Rev.Adv.Mater.Sci. 18(2008) 545-548

MAGNETIC PROPERTIES OF Co DOPED FINEMET AT ELEVATED TEMPERATURE

Aleksandra Kolano-Burian[1], Roman Kolano[1], Tadeusz Kulik[2] and Jarosław Ferenc[2]

[1]Institute of Non-Ferrous Metals, Sowińskiego 5, 44-101 Gliwice, Poland
[2]Warsaw University of Technology, Fac. Mater. Sci. and Eng. Wołoska 141, 02-507 Warsaw, Poland

Received: March 29, 2008

Abstract . The aim of this research was to investigate the effect of elevated temperatures on soft magnetic properties of the Co-modified Finemet type alloys designed for high-temperature and high-frequency applications in power electronics. The Finemet type alloys modified by Co were subjected to thermo-magnetic treatment in an external magnetic field of 160 kA/m, followed by ageing for up to 150 hours at the temperatures of 200 and 300 °C, and their AC magnetic properties have been measured. For selected alloys dependence of soft magnetic properties on temperature up to 350 °C have also been measured. The obtained results confirmed that partial substitution of Fe with Co in Finemet type alloys improves their high-temperature behaviour thus making them suitable for functional application in power electronic equipment.

1. INTRODUCTION

Considerable advances have been made recently in developing new types of soft magnetic alloys for high temperature and high frequency applications [1-6]. The partial substitution of Fe by Co in nanocrystalline Finemet–type alloys allows the extension of their outstanding soft magnetic properties to elevated temperatures [4,7]. Co addition not only increases the Curie temperature of an amorphous matrix, increasing the decoupling temperature, but also makes the material suitable for magnetic field annealing by Fe-Co pair ordering effect. These materials have a two-phase microstructure, in which ferromagnetic nanocrystals are surrounded by residual ferromagnetic amorphous matrix.

The aim of this research was to study the effect of the elevated temperature on soft magnetic properties of Finemet modified with Co.

2. EXPERIMENTAL

The $Fe_{73.5-x}Co_xCu_1Nb_3Si_{13.5}B_9$ (x = 0 - 58.8) amorphous ribbons were fabricated by melt-spinning technique. Before casting, chemical composition of the master alloys was examined using X-ray microanalyser. Amorphousness of the ribbons was also checked by means of X-ray diffractometry. The samples in a form of toroidal cores were prepared and annealed for 1 hour at the optimal temperature [5] for each particular composition in an argon atmosphere, in an external magnetic field H_T of 160 kA/m applied in parallel to the core axis.

Ageing was conducted in a resistance furnace for 150 hours at two temperatures, 200 and 300 °C, without a protective atmosphere. The AC magnetic properties (coercivity H_c, power losses P_s and magnetic permeability μ) of the cores were measured at a frequency of 50 kHz using a computerized hysteresis loop tracer (REMACOMP C-100).

Corresponding author: Aleksandra Kolano-Burian, e-mail: olak@imn.gliwice.pl

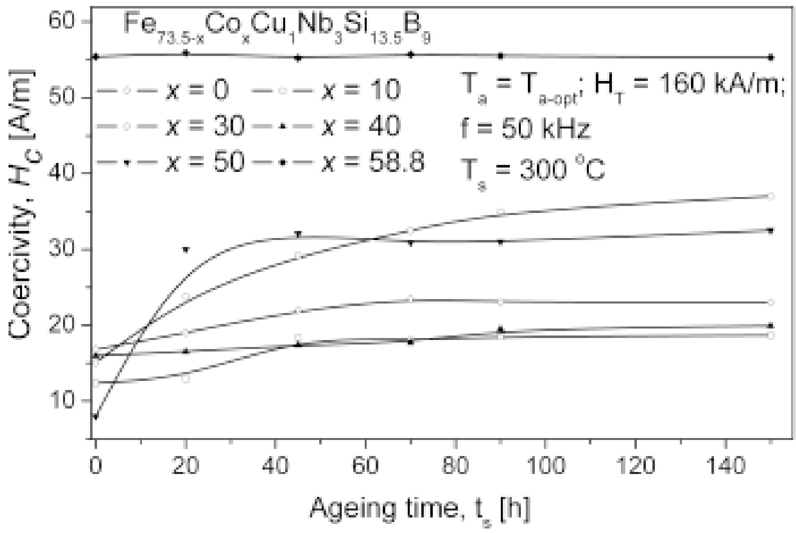

Fig. 1. The dependence of coercivity H_c on the time of ageing conducted at 300 °C for the alloys treated in a transverse magnetic field, at the frequency of 50 kHz at room temperature.

The measurements were made at an elevated temperature for three selected $Fe_{73.5-x}Co_xCu_1Nb_3Si_{13.5}B_9$ alloys (x = 0, 40, and 58.8). The cores were inserted into special ceramic boxes. Temperature in the furnace was controlled automatically, and after reaching the pre-set value it was maintained at the same level with the accuracy up to ± 3 °C. The temperature measurements were also made directly on the surface of the samples. The AC magnetic properties (magnetic induction B_m, coercivity H_c, power losses P_s and magnetic permeability μ) at the frequencies of 50 Hz, 50 kHz, and 100 kHz and at the temperatures of 100, 200, 300, and 350 °C have been determined.

3. RESULTS AND DISCUSSION

It was found that ageing conducted at the temperature of 200ºC did not result in irreversible changes of the magnetic properties (H_c, P_s, and μ) of the alloys studied, since after cooling them down to room temperature, these properties returned to their initial values. However, in the case of ageing conducted at 300 °C H_c and P_s were increasing with ageing time for the alloys $0 \leq x \leq 40$, and the changes were irreversible. The behaviour of the alloy x = 58.8 was different since the changes of its magnetic properties were insignificant and they were returning back to the initial room temperature values. The dependence of coercivity H_c measured at the frequency of 50 kHz on the time of ageing conducted at 300 °C has been illustrated in Fig. 1.

The similar behaviour was observed in the case of permeability μ, which for the alloy x = 58.8 aged at the temperatures of 200 and 300ºC maintained at the unchanged level. The greatest changes resulting from ageing at 300ºC exhibited the alloys x = 0 and 10, in which μ decreased significantly already after 20 hours (from 34100 to 19000 for the alloy x = 0 and from 22000 to 13000 for the alloy x = 10), whereas much smaller drop of μ was observed for the alloys x = 30 and 40.

The examination of magnetic properties of the materials at elevated temperatures is of a great practical importance. Therefore, the $Fe_{73.5-x}Co_xCu_1Nb_3Si_{13.5}B_9$, alloys, at x = 0, 40, and 58.8, were selected as potentially suitable for an application in power electronic equipment operating at elevated temperatures and at high-frequency magnetising fields, whereas the alloy without Co addition was taken as a reference. Their dynamic magnetic properties were measured within a temperature range up to 350 °C at the magnetising field frequencies of 50 Hz, 50 kHz, and 100 kHz. At the temperature increase to over 350 °C, a drop in the magnetic induction was observed to such a low level, which made practical use of the material impossible. It was found that the induction B_m of

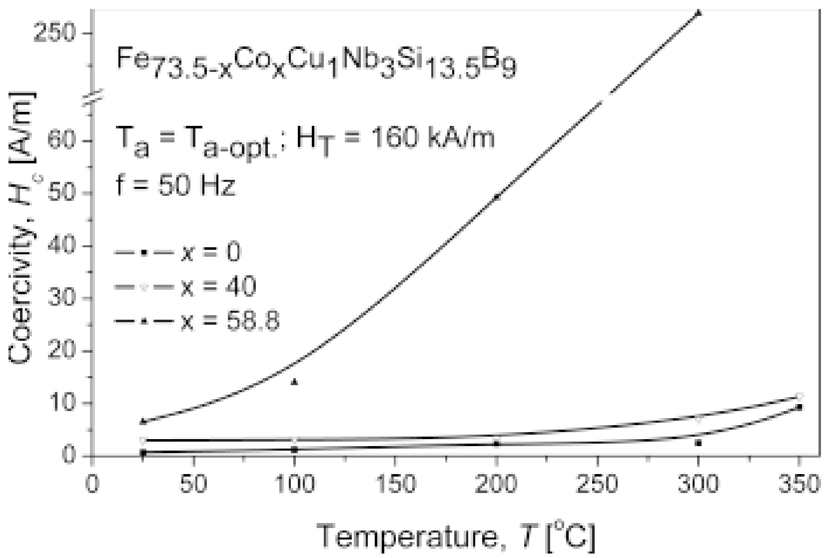

Fig. 2. The dependence of coercivity H_c on temperature at the frequency of 50 Hz for selected alloys.

the alloy x = 58.8 decreased rapidly already at the temperature over 200 °C and reached only 0.08 T at 350 °C. For the alloys x = 0 and 40, however, the value of B_m was decreasing slowly and in a similarly stable manner up to the temperature of 200 °C. Over that temperature, the value of B_m for the alloy without Co started to drop rapidly, whereas the drop for the alloy x = 40 was still slow. At 350 °C, the value of B_m for the alloy x = 0 was 0.39 T, and for the alloy x = 40 – 0.64 T. Temperature dependence of coercivity H_c for the alloys x = 0 and 40 was also stable, showing a slowly growing trend as the temperature exceeded 200 °C. In the case of the alloy x = 58.8, however, H_c increased very rapidly already over 100 °C so that at 300 °C it reached 266 A/m. The dependence of H_c on temperature at the frequency of 50 Hz is shown in Fig. 2. At magnetising field frequencies of 50 and 100 kHz the temperature dependence of H_c was of a similar character. The dependence of P_s on temperature measured at 50 and 100 kHz had the same character as dependence of H_c.

From the point of view of potential applications, it is important to determine temperature dependence of the magnetic permeability. The measurements showed that magnetic permeability of the alloy x = 0 drops rapidly with the temperature increase thus making the material unsuitable for application in power electronics. The alloys x = 40 and x = 58.8 are characterised by almost constant and relatively low magnetic permeability (μ = 8000 - 5 500 for x = 40 and μ = 850 for x = 58.8) over a wide frequency range. However, the magnetic permeability of the alloy x = 58.8 decreases rapidly at the temperatures over 200 °C and therefore, it can be applied in power electronic equipment operating up to this temperature. Such behaviour of the alloy x = 58.8 is closely related with its Curie temperature, which equals to 360 °C. Better properties has the alloy x = 40, which still at 350 °C exhibits sufficiently good magnetic properties to make it suitable for an application in power electronic devices operating at significantly higher temperatures, better than those of the alloy x = 58.8.

4. CONCLUSIONS

The effect of the temperature on soft magnetic properties of the Finemet type alloys modified with Co was investigated. It was found that ageing at the temperature of 200 °C resulted in reversible changes of the main magnetic properties of all the alloys examined, whereas in the case of ageing conducted at 300 °C the coercivity and power losses were increasing with ageing time and were irreversible except for the alloy containing 58.8 at.% Co. The permeability of the latter alloy was also not affected by the temperature increase, then that of the alloy with 40 at.% Co showed only slight decrease at the temperature of 300 °C, whereas the alloys with lower Co content exhibited a significant drop in permeability during ageing at 300 °C.

The measurements at an elevated temperature showed that the magnetic permeability of the alloy $x = 0$ drops rapidly with the temperature increase, thus making the material unsuitable for application in power electronics. The alloys $x = 40$ and $x = 58.8$ are characterised by almost constant and relatively low magnetic permeability over a wide frequency range. It has been concluded, that the alloys containing 40 and 58.8 at.% Co, are the most suitable for an application in power electronic equipment operating up to 350 °C and 200 °C, respectively.

ACKNOWLEDGEMENT

Aleksandra Kolano-Burian is the holder of the scholarship of the Foundation for Polish Science.

REFERENCES

[1] M. Ohnuma *et al.,* In: *Proceedings of the 22nd International Symposium on Material Science 341* (2001).

[2] C. Gomez-Polo // *Physical Review B* **65** (2001) 024433.

[3] Y. Yoshizawa *et al.* // *Scripta Mater.***48** (2003) 863.

[4] L.K. Varga *et al.* // *JMMM* **272-276** (2004) 1506.

[5] A. Kolano-Burian *et al.* // *JMMM* **272-276** (2004) 1447.

[6] R. Kolano *et al.* // *Mater. Sci. Eng. A* **375-377** (2004) 1072ţ

[7] J. S. Blazquez *et al.* // *J. Phys. : Condens. Matter* **15** (2003) 3957.