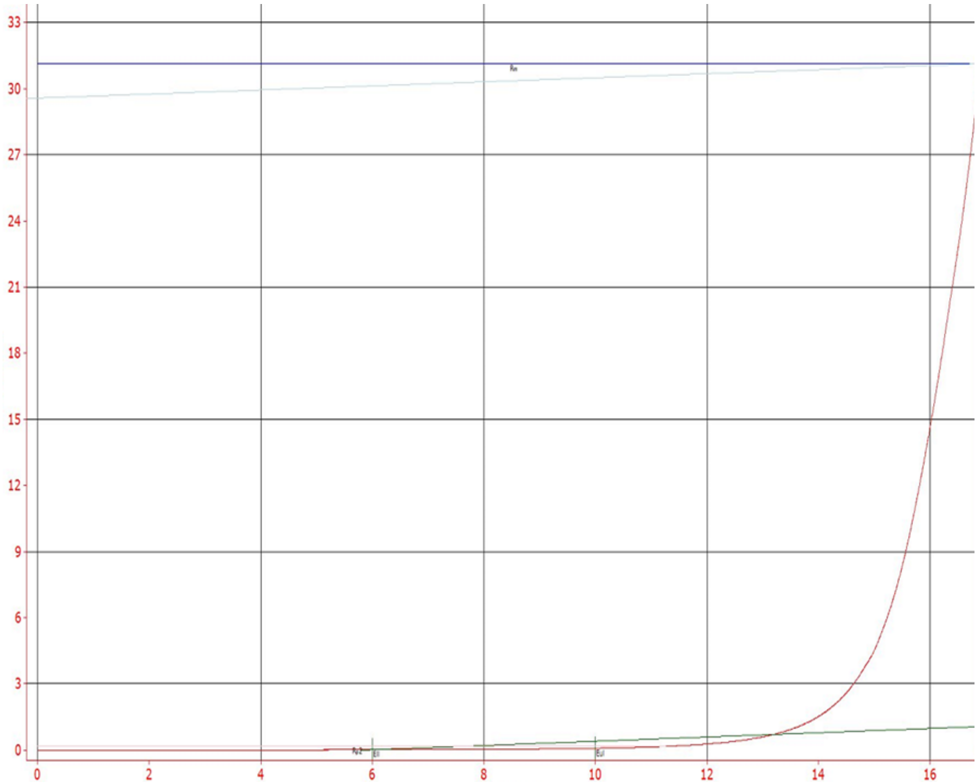


Fig. 3. Diagram of the change in compression load of the sample at the initial stage during retesting.

Figure 3 shows the nonlinear character of change of the compression load P in kN depending on the value of deformation ε of the test sample in mm. Let us consider the initial compression section. At a compression load up to 0.01 kN the deformation of the sample is located in the range of 5.5 mm. When the load is increased up to 0.1 kN, the deformation of the sample is located in the range up to 11 mm.

Figure 4 shows the complete compression diagram P in kN as a function of the deformation values ε of the sample in mm.

P, kN



ε, mm

Fig. 4. Diagram of compression P in kN as a function of deformation values ε of the sample in mm.

From the diagram in Figure 4, it can be seen that the sample deforms between 16 and 17 mm when the compression force P is slightly greater than 30 kN.

Figure 5 shows the complete diagram of compression P of the sample in kN as a function of the values of deformation ε of the sample in percent (%) of the initial deformation.

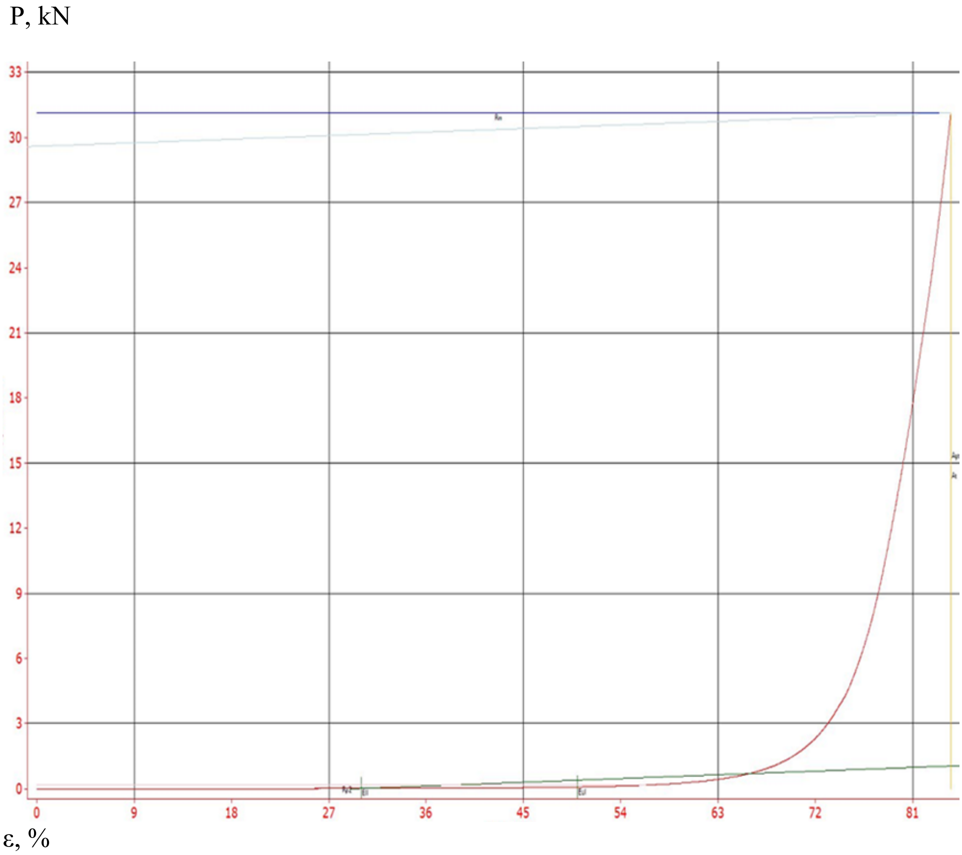


Fig. 5. Full compression diagram of the sample in kN as a percentage of the initial strain (%).

Nonlinear character of dependence of deformation on compression forces of the sample was observed in the range of 12 to 18 mm, with the deformation of the sample located from 63% to 86%, and the compression forces in this range increased more than 10 times.

4 Findings and possible research directions

Multiple tests of the presented samples of magnetoactive composite based on elastomeric matrix PDMS with isotropic fillers of carbonyl iron particles of 2-5 microns in size with a concentration of 80% wt% under extreme compression regimes have shown the property of self-recovery of shape, which is not typical for other known elastic materials.

In previous studies [7, 8], it was shown that a sample of magnetically active composite demonstrated unique capabilities of the material to self-repair of shape under extreme compression up to 10 kN. Namely, under repeated, more than 500%, elastic stretching of the sample in transverse, horizontal direction and, respectively, under compression in height up to 96%.

When retested, the sample was subjected to a stronger extreme compression load of up to 30 kN and a compression in height in the neighborhood of 86%. The re-tested sample, as in the initial tests, exhibited self-recovery of shape in height to values of approx. 10-14 mm. Thus, the effect of reversible deformation after extreme loads, which exceeded the initial ones by 3 times, was confirmed.

The boundaries of the location of linear and nonlinear areas of change in the compressive forces in different modes of deformation of the material are given.

The test sample demonstrates "memory of the original shape" of the material after such significant extreme loads. The tested material can practically restore its size due to application of insignificant pulsating deformations applied in the transverse direction along its diameter and under the influence of other factors.

In further tests it is of great practical interest to determine the boundaries, conditions of reversible and irreversible deformation, and fracture when using differently characterized filler materials of the test samples.

The effect of self-restoration of shape for magnetically active composites can be used in solving problems associated with the creation of new products that are operated under extreme loading modes.

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References

1. L. A. Makarova, Yu. A. Alekhina, F. S. Omelyanchuk, et al., Elsevier BV **485**, 413-418 (2019) DOI:10.1016/j.jmmm.2019.04.001
2. V. V. Sorokin, G. V. Stepanov, M. Shamonin, et al., Polymer **76**, 191-202 (2014) DOI:10.1016/J.POLYMER.2015.08.040
3. T. L. Becker, K. Zimmermann, D. Y. Borin, G. V. Stepanov, and P. A. Storozhenko, Journal of Magnetism and Magnetic Materials **449**, 77 -82 (2018) DOI:10.1016/J.JMMM.2017.09.081
4. T. A. Nadzharyan, S. A. Kostrov, G. V. Stepanov, and E. Yu. Kramarenko, Polymer **142**, 316-329 (2018) DOI:10.1016/j.polymer.2018.03.039
5. Yu. A. Alekhina, L. A. Makarova, T. S. Rusakova, et al., Journal of the Siberian Federal University. Series: Mathematics and Physics **10**, 45-50 (2018) DOI: 10.17516/1997-1397-2017-10-1-45-50
6. A. Ja. Minaev, J. V. Korovkin, Forum **945**, 369-373 (2019) DOI:10.4028/www.scientific.net/MSF.945.369
7. A. Ya. Minaev, Journal of Physics: Conference Series **2373**, 22035 (2022) DOI:10.1088/1742-6596/2373/2/022035
8. A. Minaev, H. Valiev, G. Stepanov, E3S Web of Conferences **402**, 11001(2023) DOI:10.1051/e3sconf/202340211001