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Hard Magnetic Properties of Mn-Al-C Alloys Doped with Titanium and Iron

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Abstract

As part of the study of hard magnetic alloys on the basis of manganese, the impact of titanium and iron in the range up to 5 wt. % on the magnetic hysteretic properties of the 72Mn–27Al–1C hard magnetic alloy is considered. It is shown that upon alloying to 2 wt. %, both Ti and Fe increase the magnetic hysteretic properties of the alloy, and then reduce them. On the 72Mn–27Al–1C–2Ti(Fe) alloys, the maximum energy product $(BH)_{max}$ = 12 kJ/m^3 (11,5·10^6 G·Oe) was obtained with a residual induction of B_r up to 0.36 T (3600 G) and the coercive force H_{cB} of 110–120 kA/m (1400–1500 Oe), which corresponds to the best Japanese data for these alloys.

Keywords

Hard magnetic alloy; coercive force; residual induction; maximum energy product; induction melting; hysteresis graph; manganese; aluminum; carbon.

Introduction

Mn-Al hard magnetic alloys were intensively studied in the 1960s and 1970s because of their unquestionable advantages, such as low cost of the melting stock and a sufficiently high level of magnetic hysteresis and mechanical properties (primarily because of high values of coercive force H_c of more than 120 KA/m) [1]. However, the emergence of new hard magnetic materials based on rare-earth metals (**REM**) $SmCo_5$, Sm_2Co_{17}, and especially $Nd_2Fe_{14}B$, hard magnetic alloys based on the Fe–Cr–Co made researchers less interested in Mn-Al hard magnetic alloys. At the beginning of this century interest in Mn–Al alloys began to return, but mainly at the level of experts [2–4].

Two-component (Mn–Al) alloys have relatively low magnetic hysteresis properties: residual induction Br ~ 0.26 T, the coercive force H_{cB} ~ 75 kA/m and the maximum energy product $(BH)_{max}$ ~ 4 kJ/m^3. Castings of two-component alloys are well suited for turning, but they contain cracks and therefore it is difficult to prepare qualitative samples for research [5]. Carbon is the most effective alloying element, which allows increasing $(BH)_{max}$ of two-component alloys to 10–11 kJ/m^3 [6]. In Mn–Al–C magnetic alloys, after casting and cooling at a rate below critical, cracks are usually not formed, the alloy itself gets harder than two-component alloys and can also be turned. Phase transformations associated with the formation of a high-coercive state occur at a slow rate, which makes it possible to better control the process of their heat treatment. Further increase in the magnetic hysteresis properties of the Mn–Al alloys is attributed both to the development of new technologies for their processing (for example, hot plastic deformation) and to the additional alloying of tree-component (Mn–Al–C) alloys by different elements.

The objectives of this work, which is one of the few recent experimental works on this topic, were, firstly, the desire to repeat the results of Japanese researchers on three-component (Mn–Al–C) alloys and, secondly, to investigate the effect of additional alloying of three-component alloys with titanium and iron on their magnetic hysteresis properties. The choice of elements for additional doping of three-component (Mn–Al–C) alloys was due to the fact that, according to the published data, the presence of titanium in the amount of 1–2 % in two-component alloys slightly increases their plastic properties and saturation magnetization, while iron can possibly increase the saturation magnetization of the three-component alloy and increase the residual induction.

Experimental. Materials and methods

Three-component

70Mn–29Al–1C, 71Mn–28Al–1C, 72Mn–27Al–1C

and four-component

72Mn–27Al–1C + (1–5)Ti,

72Mn–27Al–1C + (1–5)Fe

alloys (mass %) were investigated. The alloys were melted in an induction five-kilogram furnace in an atmosphere of technically pure argon in an alundum crucible with casting into quartz tubes 13–15 mm in diameter, into sand molds, or into shell molds. To prevent cracking in castings, the molds were heated to 800 °C. The molten metal easily overheats, has a high enough fluidity and is well poured into the molds. When the melt solidified, a large shrinkage shell was formed. While melting, charge materials industrial purity: Mp0 manganese, AB0 aluminum, carbon in the form of powder graphite electrode, iron of commercial quality, TG100 titanium. It should be noted that carbon promotes columnar crystallization of the melt and leads to a strong growth of grain in the casting. When doping tree-component (Mn–Al–C) alloy with titanium and iron, to every 100 wt. of the alloy were added from 1 to 5 wt. % of titanium and iron. After extraction from the molds, the cast rods were cut with an abrasive disc into samples of 15–20 mm in length and grinded on a centreless grinding machine. Magnetic hysteresis properties (residual induction B_r, coercive force H_{cB} and H_{cM}, maximum energy product $(BH)_{max}$) were measured on the Permagraph L. Heat treatment was carried out in laboratory muffle furnaces as follows: homogenization at 1100 °C for two hours, hardening in a heated to 50–60 °C engine oil and tempering at 600 °C for an hour.

Table 1

Magnetic hysteresis properties of three-component (Mn–Al–C) hard magnetic alloys

Alloy	B_r, T	H_{cB}, kA/m	$(BH)_{max}$, J/m^3
70Mn–29Al–1C	0.32	95	7.6
71Mn–28Al–1C	0.30	103	8.1
72Mn–27Al–1C	0.33	112	10.0

Results and discussion

Table 1 shows the results of measuring the magnetic hysteresis properties of three-component (Mn–Al–C) hard magnetic alloys.

Fig. 1 and 2 show the graphs of the dependence of the maximum energy product $(BH)_{max}$, depending on the content of titanium and iron, respectively.

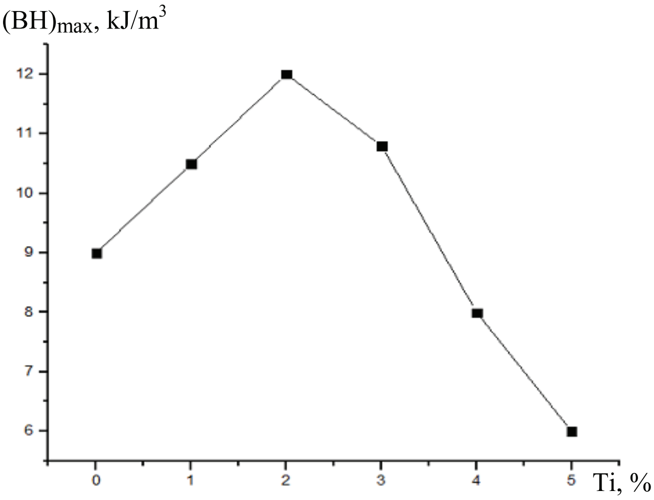

Fig. 1. Dependence of the maximum energy product $(BH)_{max}$ of the four-component (72Mn–27Al–1C–Ti) hard magnetic alloy

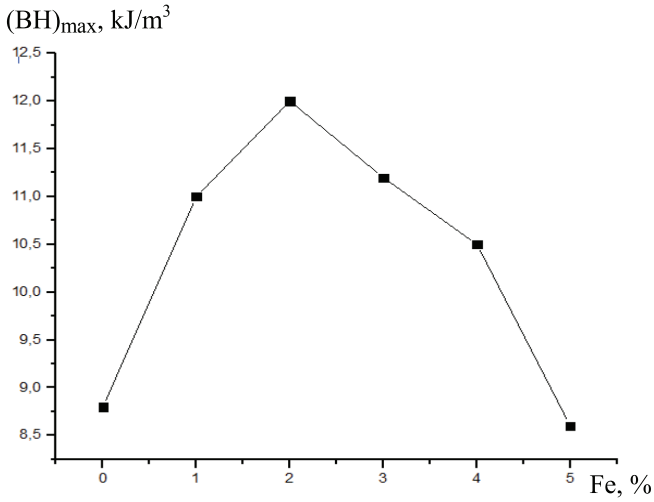

Fig. 2. Dependence of the maximum energy product $(BH)_{max}$ of the four-component (72Mn–27Al–1C–Fe) hard magnetic alloy

As can be seen from the data in Fig. 2 and 3, Ti and Fe act almost identically and the magnetic hysteresis properties of the three-component (72Mn–27Al–1C) hard magnetic alloy, first increasing them upon doping to 2 wt. %, and then decreasing. In the 72Mn–27Al–1C–2Ti (Fe) alloys, the coercive force of H_{cB} ranges from 110 to 120 kA/m, and the residual induction ranges from 0.32 to 0.36 T.

Conclusion

The experimental data obtained in this work on the effect of doping of three-component (Mn–Al–C) hard magnetic alloys with titanium and iron on their magnetic hysteresis properties are within the limits of natural experimental discrepancies and confirm the data of Japanese patents on these alloys.

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