E3S Web of Conferences **383**, 04088 (2023) https://doi.org/10.1051/e3sconf/202338304088
TT21C-2023

Atomic force microscopy of anisotropic silicone magnetoactive composites

Hammat Valiev[1*], *Yulia* Karnet[1], *Alla* Kornilova[2], *Andrey* Minaev[3], and *Gennady* Stepanov[4]

[1]Institute of applied mechanics of the Russian Academy of Sciences, Leningradskiy prospect 7, 125319 Moscow, Russia
[2]Moscow State University, Faculty of Physics, 1-2 Leninskiye Gory, 119234 Moscow, Russia
[3]Mechanical Engineering Research Institute of the Russian Academy of Sciences, 4 Maly Kharitonyevsky Pereulok, 101000 Moscow, Russia
[4]State Research Institute for Chemical Technologies of Organoelement Compounds, Enthusiastov Highway 38, 105118 Moscow, Russia

Abstract. New anisotropic magnetically active elastomers using carbonyl iron micrometer size ferromagnetic fillers in the silicone matrix were synthesized. Samples with orientation of the outer magnetic field strength vector applied in perpendicular or in parallel direction to the mold surface during polymerizing composite mass were investigated. These composites surface structure was studied using the topography and phase contrast images in the atomic force microscope. Significant surface magneto-deformation effects in these composites, comparable with Terphenol-D, under the application of small external magnetic fields were visualized by atomic force microscopy methods. The transverse magneto-deformation constant value was determined for both samples. Greatly periodically deformed surface structure background was observed in these composites. The obtained experimental results analysis show that significant component of these materials unique properties is due to the ferromagnetic fillers restructuring in both isotropic and anisotropic magnetically active composites under small external magnetic fields influence.

1 Introduction

The "Smart" materials studies, which include magnetically active elastomers, have revealed their numerous unique properties. These composites based on low-modulus rubbers with ferromagnetic fillers can be effectively reversibly controlled by external magnetic fields, exhibiting various magneto-rheological, magneto-electro-rheological, magneto-deformation, magneto-dielectric, magneto-resistive, piezo-resistive, piezoelectric, magneto-optical, magneto-acoustic and other effects [1-12]. This opens up wide opportunities for their important practical applications, e.g., in the active and passive damping devices design, actuators, micro-motors, micro-robots, and in bio-medicine. However, the relationship between these remarkable macro-properties and the internal microstructure features of such composites remains poorly investigated. Atomic force microscopy (AFM)

* Corresponding author: hhvlv@mail.ru

can be particularly informative for revealing such microstructure characteristics. This method has been successfully used in the silicone magnetically active elastomers study with isotropic iron fillers [13-14]. The composites study with anisotropic fillers is also of great interest [15-25]. The fillers magnetic moments orientations in such composites occur simultaneously with the elastomer curing in the external magnetic field presence. The resulting composites contain ferromagnetic filler in an ordered state, forming filler magnetic moments chains that are aligned in the applied magnetic field direction, and retaining this state in the cured elastomer. In this work, such magnetically active anisotropic elastomers were synthesized and studied using AFM.

2 Materials and methods

The anisotropic composites under study were obtained by magnetic filler powder dispersion in liquid silicone rubber with the subsequent composition polymerization in the mold. Carbonyl iron powders with a concentration 9 wt % and a particle sizes 2 - 6 micrometers (μm) were used as magnetic fillers. To improve compatibility with the organic binder, the fillers were modified with surfactants and organosilicon compounds. Organo-phosphorus surfactant KD-6, silicone oil PMS-100 and hydride-containing silicon GKZh-94 was used. On the carbonyl iron powder surface were applied modifiers 2 wt % from a petroleum ether solution. The filler prepared in such a way was rubbed with liquid silicone rubber SIEL mark (GNIIChTEOS, Moscow). The composites were cured at 150 o C for 1 hour. Two anisotropic composites groups named A and B were synthesized. The samples A were obtained using external magnetic field 2000 Oersted (Oe) with orientation of magnetic field strength vector in perpendicular direction to the mold surface with polymerizing composite mass, and the samples B with this vector orientation in parallel direction to the mold surface with polymerizing composite mass. From prepared composites A and B samples with a thickness 1 mm and area 5 x 5 mm were cut out for research.

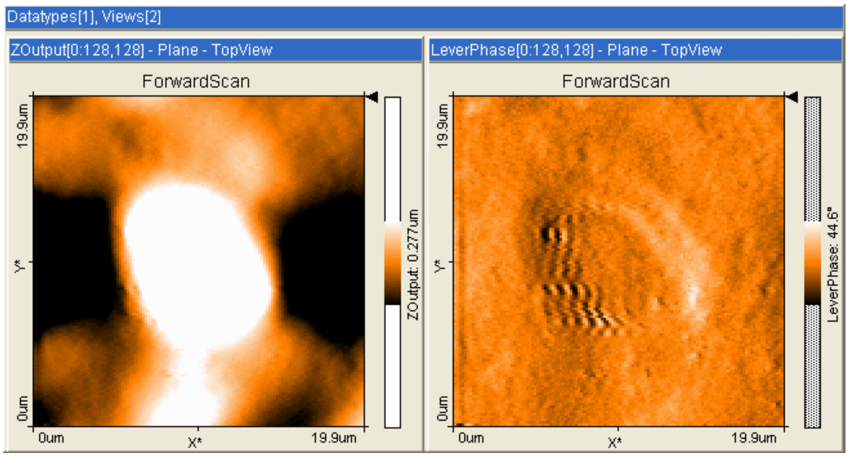
These composites surface structure was investigated using an atomic force microscope (AFM) EasyScan (Nanosurf, Switzerland) operated in semicontact mode in air at room temperature and using a phase contrast mode. The AFM was protected from external excitation by a TS-150 dynamic anti-vibration stage (Fabric am Weiher, Switzerland). The external constant magnetic field gradient influence produced by a neodymium magnet on the investigated composites was carried out in a specially design, allowing the AFM imaging to be performed with a fixed samples position, excluding the investigated samples displacement when introducing and withdrawing the magnet under the materials under study. The introduced neodymium magnet field strength directly in the studied composite place during AFM scanning was about 500 Oe.

3 Experimental results

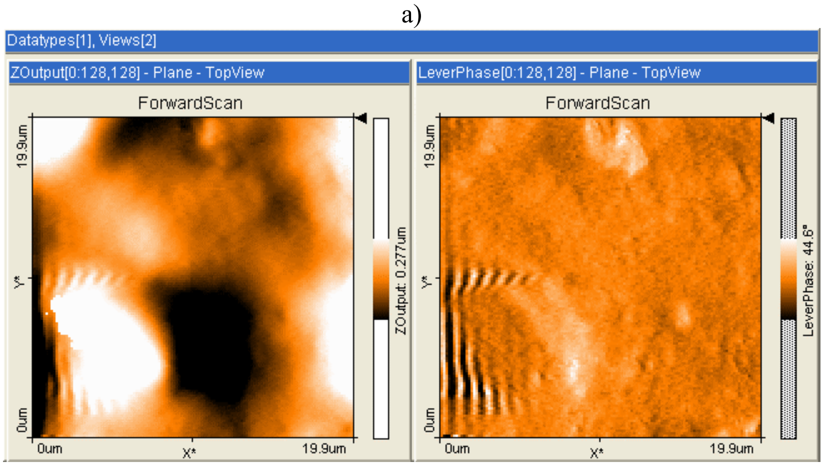
Fig. 1 a, b show the synthesized anisotropic magnetically active composite group A surface AFM images, both in the magnetic field absence and under the introduced external field gradient neodymium magnet influence. All images show topography on the left and phase contrast on the right. A light filler agglomerate about 5 μm in size is visualized against the surface structure of the anisotropic composite A (Fig. 1 a). The perpendicular external magnetic field 500 Oe application to such composite surface resulted to the magneto-deformation restructuring with the deformation value in the composite plane direction about 5 microns (Fig. 1 b). Fig. 2 a, b present the synthesized anisotropic magnetically active composite group B surface AFM images both in the magnetic field absence (Fig. 2 a) and under the neodymium magnet external field gradient influence (Fig. 2 b). The light filler

https://doi.org/10.1051/e3sconf/202338304088

agglomerate with size about 4 μm is visualized against the anisotropic composite greatly periodically deformed surface structure background (Fig. 2 a, b). In this composite the surface magneto-deformation restructuring was visualized with deformation magnitude value in the composite plane direction about 3 μm (Fig. 2 b).

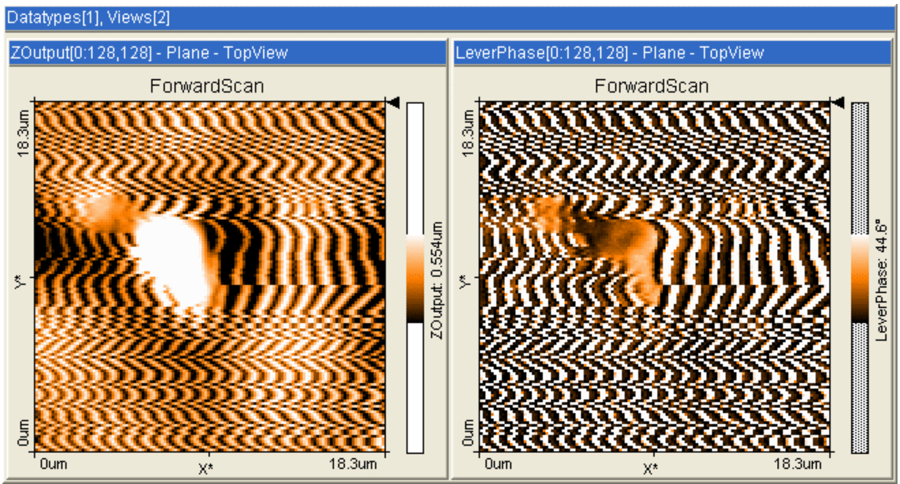


a)

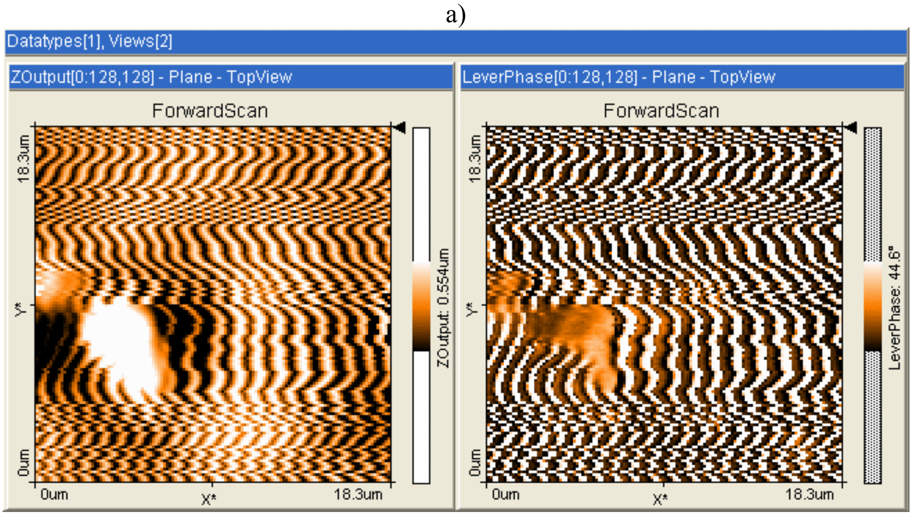


b)

Fig. 1. The anisotropic magnetoactive elastomer group A surface structure AFM images. Scans 19.9 x 19.9 μm2: a) without magnetic field; b) in an external magnetic field 500 Oe.



a)



b)

Fig. 2. The anisotropic magnetoactive elastomer group B surface structure AFM images. Scans 18.3 x 18.3 µm2:a) without magnetic field; b) in an external magnetic field 500 Oe.

4 Discussion

The AFM images analysis (Figs. 1 a, b and 2 a, b) makes it possible to find the investigated composites surface magneto-deformation restructuring, when an external magnetic field 500 Oe perpendicular to the sample surface is applied. For anisotropic magnetically active elastomer group A, the transverse magneto-deformation constant value determined by the relation: $\lambda = \Delta L/L = 5$ µm / 5 mm is 1.0·10-3. For anisotropic magnetically active elastomer group B, this value $\lambda = \Delta L/L = 3$ µm / 5 mm would be 0.6·10-3.

It is interesting to compare these values with the highest values in giant magnetostriction $\lambda \sim 2.0 \cdot 10$-3 known in Terphenol-D. Even with such a carbonyl iron ferromagnetic fillers small concentration, amounting to only 9 % in the silicone matrix, very high magneto-deformation constants values in the investigated composites is observed.

The investigated magnetically active composites significant magneto-deformations determined by AFM reveal prospects for the new materials and devices creation, which provide significant advantages over the currently used ones, which are directly in demand in practice. Direct visualization the magnetoactive iron particles in an anisotropic siloxane composite restructuring under a small external magnetic field influence using AFM studies allows us to better understand the reasons for the such materials unique properties under different external influences.

It can be assumed that these properties significant component is due to the ferromagnetic fillers restructuring in both isotropic and anisotropic magnetically active composites in the small external magnetic fields.

5 Summary

The experimental data obtained on the synthesized silicone anisotropic magnetoactive composites magneto-deformation properties show their effective practical application directions in the creation active and passive damping devices designs, actuators, and in other promising areas.

Acknowledgments

The work was done within the framework in the State Research Program for Institute Applied Mechanics Russian Academy of Sciences (IPRIM RAS) and on the state assignment in IMASH RAS. Number of state registration: 01201355403.The work was also supported by RFBR Grant No. 19-53-12039

References

1. G.V. Stepanov, E.Yu. Kramarenko, N.S. Perov, A.S. Semisalova, et. al., PNRPU Mech. Bulletin Mech. **4,** 106-137 (2013)
2. D. Borin, Phil. Trans. R. Soc. A **378,** 20190256 (2020)
3. E.Yu. Kramarenko, G.V. Stepanov, A.R. Khokhlov, INEOS OPEN **2,** 178-184 (2019)
4. S.A. Kostrov, V.V. Gorodov, B.O. Sokolov, A.M. Muzafarov, E.Y. Kramarenko, Polymer Sci., Ser. A. **62,** 383-391 (2020)
5. M. Watanabe, Y. Takeda, T. Maruyama, et. al., Int. J. Mol. Sci. **20,** 2879 (2019)
6. Y. Tsujiei, S. Akama, J. Ikeda, et. al., React. Funct. Polym. **130**, 1 (2018)
7. P.A. Sánchez, T. Gundermann, A. Dobroserdova, S.S. Kantorovichab, S. Odenbach, Soft Matter. **14,** 2170 (2018)
8. J. Nanpo, K. Nagashima, Y. Umehara, M. Kawai, T. Mitsumata, J. Phys. Chem. B. **120,** 12993 (2016)
9. J. Sutrisno, A. Purwanto, S.A. Mazlan, Adv. Eng. Mater. **17,** 563 (2015)
10. V.V. Gorodov, S.A. Kostrov, R.A. Kamyshinskii, et. al., Russian Chem. Bull., Int. Edition **67,** 1639-1647 (2018)
11. Yu.A. Alekhina, L.A. Makarova, T.S. Rusakova, A.S. Semisalova, N.S. Perov, J. of the Siberian Federal University. Series: Math. and Phys. **10,** 45-50 (2017)
12. V.P. Mikhailov, A.M. Bazinenkov, J. of Magnetism and Magn. Mater. **431,** 266-268 (2017)
13. Kh.Kh. Valiev, A.Y. Minaev, G.V. Stepanov, Y.N. Karnet, O.B. Yumashev, J. Surface Invest. X - Ray, Synchrotron and Neutron Tech. **13,** 825-827 (2019)

14. H.H. Valiev, V.M. Cherepanov, Yu.N. Karnet, et. al., IOP Conf. Series: Mater. Sci. Engin. **862,** 022062 (2020)
15. V. Kumar, D.J. Lee, J. Magn. Magn. Mater. **441,** 105–112 (2017)
16. D. Ivaneyko, V. Toshchevikov, M. Saphiannikova, Polymer **147,** 95–107 (2018)
17. S. Yarra, F. Gordaninejad, M. Behrooz, G. Pekcan, J. Intell. Mater. Syst. Struct. **30(2),** 228–242 (2019)
18. M. Asadi Khanouki, R. Sedaghati, M. Hemmatian, Compos. B Eng. **176**, 107311 (2019)
19. A.V. Bodnaruk, A. Brunhuber, V.M. Kalita, et. al., Polymer **162,** 63–72 (2019)
20. S. Wu, W. Hu, Q. Ze, M. Sitti, R. Zhao, Multifunct. Mater. **3(4),** 042003 (2020)
21. A.K. Bastola, M. Hossain, Compos. B Eng. **200,** 108348 (2020)
22. A.A. Snarskii, M. Shamonin, P. Yuskevich, D.V. Saveliev, I.A. Belyaeva, Phys. A Stat. Mech. Appl. **560,** 125170 (2020)
23. M.N. Alam, V. Kumar, S.R. Ryu, J. Choi, D.J. Lee, J. Intell. Mater. Syst. Struct. **32**, 1604–1613 (2021)
24. L. Xia, Z. Hu, L. Sun, Smart Mater. Struct. **30(9),** 095001 (2021)
25. S. Lucarini, M. Hossain, D. Garcia-Gonzalez, Compos. Struct. **279,** 114800 (2022)