The Influence of the Soaking Process on Magnetization Saturation and Coercivity Field of the Classic Amorphous Alloy $Fe_{61}Co_{10}Y_8Nb_1B_{20}$.

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This study presents the results of Mossbauer research and magnetic properties. The tests were carried out for amorphous $Fe_{61}Co_{10}Y_8Nb_1B_{20}$ alloys produced in the form of strips with a thickness of approximately 35 mm. Mossbauer spectra were measured in transmission geometry for solid samples. Measurements were taken for samples in solidified state and after two heating processes. The first process was carried out at 700K and 60 minutes, the second at 720K and 210 minutes. For the samples prepared in this way, magnetization tests were performed as a function of the magnetic field strength. The values of saturation magnetization and the value of the coercive field were determined from these matrices. It was found that the performed thermal treatments had a negative effect on the value of saturation magnetization and change in the value of the coercive field.

Keywords: amorphous materials, mossbauer effect, saturation magnetization, coercivity field

Shaping the structure of alloys has been used for a very long time, since people began to process the first metal products. Their consciousness was not then shaped as it is today, when the selected properties of alloys are formed by thermal treatment. It is the material engineers who are involved in forming the properties of the products so that they will face ever-increasing expectations towards new engineering materials. The strongly developing industry forces the production of ever better materials, taking into account the reduction of the costs of obtaining them and the possibilities of their continuous improvement. The power industry, electrics and electronics are developing strongly in the last century. All devices that surround us require permanent or battery power supply. Regardless of the type of device operation, it is important to limit the energy consumption. Therefore, the development of materials to reduce the consumption of electricity is so important. In the seventies of the last century, ferromagnetic amorphous alloys were created, which were characterized by exceptional properties much better than those observed in crystalline materials with the same chemical compositions [1-3]. It was noticed already, that small changes in parameters in the process of their production are a reason for changing their properties. What is the most interesting, all changes occurred within the amorphous state, which has not been well described so far. The lack of a pattern for the amorphous state is a very big obstacle that makes it impossible to accurately characterize its structure. Therefore, studies that allow to distinguish differences in the structure of internal amorphous alloys are very important. It is known that in crystalline materials there is an order in the arrangement of atoms over longer distances, while maintaining the periodicity of systems and angular translations. In contrast, in the amorphous materials atoms interact with each other at close distances, are chaotically scattered and this arrangement is characterized by chemical and topological disorder [4, 5]. Studying the structure of amorphous alloys is a task that causes many difficulties. There are several available techniques that give the possibility to analyze the structure of amorphous alloys. One of them is high-resolution transmission microscopy, however, it gives the possibility to analyze very small areas [6, 7]. In addition, in the case of ferromagnetic alloys, this technique is highly imperfect in terms of use. There is a high probability of damage to the column of the microscope, which is why in a few research centers there are specialists who undertake such research. Using the scanning electron microscopy, the structure of the fractures of amorphous alloys can be analyzed, which gives the possibility of a comparative assessment of their plasticity. The real structure of ferromagnetic amorphous alloys has been studied for years using transmission and reflective Mössbauer spectroscopy [8-12].

For ferromagnetic alloys containing Fe, it is used as the Mössbauer source of ^{57}Co. The Mössbauer effect for ferromagnetic alloys is visible in the spectra in the form of the Zeeman sextet [13]. As a result of the numerical analysis of the obtained spectra, detailed parameters describing the structure of alloys can be determined. These parameters include: the value of the induction of the effective hyperfine field, the relative intensity of the second and the fifth lines in the Zeeman sextet, the dispersion parameter of the amorphous state [9, 14]. Due to the fact that the Mossbauer research is characterized by high resolution, it is possible to determine the changes in the amorphous structure after partial relaxation. In particular, such tests are useful when the samples undergo an annealing process aimed at relaxing the sample and improving its performance [15-23]. This work presents the results of investigations of the structure and magnetic properties of the amorphous alloy (in the form of a strip with a thickness of approximately 35μm) $Fe_{61}Co_{10}Y_8Nb_1B_{20}$ in solid state and after thermal treatment performed at parameters: 700K / 60min and 770K / 210min.

Computational details

The material in the form of tapes with a thickness of about 35 mm was made by a rapid casting of liquid metal on a copper spinning roller - spinning melt. The components for the production of the research material had a high purity of more than 99.99% at. Boron was added in the form of an alloy with iron of known chemical composition $Fe_{45,4}B_{54,6}$. The production cycle consisted of two stages. In the first stage, alloy components were melted in a vacuum arc furnace bold according to the recipe. The ingots thus obtained, weighing about 10g, were cleaned mechanically

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and in an ultrasonic washer to remove impurities. Then the ingots were divided into smaller batch portions for melting the tapes. The alloy pieces were placed in a quartz capillary, melted using an induction furnace and pressed under a argon pressure on a copper rotating wheel. The linear speed of the wheel was chosen so as to obtain tapes with a thickness of about 35μm. The tape prepared in this way was prepared for testing. The beginning of the tape and the end was cut off, these were sections about 5 m long. Then three pieces were cut from the remaining tape after a few meters. Each of the pieces was examined separately. Three groups of samples were prepared: in solidified state and after heat treatment in a vacuum oven at 700 K / 60 min and 770 K / 210 min.

For the Mossbauer investigations, the strips were cut into strips of about 15 mm in length, which were stacked tightly in heaps of 10 mm in diameter cut in copper foil. The thickness of the samples was optimal, which resulted in obtaining the right number of counts and obtaining a good Mössbauer effect from the sample. Then the prepared sample was placed in the POLON 2330 spectrometer. The whole system worked in transmission geometry at constant acceleration of the source (the ^{57}Co isotope in the matrix). -Fe foil (20 μm). αCalibrations of the Mossbauer spectrometer were made with a thin Numerical analysis of experimental data was carried out using the NORMOS program [24-26]. All Siemens measurements were made at room temperature.

Images of the fracture surfaces for the alloy samples in the form of a strip in solidified state and after two heating processes were performed using scanning electron microscopy. For this purpose, a microscope made by the company *Supra 25 Zeiss from Detector SE* was used, equipped with an EDS (Energy Dispersive X-ray Spectroscopy) microanalyzer.

Static magnetic hysteresis loops were obtained from M-H measurements made using a LakeShore vibration magnetometer operating at a magnetic field strength up to 2 T.

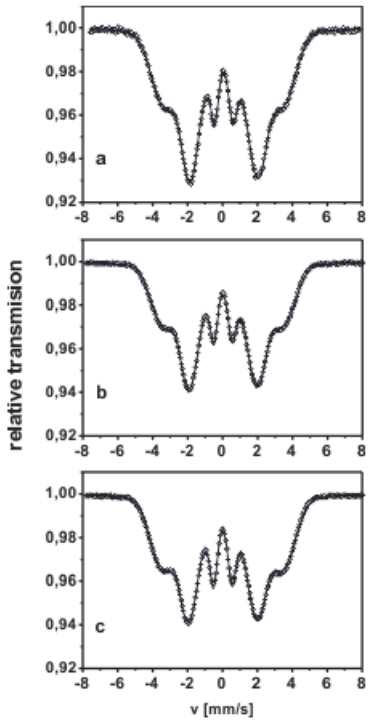

Fig. 1. Transmission mossbauer spectra for $Fe_{61}Co_{10}Y_8Nb_1B_{20}$ in state: a - after solidification, b - 700K/60 min, c -770K/210 min

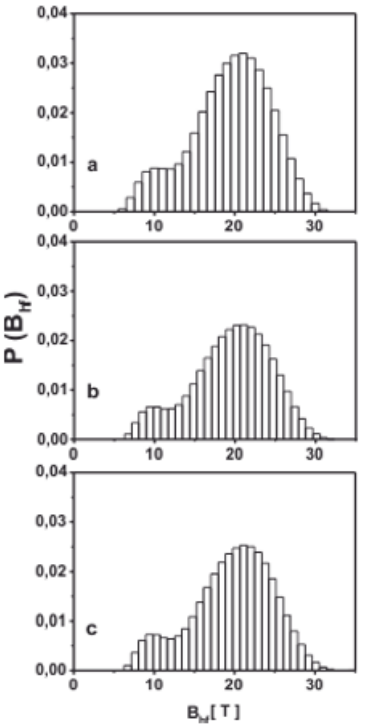

Fig. 2. Hyperfine field distributions for samples of the tested $Fe_{61}Co_{10}Y_8Nb_1B_{20}$ alloy in the state: a - after solidification, b - 700K / 60 min, c - 770K / 210 min

Results and discussions

In figure 1, the Mossbauer transmission spectra recorded for the alloy samples in the form of a strip after solidification and after the thermal treatment performed at the parameters: 700K / 60 min and 770K / 210 min.

All the Mossbauer spectra shown in figure 1 are similar. They consist of wide asymmetrical overlapping lines. This shape of Mossbauer transmission spectra is typical for amorphous materials, which are characterized by a lack of chemical and topological order. The shape of the spectra is well described by Zeeman's sextet and it can be stated that these are ferromagnetic materials. In addition, it should be concluded that the tested samples, regardless of the state of stress of the structure, are magnetics in the magnetically ordered phase. Confirmation of the chemical and topological disorder in the samples being tested is the fact that the symmetry of the line arrangement relative to the center is present. The lack of significant changes in the shape of the Mossbauer spectrum after the heating processes at a temperature lower than the crystallization temperature in the form of narrow components indicates that the whole sample is in an amorphous state. Using the NORMOS program, the experimental numerical analysis of the Mossbauer spectra was performed and the hyperfine index distributions on ^{57}Fe ions were determined (fig. 3).

The hyperfine field distributions presented on figure 2 on 57Fe iron nuclei are bimodal. They range from about 5 T to 31 T. The shape of these distributions is typical of magnetic materials in a ferromagnetic state. For a sample in solidified state, low-field and high-field components are separated, but the exact profile of this division can not be determined. Gauss line curves do not overlap two hills from the low and high-field components. For the two remaining samples after isothermal heating processes, Gauss type lines fit well to the distribution of components with an induction value of around 11-12 T. The maxima value for low and highpolar components in the presented hyperfine index distributions on the 57Fe iron cores is independent of the ones performed thermal treatments. The observed transition between low and high-field components is the point separating areas with different concentrations of iron. The shape changes of this transition are undoubtedly related to the migration movements of atoms in the volume of the alloy. Figure 3 shows photos of a sample of the tested alloy in the state after solidification.

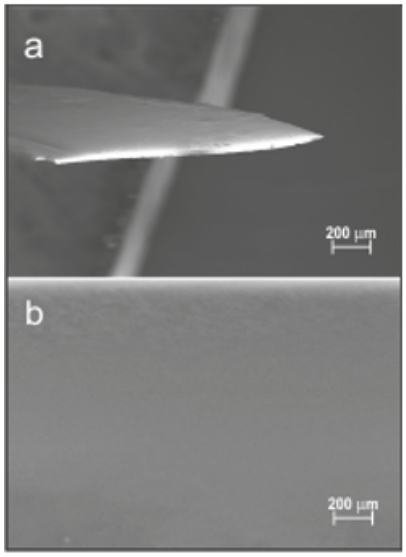

Fig. 3 Photographs of the test alloy sample in the form of a strip in the state after solidification: a - general view, b - tape cross-section

Table 1

INDICES OF THE EFFECTIVE HYPERFINE FIELD B_{ef} On The ^{57}Fe NUCLEI, DISPERSION OF HYPERFINE FIELD D_{am} FOR TESTED ALLOY SAMPLES $Fe_{61}Co_{10}Y_8Nb_1B_{20}$, M_s-SATURATION MAGNETIZATION, H_c - COERCIVE FIELD IN THE STATE AFTER SOLIDIFICATION AND AFTER ISOTHERMAL ANNEALING

Parameter / Sample	State	B_{hf} [T]10^{-1}	D_{am} [T]10^{-1}	M_s [T]	H_c [A/m]	Ref.
$Fe_{61}Co_{10}Y_8Nb_1B_{20}$	ASQ	19.39 [+-0.02]	4.99 [+-0.02]	1.38	101	[20]
	700K/60 min	19.50 [+-0.02]	5.13 [+-0.04]	1.32	29	
	770K/210 min	19.72 [+-0.03]	5.18 [+-0.04]	1.25	56	

The tested sample in the solidified state is characterized by a smooth breakthrough, which indicates good relaxation of the material. Magnetic properties were determined based on the analysis of static magnetic hysteresis loops. Saturation magnetization value and coercive field value were determined. For the sample after consolidation, the saturation magnetization value was the highest at 1.38 T. For samples in the post-isothermal heating state, the magnetic saturation decreased. Initially, the first heating process decreased to the value of 1.35 T and for the second to 1.25 T. Most probably, the process of heating will affect the configuration of magnetic carriers in the volume of the alloy and possible constant competitive for the state of ferromagnetic antiferromagnetic impact. In this case, the decrease in magnetization is observed. This fact can also be confirmed by the transitions between low and high polygonal components depicted in figure 2 in indices of hyperfine fields. While it is easy to explain the change in the value of the state of saturation, the difficulty in determining the change in the value of the coercive field is much greater. It can be assumed that the soaking process performed at 700K / 60min parameters led to the relaxation of the structure, consisting in the release of the relaxants in the form of free volumes to the sample surface and their conglomeration to two-dimensional creations called pseudodislocation dipoles. It is also important to change the potential of domain wall anchoring, which in amorphous materials strongly depends on the number of relaxants. As a result of heating at a higher temperature and for a longer time of the process of 770K / 210 min, the areas of high and low concentration of iron occurred in the sample volume (fig. 2).

Data obtained from the numerical analysis of Mossbauer transmission spectra and static magnetic hysteresis loops are presented in table 1.

Conclusions

Using the method of unidirectional continuous liquid casting on a copper rotating wheel, amorphous tapes with a thickness of about 35µm can be produced from the $Fe_{61}Co_{10}Y_8Nb_1B_{20}$ alloy. Using the Mossbauer spectroscopy, subtle changes in the structure of amorphous alloys can be studied. Mossbauer's tests for tapes performed in transmission geometry give the possibility to analyze the structure in their entire volume. On the basis of numerical analysis of Mossbauer transmission spectra, distribution of hyperfine fields on ^{57}Fe iron nuclei were obtained. As a result of their analysis, it was found that in the structure of the samples small changes occurred as a result of the heating processes carried out. However, they played a large role in changing magnetic parameters such as saturation magnetization and coercive field. Structural relaxation that took place in the sample volume subjected to the soaking process of 700 / 60min resulted in a slight decrease in the saturation magnetization value and over three times the coercive field values. This indicates that the parameters of this process have been correctly selected. Then, for the sample in the condition after solidification, thermal treatment was again performed at the parameters 770K / 210min. It was believed that heating at a temperature closer to the crystallization temperature and with extended time would affect the significant improvement of the analyzed magnetic parameters. Unfortunately this did not happen. The tendency to decrease the magnetization value, however, was observed to have a negative effect of this process on the value of the coercive field which increased more than four times in relation to the sample soaked in the first 700K / 60min process. The conclusions drawn from these studies are unequivocal, that not always the process of relaxing the structure within the amorphous state positively affects the magnetic parameters mentioned. Not always migrations of alloy components to homogenize them have a positive effect on magnetic properties. The change in the configuration of atoms in different areas leads to averaging of the parameter values and may be the reason for adverse changes as in the case of the 770K / 210min process. The release of a large number of relaxants to the surface of the sample promotes the formation of systems with a dense packing of magnetic atoms, especially visible for the distributions of magnetic fields in the range 5T - 10 T. In such systems may occur between ferromagnetic and antiferromagnetic interactions. Verification of the latter using Mossbauer spectroscopy is very difficult. In summary, when designing materials for use in electrotechnical equipment, too much stress should be taken into account of the amorphous structure leading to the formation of areas significantly different in terms of the number of magnetic atoms.

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