Modelling the influence of temperature on the magnetic characteristics of $Fe_{40}Ni_{38}Mo_4B_{18}$ amorphous alloy for magnetoelastic sensors

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Abstract

This paper presents results of the modelling of the influence of temperature on the magnetic characteristics of $Fe_{40}Ni_{38}Mo_4B_{18}$ amorphous alloy in as quenched state. For modelling Jiles-Athertos-Sablik model was used. Evolutionary strategies together with Hook-Jevies optimization were applied for calculation of model's parameters on the base of experimental results. To provide sufficient (from technical point of view) agreement between model and experimental data, the extension of Jiles-Athertos-Sablik model was proposed. This extension connect model's parameter k, describing magnetic wall density, with magnetic state of the material. Good agreement between experimental data and modelling confirms, that extended Jiles-Atherton-Sablik model creates the possibility of modelling of thermo-magnetic characteristics of cores of magnetoelastic sensors.

1. Introduction

Soft magnetic materials such as amorphous alloys are commonly used as a cores of the mechatronic inductive components such as cores of magnetoelastic sensors or transformers as well as inductive elements of switching mode power supplies [1]. It should be indicated, that magnetic characteristics of amorphous alloys depends significantly on temperature. This phenomenon has significant technical consequences. Functional properties of inductive component with soft magnetic material core may change during its operation, especially if it is heated. It may cause malfunction or damage of mechatronic device.

For this reason knowledge about the influence of temperature of magnetic characteristics of amorphous alloys is very important from practical point of view. On the other hand complete model describing of temperature dependences of inductive components was still not presented.

Among four main models of magnetization process [2] only Jiles-Atherton-Sablik (J-A-S) model gives some possibility of modelling the temperature dependences of magnetic characteristics. Unfortunately, original J-A-S model do not create possibility of modelling the different magnetic hysteresis loops of the same material, with one set of model's parameters [3]. This is significant barrier in practical application of the modelling of the magnetic characteristics. Presented extension of the J-A-S model gives possibility of overcoming of this barrier.

2. Extension of the model

Total magnetization M of the soft magnetic material may be presented as the sum of reversible magnetization M_{rev} and irreversible magnetization M_{irr} [4]. In the J-A-S model the irreversible magnetization M_{irr} is given by the equation (1) [5]:

$$\frac{dM_{irr}}{dH} = \delta_M \frac{M_{an} - M_{irr}}{\delta \cdot k} \tag{1}$$

where parameter δ describes the sign of $\frac{dH}{dt}$ and k quantifies average energy required to break pining site. Parameter δ_M guarantees the avoidance of unphysical stages of the J-A-S model for minor loops, in which incremental susceptibility becomes negative [6]. Other parameters of J-A-S model, such as a, c, α, M_s, t and K_{an} are closely connected with physical properties of the material [4]. As a result J-A-S model can be used for physical analyses of the magnetization process.

It was indicated [4] that the J-A-S model parameter k changes during the magnetization process, due to change of the average energy required to break pining site [7]. On the other hand, previously presented extension of the J-A-S model [3], where the J-A-S model parameters change in the function of magnetizing field H, seems unjustified from the physical point of view. Parameter k should be connected with magnetic state of the material (described by magnetization M), not with magnetizing field H [8].

To overcome original J-A-S model limitation it should be extended by incorporation of connection between magnetic state of the material (describet by its magnetization *M*) and model's parameter *k*. Parameter *k* can be described by the vector of 3 parameters k_0, k_1 and k_2, and *k* is given as [8]:

$$k = k_0 + \frac{e^{k_2 \cdot (1-|M|/Ms)} - 1}{e^{k_2} - 1} \cdot (k_1 - k_0) \tag{2}$$

In the dependence given by equation (2), parameter k_0 determines the minimal value of *k*, parameter k_1 determines maximal value of *k* and k_2 is shape parameter.

4. Results

Experimental measurements were carried out on the ring-shaped sample made of $Fe_{40}Ni_{38}Mo_4B_{18}$ amorphous alloy in as-quenched state. Stable temperature was achieved by criostat, whereas magnetic hysteresis loops were measured by hysteresisgraph HBPL. Parameters of J-A-S model were determined during the optimization process. For optimization, the evolutionary strategies [9] together with Hook-Jevis gradient optimization were applied .

In figure 1 the experimental results (marked as dots) together with results of the modelling (marked as solid lines) are presented. One set of J-A-S model's parameters was determined for three different hysteresis loops measured in given temperature. Dependence of the J-A-S model parameters on temperature is presented in Table 1.

Results presented in figure 1 shows very good agreement between extended J-A-S model and experimental results. To confirm this agreement r^2 coefficient was calculated between model and experimental results. Due to the fact, that r^2 is higher than 0.99, it was indicated that 99% of total variation of experimental results is described by the extended J-A-S model [10].

It should be indicated, that one set of parameters enable modelling of different hysteresis loop at given temperature. If temperature changes, new set of parameters should be calculated. On the other hand, on the base of table 1, temperature dependence of J-A-S parameters can be interpolated for different temperatures from 20 °C up to 120 °C, as well as extrapolated for higher or lower temperatures.

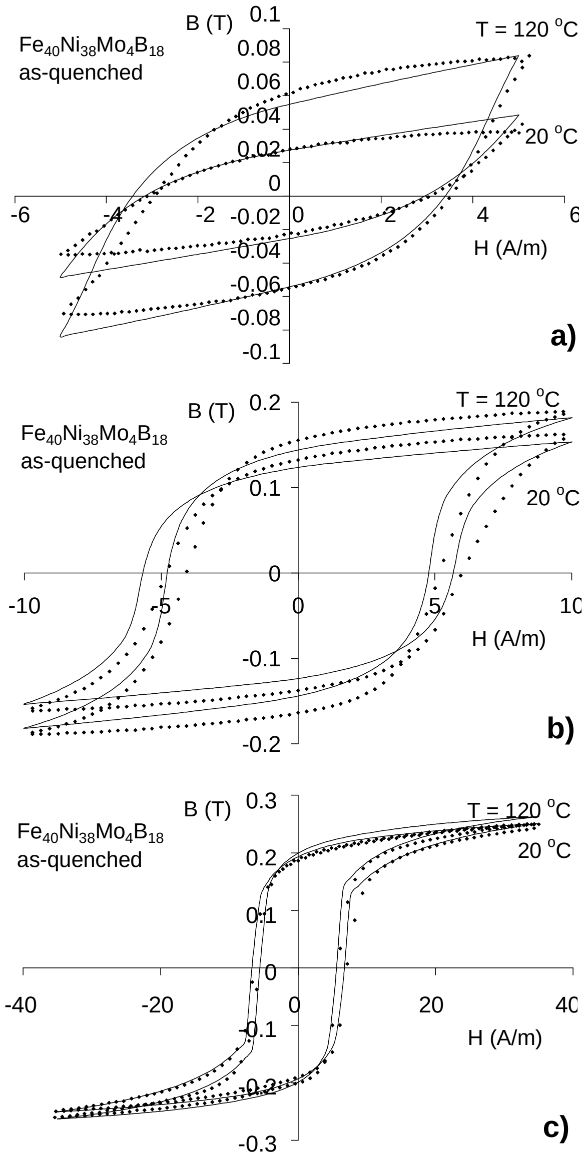

Fig. 1. Results of the modelling the influence of temperature on the shape of hysteresis loop achieved for one set of parameters of extended J-A-S model for magnetizing field Hm (♦ experimental results, — results of the modelling): a) 5 A/m, b) 10 A/m, c)35 A/m

Table 1. Results of the modelling temperature dependence of magnetic characteristics according to extended Jiles-Atherton-Sablik model.

Temp. (^{o}C)	a A/m	k_0 A/m	k_1 A/m	k_2	c	$M_s \cdot 10^{-5}$ A/m	$\alpha \cdot 10^4$	K_{an} J/m^3	t
20	112.7	467.6	11.12	-8.26	0.466	2.97	2.39	547	0.80
40	97.3	387.5	11.46	-8.66	0.469	3.11	1.93	1 522	0.80
60	93.6	454.4	11.95	-8.97	0.494	3.20	1.83	1 769	0.80
80	92.1	830.6	11.63	-9.18	0.501	3.23	1.78	1 812	0.80
100	90.3	1238.5	11.35	-9.22	0.506	3.21	1.77	1 731	0.80
120	85.5	1905.4	9.69	-11.1	0.480	3.03	1.75	813	0.80

5. Conclusion

One set of parameters of extended J-A-S model enables modelling of the hysteresis loops of amorphous alloys for different value of maximal magnetizing field. In such a case over 99% of total variation of experimental results is described by the extended J-A-S model.
Presented temperature dependences of J-A-S model parameters enables modelling of magnetic hysteresis loops for temperatures from 20 ^{o}C up to 120 ^{o}C. Such model may be very useful for determining the temperature dependence correction factors for magnetoelastic sensors or magnetic sensors (e.g. such as fluxgates) .

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