Microscopic research of amorphous alloys AlFeNiLa exposed to magnetic pulse processing

A A Viryus¹, T P Kaminskaya², M N Shipko³*, N D Bakhteeva⁴, V V Korovushkin⁵, A G Savchenko⁵, M A Stepovich⁶, E S Savchenko³ and E V Todorova⁴

¹Institute of Experimental Mineralogy, 4 Academician Ossipyan Street, Chernogolovka, Moscow District, 142432 Russia
²Lomonosov Moscow State University, Faculty of Physics, House 1, Building 2, Lenin Hills, 19991 GSP-1 Moscow
³Lenin Ivanovo State Power Engineering University, 34 Rabfakovskaya Street, Ivanovo, 153025 Russia
⁴Baikov Institute of Metallurgy and Material Science RAS, 49 Leninsky Ave., Moscow GSP-1 119991 Russia
⁵National Research Technological University "MISiS", 4 Leninsky Ave., Moscow, 119049 Russia
⁶Tsionkovsky Kaluga State University, 26 Stepan Razin Street, Kaluga, 248023 Russia
E-mail: michael-1946@mail.ru

Abstract. The structure of the solid solution foil Al₈₅Fe₇Ni₅La₃ was studied, obtained by the spinning method, before and after magnetic pulses treatment. Comparison of the effects of pulses of weak magnetic field on the topology of the alloy surface allows us to conclude that when exposed to 30 pulses, the surface becomes more smooth. It was found that treatment with magnetic pulses significantly affects the magnetic characteristics of the alloy, which may allow this type of effect on amorphous alloys to be used in practice.

1. Introduction

The research for amorphous alloys has nowadays become noticeably interesting due to the increased possibility of using their unique features in space, aviation, and radio-electronic devices in practice. Unlike their crystalline substitutes, amorphous alloys enable obtaining a greater variety of features by changing their composition or due to various physicochemical effects. For instance, the short-range order of the atoms in the alloys, and therefore, their electromagnetic features can be influenced by these features [1, 2]. Previously [3-5], we studied the effect of influence of weak magnetic field pulses on the structure and properties of some electrotechnical materials. In the present work, similar studies were performed for amorphous Al₈₅Fe₇Ni₅La₃ alloys.

2. Research methodology

The amorphous Al₈₅Fe₇Ni₅La₃ alloy was studied in the form of a foil 20 μm thick, obtained by the spinning method, before and after magnetic pulse treatment (MPT). MPT was carried out by rectangular magnetic field pulses with a frequency of 10-20 Hz, intensity 10-100 kA/m. We studied the initial samples (before MPT) and samples subjected to 10, 20, and 30 magnetic pulses.
The structure and elemental composition of the samples were studied using a Tescan Vega II XMU scanning electron microscope (SEM) with an INCAx-sight energy dispersive X-ray spectrometer. Smaller details of the alloy surface were studied by atomic force microscopy (AFM) using a SMENA-A scanning probe microscope, Solver platform, NT-MDT, Russia, in semi-contact and contact modes at room temperature.

Magnetic parameters: residual magnetization, specific saturation magnetization, coercive force, shape of the magnetic hysteresis loop – were measured on a VSM-250 vibration magnetometer in a magnetic field of 20 kOe strength at room temperature.

3. Results
The surface topologies of the AlNiFeLa foil on the matte and shiny side differ dramatically; the shiny side is smooth and much more uniform – see figure 1-figure 5. Therefore, research was mainly carried out on the shiny side of alloys.

Figure 1. A micrograph of the matte (left) and shiny (right) side of the foil, obtained in SEM after exposure to the foil with 30 pulses of a magnetic field.

Figure 2. A micrograph of the matte (left) and shiny (right) side of the foil, obtained in AFM after exposure to the foil with 30 pulses of a magnetic field. The scanning area is 70 μm×70 μm.
Comparison of the surface topology of the shiny side of the initial sample and the sample after 30 pulses shows that when exposed to a pulsed magnetic field, the surface becomes clearly uniform and structured – see figure 1 and figure 2. The average size of the structural element of the surface is 40-60 nm. Comparison of the effects of 20 pulses and 30 pulses on the topology of the alloy surface allows us to conclude that when exposed to 30 pulses, the surface becomes more smooth and some of the pores are drawn out.

Figure 3. Micrograph (left) of the shiny side of the foil obtained in AFM, after exposure to the foil with 30 pulses of a magnetic field. The scanning area is 1.2 mkm×1.2 mkm. The linear profile (right) of the micrograph element marked on it with a straight line segment.

Figure 4. Three-dimensional micrograph of shiny side of the foil obtained in the AFM, after exposure to the foil with 30 pulses of a magnetic field. The scanning area is 2.5 mkm×2.5 mkm.

It was established that the MPT significantly affects the magnetic characteristics of the alloy. The hysteresis characteristics of the amorphous Al$_{85}$Fe$_7$Ni$_5$La$_3$ solid solution before and after the MPT: specific saturation magnetization in a field of 20 kOe, specific remanent magnetization, coercive force and hysteresis loop areas are given in the table, and the corresponding magnetic hysteresis loops obtained using a vibration magnetometer are shown in figure 5 [6].
Table 1. Hysteresis characteristics of the amorphous Al$_{85}$Fe$_7$Ni$_5$La$_3$ alloy before and after magnetic pulse treatment.

| Number of pulses | Specific saturation magnetization (A·m$^2$/kg) | Specific remanent magnetization (A·m$^2$/kg) | Coercive force (kA/m) | Hysteresis loop areas (A·m$^2$/kg) |
|------------------|-----------------------------------------------|----------------------------------------------|-----------------------|-----------------------------------|
| 0                | 3.6                                           | 1.4                                          | 110                   | 300                               |
| 10               | 2.3                                           | 0.5                                          | 34                    | 110                               |
| 30               | 22.7                                          | 4.4                                          | 9                     | 215                               |

Figure 5. Magnetic hysteresis loops of the amorphous Al$_{85}$Fe$_7$Ni$_5$La$_3$ alloy obtained using a vibration magnetometer in the initial state (left) and after MPT: 10 (in the center) and 30 (right) by pulses.

4. Conclusions
The structure of the solid solution foil was studied, obtained by the spinning method, before and after magnetic pulses treatment. Comparison of the effects of pulses of magnetic field on the topology of the alloy surface allows us to conclude that when exposed to 30 pulses, the surface becomes more smooth. The average size of the structural element of the surface is 40-60 nm. It was found that treatment with magnetic pulses significantly affects the magnetic characteristics of the alloy, which may allow this type of effect on amorphous alloys to be used in practice.

Acknowledgments
The work was carried out on the State (Russian Federation) assignment No. 007-00129-18-00, as well as with partial financial support of the Russian Fund for Basic Research (project No. 19-03-00271), the RFBR and the Government of Ivanovo District (project No. 18-43-370012) and the RFBR and the Government of the Kaluga District (project No. 18-41-400001).

References
[1] Kekalo I B 2006 Atomic structure of amorphous alloys and its evolution (Publishing House “Study” MISiS, Moscow) 340 p. [in Russian]
[2] Glezer A M and Molotilov B V 1992 Structure and mechanical properties of amorphous alloys (Metallurgy, Moscow) 208 p. [in Russian]
[3] Shipko M N, Korovushkin V V, Kostishin V G, Isaev I M, Stepovich M A and Savchenko E S 2018 Effect of magnetic pulse processing on the structure and magnetic properties of ferrites Bulletin of the Russian Academy of Sciences: Physics 82 203-7.
[4] Shipko M N, Tikhonov A I, Stepovich M A, Viryus A A, Kaminskaya T P, Korovushkin V V, Savchenko E S and Eremin I V 2018 Effect of Magneto-Pulse Processing on the microstructure and magnetic behavior of amorphous electrotechnical steel Bulletin of the Russian Academy of Sciences: Physics 82 988-92.
[5] Viryus A.A., Shipko M.N., Stepovich M.A., Kaminskaya T.P., Korovushkin V.V., Tikhonov A.I. and Savchenko E.S. 2019 Analysis of the structure and composition of Fe$_3$O$_3$...
oxides subjected to magnetic pulse treatment *Journal of Surface Investigation. X-ray, Synchrotron and Neutron Techniques* 13 215-20.

[6] Shipko M N, Korovushkin V V, Savchenko A G, Stepovich M A, Bakhteeva N D, Savchenko E S and Todorova E V 2019 The effect of magnetic pulse treatment on the magnetic properties of amorphous solid solution Al$_{85}$Fe$_7$Ni$_{15}$La$_3$ *Applied Physic [Prikladnaya fizika]* 3 81-5 [in Russian]