Conference Paper

Influence of Technological Parameters on Magnetic Properties of Co-Rich Amorphous Ferromagnetic Microwires

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Abstract

The series of amorphous ferromagnetic glass-coated microwires of composition $Co_{69}Fe_4Cr_4Si_{12}B_{11}$, manufactured by Taylor-Ulitovsky technique, was investigated. The series consisted of six types microwires fabricated under different technological conditions. The metallic nucleus and glass coating diameters of microwires ranged within 11-20 μm and 26-35 μm, respectively. Investigation of the magnetic properties of microwires was carried out using induction and the small-angle magnetization rotation techniques. The anisotropy field, the magnetostriction constant and the average value of the quenching stresses are estimated for all types of microwires. Based on the experimental data obtained, influence of technological parameters on the microwire's magnetic properties was investigated.

Keywords: Amorphous ferromagnetic microwire, cobalt alloy, magnetic measurements, magnetostriction, internal stresses

Received: 21 December 2017
Accepted: 15 April 2018
Published: 6 May 2018

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Selection and Peer-review under the responsibility of the MIE-2017 Conference Committee.

1. INTRODUCTION

Amorphous ferromagnetic glass-coated microwires, obtained by quenching the melt by the Ulitovsky-Taylor method, have a unique combination of magnetic and strength characteristics [1, 2]. Currently, the technology of manufacturing of microwires with diameters from a few to tens of micrometers is well developed [3]. Microwires based on Co-rich alloys with a close to zero negative magnetostriction constant are characterized by small enough anisotropy field ~ 1 – 10 Oe and a very low, < 0.05 Oe, coercive force. These microwires are magnetized circularly in the ground state and show the giant magnetoimpedance effect (GMI) with GMI ratio of hundreds percent

[4-6]. These properties are widely used to develop high sensitive magnetic sensors [7-9].

Magnetic properties of mictowires are dependent on microwire composition, i.e. magnetostriction coefficient of metallic core material and residual stresses in it [10-11]. In turn, the value of the residual stress and the induced anisotropy depends on the ratio d/D of the metal core diameter *d* to the total diameter *D*. Consequently, it is possible to control the soft magnetic properties of glass-coated microwires by changing their geometric parameters. Technological features of the manufacture process of microwires allow to produce them with different diameters of the metallic core and the glass coating. The aim of this work was to investigate the influence of technological regimes on geometrical properties of Co-rich microwires and their soft magnetic properties.

2. EXPERIMENTAL DETAILS

In this work we studied the six types of microwires with $Co_{69}Fe_4Cr_4Si_{12}B_{11}$ metall core composition. These microwires were manufactured by the Taylor-Ulitovsky method under different technological conditions. As a result the metallic nucleus diameter and outer glass coating ranged within 12-24 μm and 26-35 μm, respectively, for different types of the microwires.

During microwire's fabrication, the following parameters were monitored:

- inductor power (a parameter characterizing the heating temperature of the droplet),
- the wind rate of the microwire,
- feed rate of the glass tube.

These parameters determine a metal core and a glass coating diameters. The characteristics of technology conditions and geometrical parameters obtained microwires are given in the Table 1.

The amorphous state of all microwires was controlled by testing the plasticity and the ability of a node formation. All microwires have demonstrated the possibility tightening in the full node. Investigations of the magnetic properties of microwires were carried out using the induction method and the small-angle magnetization rotation technique (SAMR) [12]. For all types of microwires saturation magnetization, the magnetostriction constant and the average value of the quenching stresses were estimated.

Table 1: The characteristics of technology conditions and geometrical parameters obtained microwires.

Sample	Power P, W	Wind rate V, m/min	Glass feed rate V, mm/min	Core diameter d, μm	Ratio d/D
M-2	1178	177	2.7	18.02	0.53
M-4	860	162	2.2	12.54	0.42
M-5	860	162	2.0	13.61	0.46
M-6	860	162	2.6	23.52	0.68
M-7	1030	162	1.8	16.13	0.59
M-8	1178	162	1.8	17.94	0.67

3. RESULTS AND DISCUSSION

3.1. Geometric properties of microwires

Investigation of the microwires geometrical properties showed that the diameters of the metal core and the glass coating could change in the range 10% along a few meters microwire length, but short segments of the order of 15 - 20 cm had the constant diameters. Fig.1. shows relationships between the internal diameters of the metal core and the outer glass coating of the different microwires. During the measurements, we used pieces of microwires with a length of 15 cm.

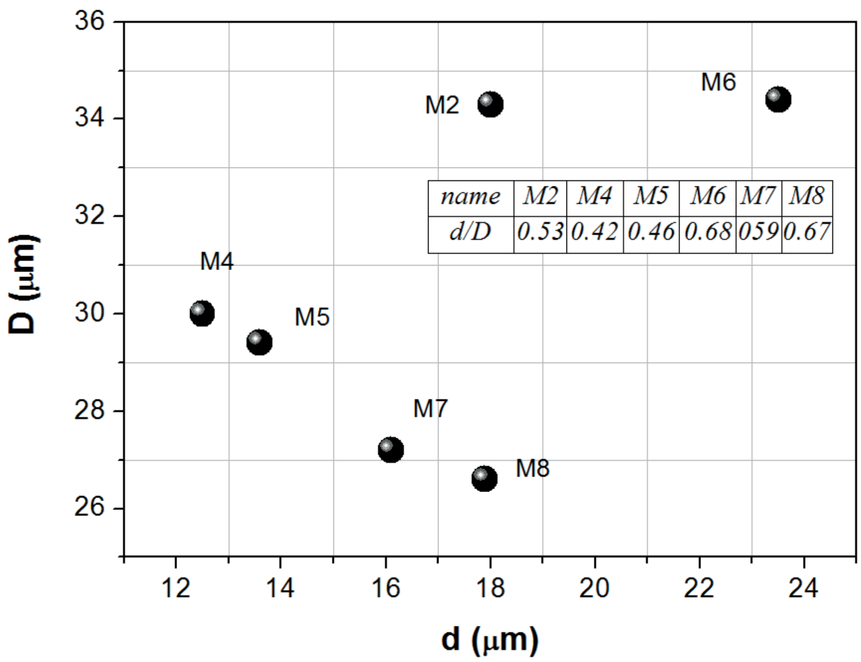

Figure 1: Diagram of the relationship between the diameters of the metal core and the glass coating of different microwires.

3.2. Magnetic properties of microwires

Measurements of the microwires magnetic properties were done after determining the diameters of the microwires. Dynamic hysteresis curves of the microwires were obtained using an induction method. The results of measurements showed, that the hysteresis curves could vary even along a length of 10 - 15 cm. These differences were mainly related to variations in the anisotropy field of microwires within ± 10%. Fig.2. shows an example of the hysteresis curves change at two points of one microwire at a distance of ~ 7 cm. Proceeding from the above, the average measured values of H_a were taken as the value of the anisotropy field.

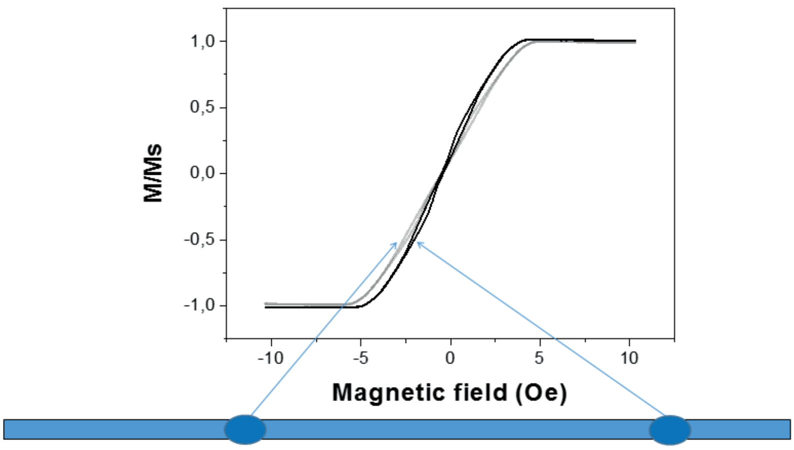

Figure 2: The hysteresis curves measured at two points located at a distance of ~ 7 cm.

A typical dynamic hysteresis loops of microwires are shown in Fig.3. As follows from the presented data, the magnetic properties of the microwires turned out to be different, even with fairly close manufacturing parameters. Fig.4 shows the values of the anisotropy fields for all the microwire types. It can be seen that the microwires M4 and M5 show lower values of H_a than another one, although they have less d/D ratio. This fact is in a contradiction with [13, 14], where magnetic anisotropy field is found to be determined by d/D ratio and decreasing with d/D.

In order to understand this discrepancy in the anisotropy field values, the measurements of the magnetostriction constant and the quenching stresses of all types of microwires using the SAMR method were done. Fig.5 and Fig.6 show the results of the evaluation of the magnetostriction constant and the quenching stresses, respectively.

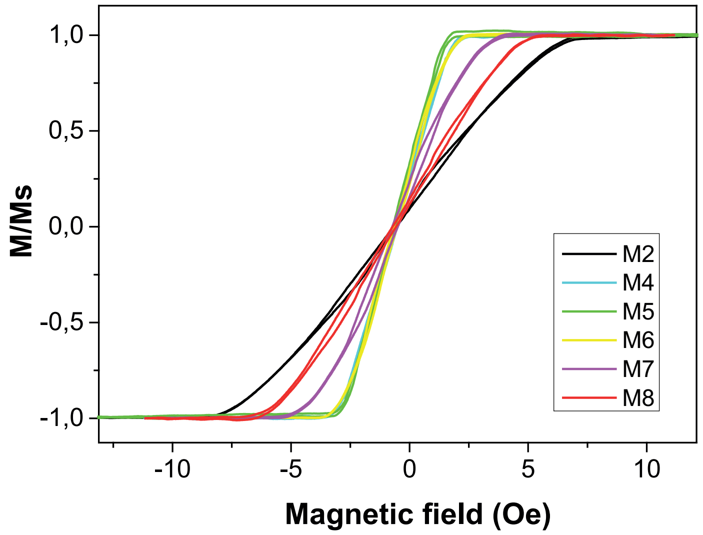

Figure 3: Dynamic hysteresis curves of microwires, prepared under different conditions.

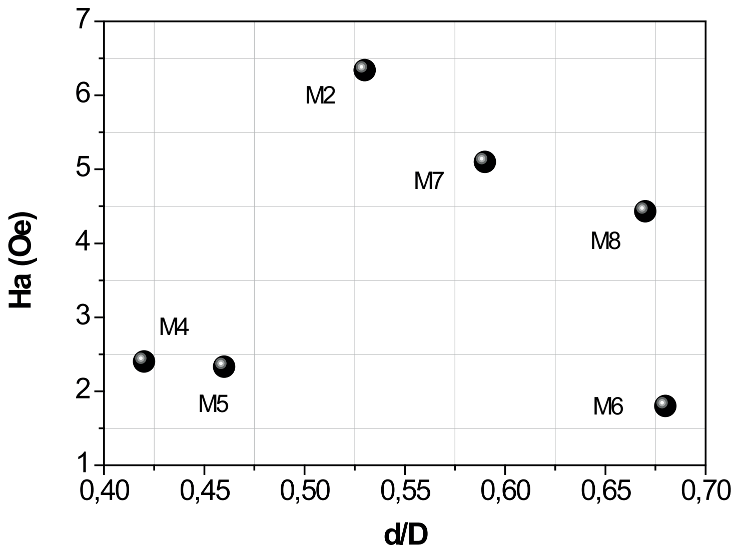

Figure 4: Values of anisotropy field depend on d/D ratio for different types of the microwires.

3.3. Interconnection of technological and magnetic parameters of microwires

Based on the received estimates of the main characteristics of microwires, the following can be noted. Firstly, the manufactured microwires were characterized by a large variety of the diameters of the inner core (within 12-24 μm), the glass coating (within 28-35 μm) and their ratio (within 0.45-0.75), Fig.1. As a result, the dynamic hysteresis loops of different types of microwires significantly varied in magnitude of

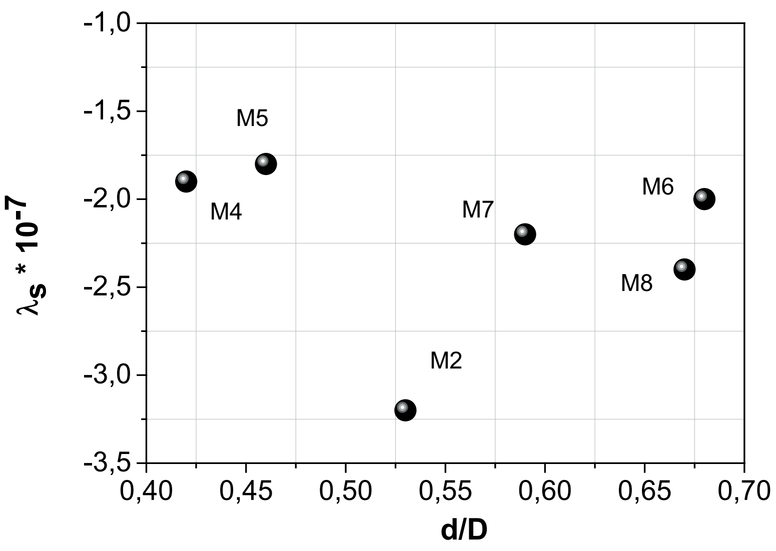

Figure 5: Values of magnetostriction constant depend on d/D ratio for different types of the microwires.

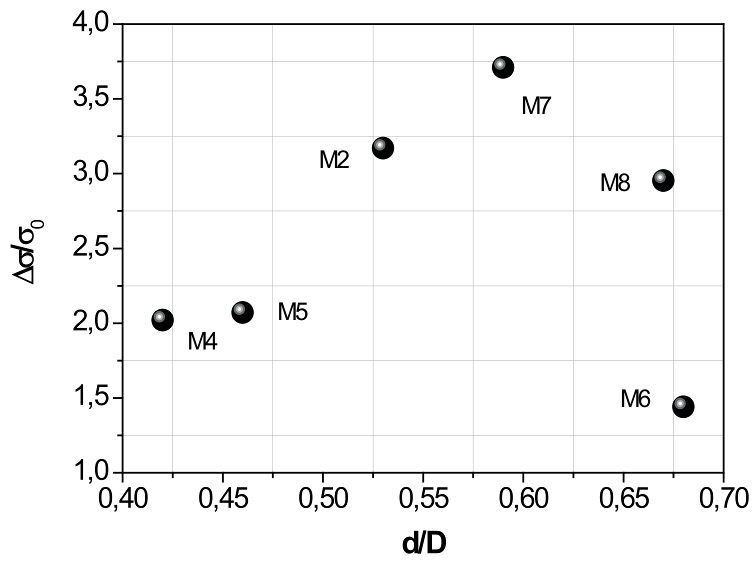

Figure 6: Values of normalized internal stresses depend on d/D ratio for different types of the microwires, where σ_0 = 100 MPa.

the anisotropy field (from 2 Oe to 6.5 Oe). Secondly, the values of the magnetostriction constant of the manufactured microwires had small negative values in the range (-1.8*10^{-7}÷ - 3.2*10^{-7}. Moreover, with the exception of microwires of type M7, the values of the magnetostriction constant lied in the range (-2.1 ± 0.3)*10^{-7}. Third, the internal quenching stresses of microwires varied within 140 ÷ 370 MPa. At the same time, the values of the quenching stresses are weakly correlated with the thickness

DOI 10.18502/kms.v4i1.2157

of the glass coating and the corresponding values of the d/D ratio for each type of microwires.

Also, it is necessary to note the characteristic features of each type of microwires depend on the conditions of their manufacture. For example, microwires type M7, M8 have the thinnest glass shell. This is due to the lowest feed rate of the glass tube, 1.8 mm/min. The microwires M2, M6, on the contrary, had the maximum diameter of the glass coating. The feed rate of the glass tube is maximal (2.7 mm/min and 2.6 mm/min, respectively). Thus, the feed rate of the glass tube correlates well with the measured values of the glass coating diameters.

At the same time, the effect of the glass coating on the characteristics of various types of microwire has been ambiguous. According to the generally accepted notions, increasing the thickness of the glass coating should increase the internal quenching stresses $\Delta\sigma$ in the microwire.

Some of our microwires meet this condition. For example, the microwires M2 and M6 have the same diameter of the glass coating, but the d/D ratios are 0.53 and 0.68, respectively. The magnitude of the quenching stresses for M2 is 317 MPa and more than twice higher than quenching stresses of the M6 (144 MPa).

However, in the other cases, this condition may not be fulfilled. In particular, according to Fig.1, microwires M2 and M8 have the same internal core diameters, but differ in the d/D ratio, which are 0.53 and 0.67, respectively. Nevertheless, as follows from Fig. 6, the quenching stresses of these microwires are quite close and are 317 MPa and 295 MPa, respectively. Another example is the microwires M4, M5, M6, manufactured around the same technological conditions. They have close values of quenching stresses, despite the significant difference in the d/D ratio. Comparison of the microwire M4 (d/D = 0.42) and M8 (d/D = 0.67) shows that M4 has a one and a half times less the value of the quenching stresses compared to the M8.

Thus, the obtained results show that there is no unique relationship between the thickness of the glass coating and the internal quenching stresses. The last one in a complex way depends on all technological parameters and the metal core composition. At the same time, it can be noted, that microwires fabricated using higher inductor power has higher values of internal quenching stresses.

4. CONCLUSIONS

In conclusions a series of glass-coated microwires of $Co_{69}Fe_4Cr_4Si_{12}B_{11}$ composition with different metallic core and glass coating diameters were fabricated by means of Taylor-Ulitovsky technique. The series included six type of microwires fabricated under different conditions. It was shown that for all microwires, the average diameters of the metal core and glass coating can be varied along a length of few meters, but at short range, of order of 15 - 20 cm, diameters are constant. The magnetic measurements showed that the effective anisotropy field of hysteresis curves of microwires can vary even along a length of 10 - 15 cm. It was found that there is no unique relationship between the thickness of the glass coating and the internal quenching stresses of the microwires. The values of the magnetostriction constant turned out to be close (-2.1 ± 0.3)*10^{-7} for all types of microwires with the exception of M2. The peculiarity of manufacturing of this microwire consisted in increasing of the wind rate parameter and the higher value of the power consumed by the heater.

ACKNOWLEDGMENTS

Authors would like to acknowledge the financial support of the Ministry of Education and Science of the Russian Federation in the framework of Increase Competitiveness Program of NUST «MISiS» (contract № K2-2015-018). S.A. Gudoshnikov wishes to acknowledge a support of the program of the Ministry of Education and Science of the Russian Federation "Organization of scientific research" (Assignment # 3.7477.2017/BY).

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