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Two phase magnetic material modelling using two dimensional extended Preisach model

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Extended Preisach model parameters can be strongly related to microstructural properties of material . It can also include real physical magnetization mechanisms such as domain wall motion and domain rotation. This paper shows that Preisach model is able to anticipate different phases in material structure. Existence of different phases in the material are due to thermal treatment, which is used to improve magnetic properties of amorphous alloys. Model was verified using ring shaped cores made of bilayered amorphous ribbons, which served as a physical model of the loosely coupled two phase ferromagnetic material with distinct magnetic properties.

K e y w o r d s: two-phase magnetic materials, Preisach model, amorphous alloys

1 Introduction

New high permeability amorphous and nanocrystalline materials exhibits high anisotropy. Core shapes used in fluxgate sensors and power conversion devices cannot ensure field homogenous direction. That causes not homogenous angles between material easy axis and its magnetization. For that reason magnetization characteristic of material, measured by producer can differ from characteristic of particular core. Moreover, review of recent literature shows emergence of peanut-shaped magnetic hysteresis, which is due to distinct, loosely coupled phases in the given magnetic material [1-4] . However, there are no readily available hysteresis models which could be applied for such results. The extended Preisach model proposed in this paper is meant for filling this gap.

2 Theoretical background

Preisach model of hysteresis assumes stable distribution of energy stored and dissipated in material. It correlates to both statistical and energetic models of hysteresis. Preisach model was developed to many different extensions, but application of the Preisach plane is their joint feature.

Preisach plane describes distribution of switching operators for two coordinates: increasing α and decreasing β magnetic field. In this research additional axis were used. They are rotated 45 degrees to field axis: $\zeta\colon\ \alpha=\beta$, which describes interaction field and $\kappa\colon\ \alpha=\beta$, which describes coercivity field. Operators represent regions of material, which exhibit the same values of coercivity. Distribution can be calculated form set of hysteresis loops for different field amplitudes. Distribution can be also fitted using two dimensional Gaussian or other probability density function. In this research combination of Cauchy distribution for interaction field and lognormal distribution for coercive field was used. Lognormal distribution which represent only positive values, is physically more justified than Gaussian distribution, because material can only dissipate energy. Switching field distribution can be described using equation

$$\mu(\zeta,\kappa)=A\frac{\exp\left(-\dfrac{(\ln\kappa-\ln\kappa_0)^2}{2\sigma_\kappa^2}\right)}{\kappa\sigma_\zeta\sigma_\kappa\sqrt{2\pi}\left(1+\dfrac{\zeta^2}{\sigma_\zeta^2}\right)}. \tag{1}$$

In previous research two dimensional [5] and three [6] dimensional Praisach models were developed. One Preisach plane is enough to simulation scalar hysteresis. To model distribution of magnetization vectors for different angles more Preisach planes are needed, depends on expected angular resolution. Mean magnetization is sum of magnetization vectors for each angle. Integral of Preisach plane can have positive or negative values.

$$\vec{M}=\int_0^{2\pi}\vec{m}(\theta)\mathrm{d}\theta. \tag{2}$$

For every cross-section plane two opposite Preisach planes exist. They represent domains oriented in the same angle but with opposite values. For magnetic materials three kind of magnetization mechanisms can be observed: domain wall bowing, domain wall motion and domain rotation. Domain wall bowing will be treated as reversible kind of domain wall motion

$$\vec{m}(\theta)==\iint_{\alpha\geq\beta}\mu(\alpha,\beta)\gamma_{\alpha\beta}[\vec{H}_{||}](\theta)\vec{\chi}_{\alpha\beta}[\vec{H}_\chi](\theta)\mathrm{d}\alpha\mathrm{d}\beta. \tag{3}$$

In domain wall movement process main role play parallel component of magnetic field vector

$$H_{||}(\theta)^0=|\vec{H}|\,\cos\theta \tag{4}$$

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When domain wall moves, domains oriented in magnetic field direction growing and domain in opposite direction shrinking proportionally.

Domain wall movement operator can be described as

$$\gamma_{\alpha\beta}[\vec{H}_{||}](\theta) = \begin{cases} +1: & H_{||}(\theta) > \alpha \\ \text{previous values}: & \beta < H_{||}(\theta) < \alpha \\ -1: & H_{||}(\theta) < \beta \end{cases} \tag{5}$$

Domain rotation process occurs for higher magnetic field values than domain wall motion. The magnetic field value, for which rotation process starts depends on saturation field, coercive field and angle between domain orientation and external magnetic field vector [7]

$$\begin{aligned} H_\chi(\theta) = (\kappa_0 - |H|\frac{\kappa_0}{H_{\text{sat}}}|\sin\theta|)\, a_\varphi + \\ +|H|\frac{H_{\text{sat}} - \kappa_0}{H_{\text{sat}}} a_\varphi |\cos\theta| \end{aligned} \tag{6}$$

where H_{sat} is the saturation field.

Domain rotation is reversible process. It can be described by rotation operator, which value is 1, when domain is parallel to given direction and zero for different direction

$$\vec{\chi}_{\alpha\beta}[\vec{H}_\chi](t) = \begin{cases} 0: & H_\chi(\theta) > \alpha \bigvee H_\chi(\theta) < \beta \\ 1: & H_\chi(\theta) < \alpha \bigwedge H_\chi(\theta) > \beta \end{cases} \tag{7}$$

To take into account two-phase behavior of the sample, the model was modified into η-factor dependent sum of two Preisach loops

$$\begin{aligned} \mu(\zeta,\kappa) = A\eta \frac{\exp\left(-\dfrac{(\ln\kappa - \ln\kappa_0)^2}{2\sigma_\kappa^2}\right)}{\kappa\sigma_\zeta\sigma_\kappa\sqrt{2\pi}\left(1 + \dfrac{\zeta^2}{\sigma_\zeta^2}\right)} + \\ +A'\eta' \frac{\exp\left(-\dfrac{(\ln\kappa - \ln\kappa_0')^2}{2\sigma'^2_\kappa}\right)}{\kappa\sigma'_\zeta\sigma'_\kappa\sqrt{2\pi}\left(1 + \dfrac{\zeta^2}{\sigma'^2_\zeta}\right)} \end{aligned} \tag{8}$$

3 Two-phase magnetic samples

The samples simulating loosely coupled two-phase magnetic materials were prepared from amorphous ribbons wound together as ring-shaped cores. Sample materials were Metglas produced:

- 2605CO $Fe_{67}Co_{18}Si_1B_{14}$
- 2714A $Co_{66}Fe_4Ni_1Si_{15}B_{14}$

The actual proportion of the material in the sample cross-section was calculated from ribbon lengths and thickness.

4 Measurement and modelling

The measurement of samples hysteresis loops was performed on the hysteresisgraph developed in our institute [8], calibrated with Magnet-Physic Gmbh produced standards. First, the loops for sample 1 and 5, that is single-phase samples, were measured with 1 Hz 50 A/m sinusoidal magnetizing field. The measurement results are given in Fig. 1. Resulting loops were approximated to the anisotropic Preisach model, for given material parameters determination.

Table 1. Sample composition - % of magnetic core cross-section

Sample	2605CO	2714A
1	100	0
2	82	18
3	60	40
4	34	66
5	0	100

Table 2. Model based sample composition assessment % of

	2605CO		2714A	
Sample	Actual	Model	Actual	Model
2	82	68	18	15
3	60	42	40	28
4	34	29	66	66

Next, the two-phase samples were measured, resulting in characteristic peanut hysteresis loop. The model (4) was then fit to the measurement data, basing on the parameters of sample 1 and 5 as starting points. The measurement results and model fit are presented in Fig. 2 to Fig. 4.

Good agreement between the model and measurement is seen in Fig. 2, whereas in Fig. 3 and Fig. 4 growing differences in the horizontal axis can be seen. It is probably the effect of magnetic coupling between the ribbons in the core, changing the effective magnetizing field in the sample.

Moreover, the model derived core composition differs from actual % values, and the results are more qualitative than quantitative.

5 Conclusions

Good model compatibility with measurement results was demonstrated. The developed extended Preisach model is fully vector and anisotropic. It can also be modified to serve as a two-phase hysteresis model with good results for semi-independent phases. The model considers the physical mechanisms of magnetization, but it is difficult to perform complete verification. Future works will be focused to consider the magnetic coupling of the phases, for better fit with the measurement results.

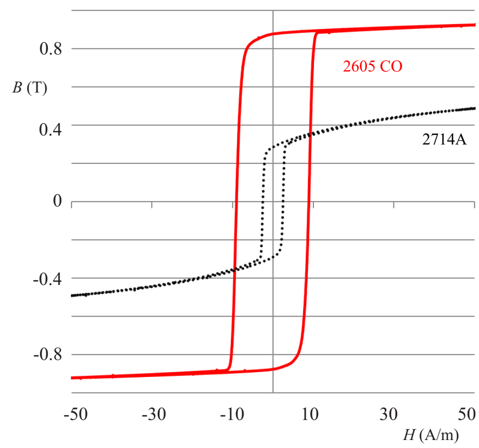

Fig. 1. $B(H)$ curve of 2605Co ($Fe_{67}Co_{18}Si_1B_{14}$) and 2714a ($Co_{66}Fe_4Ni_1Si_{15}B_{14}$) materials

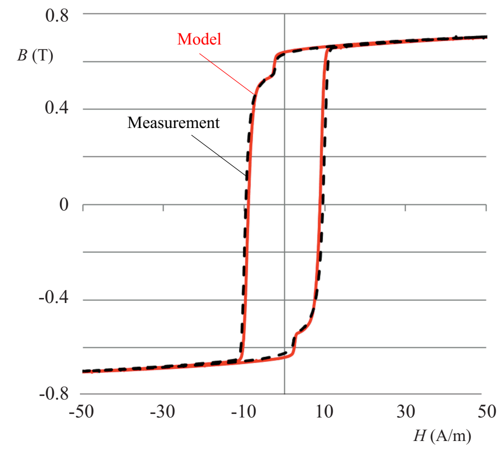

Fig. 2. $B(H)$ curve of sample 2 (82% of 2605 Co)and model fit

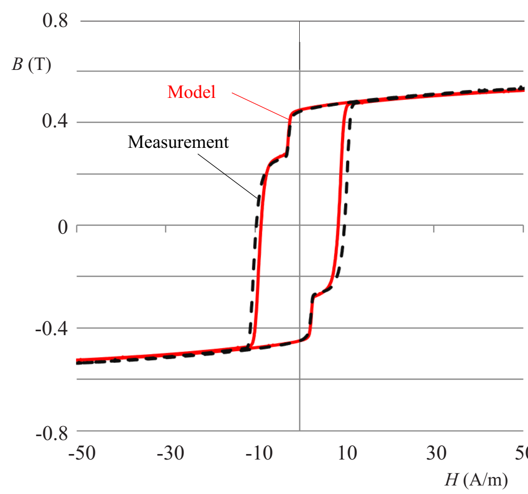

Fig. 3. $B(H)$ curve of sample 3 (60% of 2605Co) and model fit

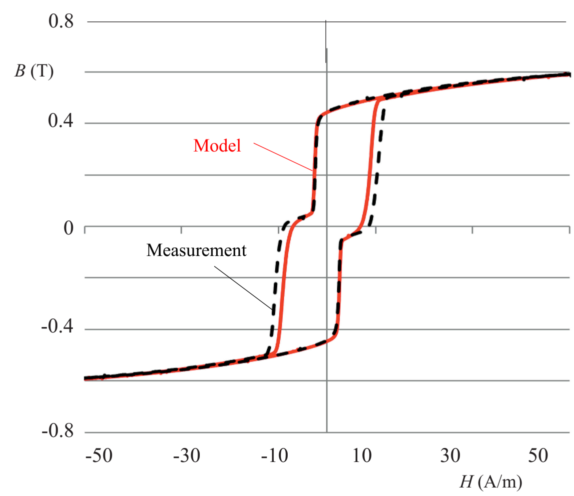

Fig. 4. $B(H)$ curve of sample 4 (34% of 2605Co) and model fit

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