

INFLUENCE OF COBALT CONTENT ON CURIE TEMPERATURE OF THE ALLOY $\text{Fe}_{43+x}\text{Co}_{29-x}\text{Y}_8\text{B}_{20}$ WHERE $x = 0$ OR 5

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Abstract

The paper presents the original results of studies on rapidly cooled alloys with chemical composition $\text{Fe}_{43+x}\text{Co}_{29-x}\text{Y}_8\text{B}_{20}$ where $x = 0$ or 5 . The alloys were made by sucking a liquid alloy into the copper mold. Samples were made in the shape of 10mm x 5mm x 0.5mm plates. The structure of the obtained alloys was examined by X-ray diffraction. The magnetic polarization of saturation as a function of temperature was measured using the Faraday magnetic weight. The measured curves $\mu_0 M_s$ (T) shows one gentle inflection from the transition from ferro to paramagnetic. On the basis of the numerical analysis of the obtained curves, the Curie temperatures of the studied alloys were determined. Significant influence of cobalt content on Curie temperature of amorphous alloys was confirmed. The tests confirmed good glass ability of alloys based on FeCoBY using a relatively low cooling rate (order of 10^2K/s).

Keywords: amorphous materials, suction method, Curie temperature

Introduction

Amorphous materials due to their unique structure have been the object of interest of scientists for several decades. Over the years, there have been many changes in the methods of producing amorphous materials. The first methods were based on the production of thin layers and coatings on the surface of metal plates. The next step was to cast a liquid alloy on a spinning copper drum [1]. This method is still used today for casting amorphous ribbons on an industrial scale. However, amorphous ribbons did not allow to fully exploiting the possibilities that generate unique properties of amorphous alloys. The breakthrough proved to be A. Inoue's research, which initiated a new group of materials, the so-called massive amorphous materials. A. Inoue defined three principles for the production of massive amorphous materials: multi-componentity of the alloy, negative heat of mixing of components and differences in the atomic radius of the main components (minimum 12%) [2-6].

Amorphous materials are characterized by different properties than their crystalline counterparts with the same chemical composition [7-9]. Amorphisation of the structure influences the change of strength and magnetic properties. The unique properties of amorphous materials result from their unusual structure. In the volume of material there is no long-range ordering of atoms, so one can talk about the chaotic arrangement of atoms. Such a structure is common for liquids. Nevertheless, amorphous materials assume the properties of solids. Of particular interest are the magnetic properties of these materials, such as the low coercive field value, the initial magnetic permeability or the high magnetization of saturation [10-14].

The so-called magnetically soft properties of amorphous alloys enable their applications in the electrotechnical industry. It should be mentioned that amorphous alloys are used as starting material for the production of nanocrystalline materials. Grains of crystalline phases with nanometric dimensions can significantly improve the magnetic properties of the materials produced [15-18]. An important parameter determining the possibility of using amorphous materials is the Curie temperature. Above this temperature, the ferromagnetic properties change to paramagnetic.

The purpose of this work was to create an amorphous alloy with the chemical composition $\text{Fe}_{43+x}\text{Co}_{29-x}\text{Y}_8\text{B}_{20}$ where $x = 0$ or 5 by suction and to study the effect of change in the cobalt content in the alloy on the structure of the material produced and on the Curie temperature of the amorphous matrix.

Studied material

An alloy with a chemical composition $\text{Fe}_{43+x}\text{Co}_{29-x}\text{Y}_8\text{B}_{20}$ was designated for research where $x = 0$ or 5 . Alloyed components were weighed with an accuracy of 0.001 grams. The elements used to create a polycrystalline ingot were characterized by a high degree of purity that is above 99.99%. The material was weighed in a quantity of 10 grams per alloy. The polycrystalline ingot was produced by the arc method. The melting process was carried out on a copper water-cooled plate. The alloy components and pure titanium were placed in the appropriate hollow plates. The batch melting process takes place after the working chamber is pumped out of the air. After reaching a high vacuum, the chamber is subjected to an inert gas, after which a high vacuum is again produced. In this way, high purity of the atmosphere prevailing in the working chamber during the melting of the charge is ensured. Argon is injected into the working chamber in the atmosphere, which the whole process is carried out. Prior to the start of the solidification process, pure titanium is melted. The aim of this treatment is to capture the remaining pollutants in the chamber (in particular oxygen) affecting the composition of the ingot being produced and directly to the chance of obtaining an amorphous structure in the proper process of rapid cooling of the liquid alloy. A very important stage in the production of the ingot is its first remelting. Too fast arcing over the batch can cause the alloy components to scatter over the working chamber, which can affect the chemical composition of the ingot. After making the first melt, the polycrystalline ingot is turned over to the other side by means of a manipulator and remelted again. This process is repeated several times in order to obtain a high uniformity of the ingot structure. Each time before the melting process, pure titanium is melted.

After cleaning of external impurities, the polycrystalline ingot was crushed to smaller elements. Pieces of ingot were placed in hollows on a copper plate along with pure titanium. Figure 1 shows a schematic diagram of the device for producing amorphous alloys by suction.

The production of the amorphous alloy takes place in a similar procedure as during the production of a polycrystalline ingot. A high vacuum is produced in the working chamber, followed by argon flushing. After the next pump down cycle, argon is injected into the chamber in the atmosphere where the liquid alloy is sucked into the water-cooled copper mold. Before melting the batch, pure titanium is melted, which affects the purity of the material obtained and, consequently, a greater chance of obtaining an amorphous structure. In the presented solution, it is possible to cast three alloys at the same time, which significantly affects the rate of production of amorphous alloys. The polycrystalline ingot is melted by means of an electric arc.

Once the right consistency has been achieved, the liquid alloy is sucked into the copper mold by means of a pump system and valves. The molds used allow casting of the alloy in the form of bars, cores or tiles, as in this case. The produced alloys are 10mm x 5mm x 0.5mm.

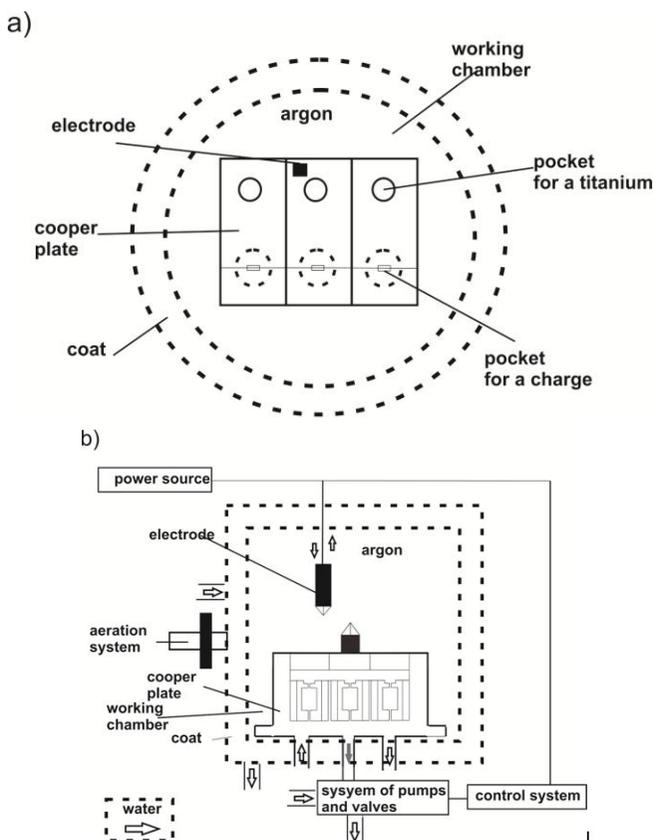


Fig. 1. Scheme of making amorphous materials by suction casting: a) top view, b) side view

The structure of the obtained material was examined using X-ray diffraction, while the magnetic polarization as a function of temperature was measured using the Faraday magnetic balance.

Experiments

Figure 2 contains X-ray diffractograms for the tested alloys. The study was carried out with the Bruker model Advanced 8 (CuK α X-ray tube). Diffraction measurements were made from the angle of 2θ from 30° to 100° by irradiating samples of 7 seconds per measuring step (0.02°). The measurement was carried out for the alloy in powder form.

The measured diffractograms are similar. Only the broad maximum called the amorphous hall was recorded. This indicates the chaotic distribution of atoms in the volume of the alloy. Lack of distinct other peaks suggests obtaining an amorphous structure in the produced materials. The measured diffractograms differ only with the intensity of the wide maximum. This shows differences in the degree of ordering of the amorphous structure. A higher intensity peak was recorded for the alloy with higher cobalt content at the expense of iron.

Figure 3 presents reduced magnetic saturation polarization curves for the tested alloys. The measurement of the magnetic saturation polarization was carried out with the Faraday magnetic weight for the temperature range from 350 K to 850 K.

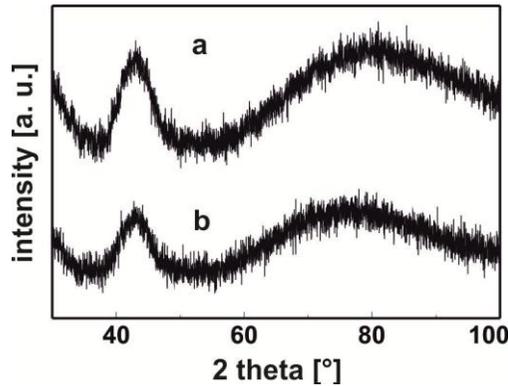


Fig. 2. XRD diffractograms for alloys in the form of powder made by suction in the form of plates with a thickness of 0.5 mm: Fe₄₃Co₂₉Y₈B₂₀ b) Fe₄₈Co₂₄Y₈B₂₀

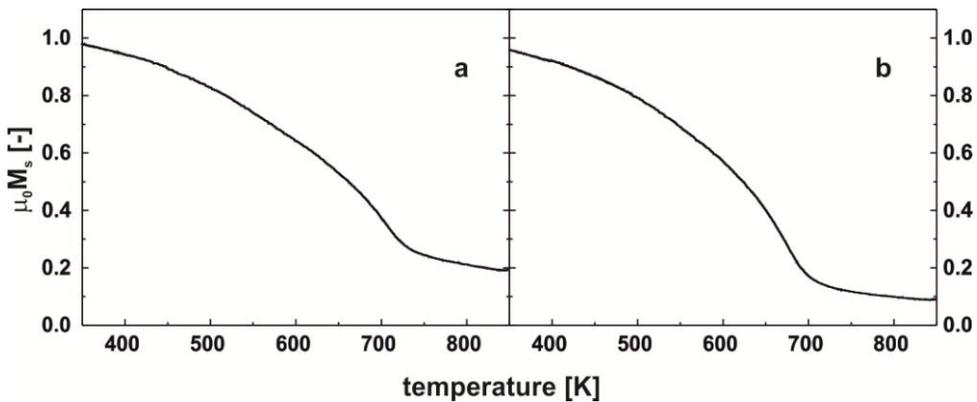


Fig. 3. Thermomagnetic curves for test alloy samples in solidified state as a powder for alloys produced by suction: a) Fe₄₃Co₂₉Y₈B₂₀ b) Fe₄₈Co₂₄Y₈B₂₀

Saturation polarization curves measured for increasing temperatures exhibit one gentle transition typical of the ferro to paramagnetic transition. This transition is related to the occurrence of an amorphous matrix in the melt volume. Analyzing the curves, it can be concluded that there are no crystalline phases or hard magnetic phases in the volume of alloys in the range from room temperature to 850K. At a temperature of 850K, the magnetic saturation polarization value still shows a significant value which may be related to the occurrence of high temperature crystalline phase, for which the transition from ferro to paramagnetic is not visible due to the temperature range in which the measurement was performed. The hypothetical crystal phase must be present in a small amount compared to the amorphous matrix, because X-ray diffraction images do not indicate the presence of crystalline phases. The resolution of the X-ray machine may not be sufficient to detect small amounts of crystalline phases in the volume of the alloy, and therefore their presence in the test samples cannot be excluded.

The curves in Figure 3 were subjected to numerical analysis assuming that the tested alloys met Heisenberg's conditions. A critical factor B of 0.36 was assumed. Based on this analysis, the Curie temperature of the alloys tested was determined (Figure 4).

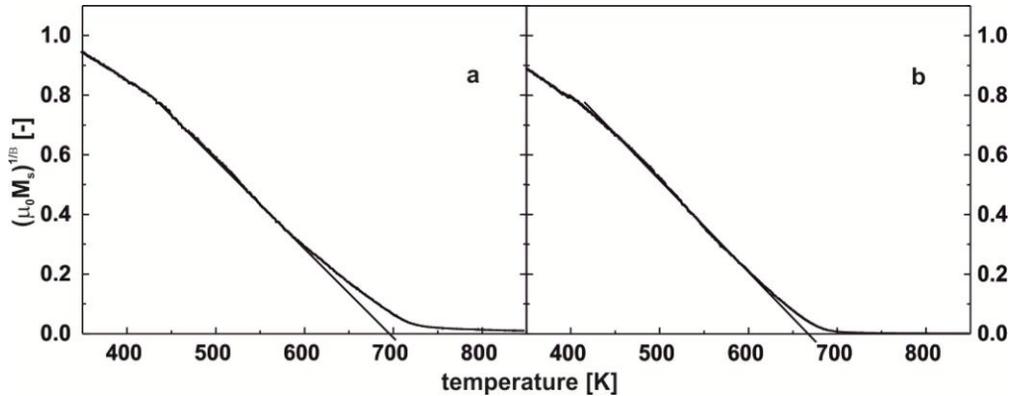


Fig. 4. Curie temperature determination for prepared alloys using the suction method a) $\text{Fe}_{43}\text{Co}_{29}\text{Y}_8\text{B}_{20}$ b) $\text{Fe}_{48}\text{Co}_{24}\text{Y}_8\text{B}_{20}$

The nature of the amorphous structure makes it very difficult to determine the exact Curie temperature of the alloys. The chaotic arrangement of atoms and the presence of areas with different energy configurations means that the transition from ferro to paramagnetism does not occur for a discrete temperature value, but rather for a certain range of temperature. The calculated value of the Curie temperature of the amorphous matrix is therefore not a discrete value and the possibility of its certain fluctuations depending on the prepared alloy sample should be taken into account. In spite of this, it can certainly be confirmed that the iron content changes at the expense of cobalt to the Curie temperature value.

For the $\text{Fe}_{43}\text{Co}_{29}\text{Y}_8\text{B}_{20}$ alloy the Curie temperature was equal 695K and for $\text{Fe}_{48}\text{Co}_{24}\text{Y}_8\text{B}_{20}$ Curie temperature is 668K.

Conclusions

The purpose of this work was to produce massive amorphous materials by sucking a liquid alloy into a copper mold. Manufactured alloys with chemical composition $\text{Fe}_{43+x}\text{Co}_{29-x}\text{Y}_8\text{B}_{20}$ where $x = 0$ or 5 proved to be characterized by a good glass transition ability. The amorphous structure of the tested alloys was obtained at the relatively low cooling rate allowed by the applied method of producing fast-cooled alloys (of the order of 10^2 K/s). Obtained X-ray diffraction images indicate the amorphous structure of the materials produced. However, differences in the intensity of the amorphous halo indicate a different degree of ordering of atoms in the volume of alloys. The X-ray images shown do not confirm the presence of crystalline phases in the volume of the samples produced. The magnetic saturation polarization as a function of temperature also excludes the presence of low-temperature crystalline phases. The only visible passage from ferro to paramagnetic is related to the amorphous matrix of the samples. The measuring range of the Faraday magnetic balance used does not allow measuring the magnetic saturation polarization at higher temperatures. Above 700K, the magnetization of the samples drops much more slowly than the temperature rises, suggesting the possibility of a crystalline magnetic phase with a Curie temperature higher than 850K. The presence of a hypothetical crystalline phase could be confirmed by using the Mössbauer spectroscopy and by means of a scanning electron microscope.

References

- [1] W. Klement, R. H. Willens, P. Duwez, *Non-Crystalline Structure in Solidified Gold-Silicon Alloys*, **Nature**, **Vol. 187** (1960), pp.869-870.
- [2] M. Nabiałek, *Influence of the quenching rate on the structure and magnetic properties of the Fe-based amorphous alloy*. **Arch. Metall. Mater.**, **Vol. 61** (2016), p. 439–444.
- [3] W. LI, Y. Z. Yang, J. Xu, *Crystallization and soft magnetic properties of metalloid-free Fe₈₉Hf₇Al₃Zr₁ amorphous alloy*, **Journal of Non-Crystalline Solids**, **Vol. 461** (2017), p. 93–97.
- [4] A. Inoue, B. Shen and T. Ohsuna: *Soft magnetic properties of nanocrystalline Fe-Si-B-Nb-Cu rod alloys obtained by crystallization of cast amorphous phase*, **Mater. Trans.**, **Vol.43 (9)** (2002), p. 2337–2341.
- [5] P. Pawlik, M. Nabiałek, E. Źak, J. Zbroszczyk, J. J. Wysłocki, J. Olszewski and K. Pawlik *Procesing of bulk amorphous alloys by suction-casting metod*, **Archiwum Nauki o Materiałach**, **Vol. 25** (2004), pp. 177-184.
- [6] A. Inoue, *Stabilization of metallic supercooled liquid and bulk amorphous alloys*, **Acta Materialia**, **Vol. 48** (2000), pp. 279-306.
- [7] A. Inoue, N. Yano, T. Masumoto, *Production of metal-zirconium type amorphous wires and their mechanical strength and structural relaxation*, **J. Mater. Science Vol.**, **19** (1984), pp. 3786-3795.
- [8] M. Szota, *Effect of structural relaxations within the amorphous structure on the magnetic properties of amorphous tapes from FeCoB family*, **Archives of Metallurgy and Materials**, **Vol. 62(1)** (2017), pp. 217-222.
- [9] H. S. Chen and C. E. Miller, *Centrifugal spinning of metallic glass filaments*, **Materials Research Bulletin**, **Vol. 11** (1976), pp. 49-54.
- [10] M. E. McHenry and M. A. Willard, Laughlin D.E.: *Amorphous and nanocrystalline materials for applications as soft magnets*, **Progress in Materials Science**, **Vol. 44**, (1999), pp. 291-433.
- [11] F. Wang, A. Inoue, Y. Han, F. L. Kong, S. L. Zhu, E. Shalaan, F. Al-Marzouki, A. Obaid, *Excellent soft magnetic Fe-Co-B-based amorphous alloys with extremely high saturation magnetization above 1.85 T and low coercivity below 3 A/m*, **Journal of Alloys and Compounds**, **Vol. 711** (2017), pp. 132-142.
- [12] G. Herze, *Modern soft magnets: Amorphous and nanocrystalline materials*, **Acta Materialia**, **Vol. 61** (2013), pp. 718–734.
- [13] Y. Han, C. T. Chang, S. L. Zhu, A. Inoue, D. V. Louzguine-Luzgin, E. Shalaan, F. Al-Marzouki, *Fe-based soft magnetic amorphous alloys with high saturation magnetization above 1.5 T and high corrosion resistance*, **Intermetallics**, **Vol. 54** (2014), pp. 169-175.
- [14] G. Herze, *Soft magnetic nanocrystalline materials*, **Scripta Metallurgica et Materialia**, **Vol. 33** (1995), pp. 1741-1756.
- [15] B. Jeź, M. Nabiałek, P. Pietrusiewicz, K. Gruszka, K. Błoch, J. Gondro, J Rzącki., M. M. A. B. Abdullah, A. V. Sandu, M. Szota, K. Jeź, A. Sałagacki, *The structure and properties of rapid cooled Iron based alloy*. **IOP Conf. Series: Materials Science and Engineering**, **Vol. 209** (2017), pp. 12-23.
- [16] B. Jeź, *Modification of Curie temperature in bulk amorphous alloys as a result of their annealing*, **Revista de Chimie**, **Vol. 68(8)** (2017), pp. 1903-1907.
- [17] M. Szota, *Effect of small addition of cobalt on magnetic properties and internal stresses sources in the form of free volumes and pseudo-dislocation dipoles in Fe₇₈Co_xSi_{11-x}B₁₁ (x = 0 or 2) alloys*, **Arch. Metall. Mater.**, **Vol. 60(4)** (2015), pp. 3095-3100.
- [18] K. Błoch, M. Nabiałek, *The influence of heat treatment on irreversible structural relaxation in bulk amorphous Fe₆₁Co₁₀Ti₃Y₆B₂₀ alloy*, **Acta. Phys. Pol. A**, **Vol. 127** (2015), pp. 442–444.

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