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Ram in Soft Magnetic $Fe_{58}Co_{25}Nb_7Cu_1B_9$ Alloy

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Abstract: ***On the basis of structural and magnetic investigations of $Fe_{58}Co_{25}Nb_7Cu_1B_9$ alloy, we have reported the comparison between the applicability of two approaches: i) Néel's theory of domain wall pinning and ii) Random anisotropy model for optimally crystallized soft magnetic materials as proposed by Herzer. In the domain wall pinning approach the random fluctuations in the energy of domain wall moving through amorphous matrix containing nanocrystallites gets averaged over a spatial scale that is determined by the amorphous phase. Whereas in the approach proposed by Herzer, correlation length scale, over which the averaging of random anisotropies takes place, is governed by the nanocrystalline phase. In the present case where the volume fraction of nanocrystalline phase is rather low and the average length of the inter-granular amorphous phase is comparable to the average grain size, it is observed that the averaging of the random magneto crystalline anisotropies is not effective over the domain wall thickness determined by the nanocrystalline phase, while the amorphous phase is governing the correlation length scale that is determining the observed magnetic behavior.***

I. INTRODUCTION

Gradually devitrified soft magnetic nanocrystalline materials offer unique opportunity to study the physics of the magnetization processes [1-5]. Soft magnetic behaviour of amorphous and nanocrystalline alloys can be understood by introducing a correlation length which can be identified with the ferromagnetic exchange length over which the magnetic moments are coupled via exchange interaction. Disorder in the structure gives rise to randomness in the interaction of magnetic moments that influences the magnetic properties strongly. In the present work, based upon the structural and magnetic investigations of $Fe_{58}Co_{25}Nb_7Cu_1B_9$ alloy, we have compared the two limiting approaches (DW and RAM) based on the averaging of random anisotropies over respective correlation length scales through magnetically coupled regions leading to soft magnetic behavior [4, 5, and 6].

II. EXPERIMENTAL DETAILS

Amorphous ribbons (~20 μm thick and 10 mm wide) of nominal composition $Fe_{58}Co_{25}Nb_7Cu_1B_9$ were annealed (370 - 430 ^oC) for 30 min. in inert atmosphere. XRD measurements on as-cast and thermally annealed samples were performed (Cu-K_α radiation) in order to obtain average grain size D, and nanocrystalline volume fraction V_x. Hysteresis loops were recorded at room temperature in order to obtain coercive field (H_c). Saturation induction (~ 1.28 Tesla) was determined by VSM (H_{max} = 700 kA/m).

III. RESULTS AND DISCUSSION

The variation in the energy of domain wall depends upon the magnetization orientation and its value fluctuates by $\pm D^3K_1 / 6$ about an average value, K_1 is the anisotropy energy constant of crystalline phase [7].

When the domain wall moves through nanocrystals by distance comparable to its width under the influence of the applied magnetic field, the typical force that hinders the domain wall movement is proportional to the fluctuations of the domain wall energy and to the characteristics length scale (domain wall width) over which these fluctuations take place and consequently coercive field has following dependence;

$$H_C \sim V_x^{1/2} \; D^{3/2} \; [K_1 / (12 \, \mu_0 \, M_S \, L^{3/2})] \qquad (1)$$

Where L is the bulk domain wall thickness governed by amorphous phase (typically ~ μm). In the RAM approach the random magneto-crystalline anisotropies get averaged out over a length scale that is larger than the grain size. This spatial scale is determined mainly by the properties of nanocrystalline phase and the coercive field varies as;

$$H_C \sim (V_x^2 K_1^4 D^6) / (A^3 \, \mu_0 \, M_S) \qquad (2)$$

It can be seen that the grain size dependence of coercive field suggested by equation (1) is weaker as compared to D^6 dependence [4, 5] in equation (2). Figure 1 (a) and (b) shows the variation of coercive field with volume fraction of nanocrystalline phase (8-28 %)

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and grain size (12-18 nm) respectively, based on the values of coercive field obtained experimentally and on those calculated using equation (1). Annealing seems to initiate the structural relaxation by the rearrangement of local disorders caused by the fact that the onset of crystallization results in the loss of Fe and Co from the amorphous matrix. Inset of figure 1 (a) and (b) depicts the comparison between the variation (with volume fraction and grain size respectively) of coercive field determined experimentally and calculated using RAM approach. It may be inferred that the random anisotropy mechanism is not governing the coercive field behaviour as expected on the basis of the corresponding correlation length (~20 nm) for nanocrystalline phase. In the present case the correlation length is mainly controlled by amorphous phase (72%-92%) and nanocrystals are only contributing to the fluctuations in domain wall energy thereby acting as pinning centres.

IV. CONCLUSION

Two approaches describing the hysteresis properties are compared on the basis of structural and magnetic investigations of $Fe_{58}Co_{25}Nb_7Cu_1B_9$ alloy. Magnetic behaviour is governed by the correlation length scale that is determined by the amorphous phase and magnetic properties seem to have a less strong dependence on average grain size with respect to the one expected in the framework of RAM approach.

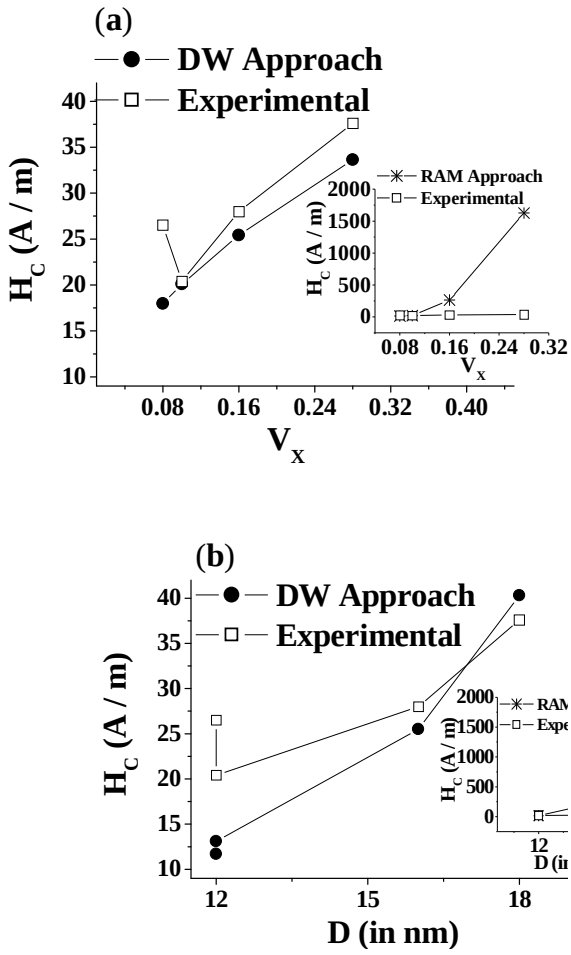

Fig. 1: (a) Volume fraction dependence of H_C (b) Grain size dependence of H_C. Inset of figures shows respective comparison with RAM approach.

Results based on DW approach shows a good agreement with the experimental observations. Limits of applicability of the two approaches seem to be dependent strongly upon the extent of nanocrystallization that considerably influences the fact that which phase is regulating the magnetic correlation length leading the magnetization process.

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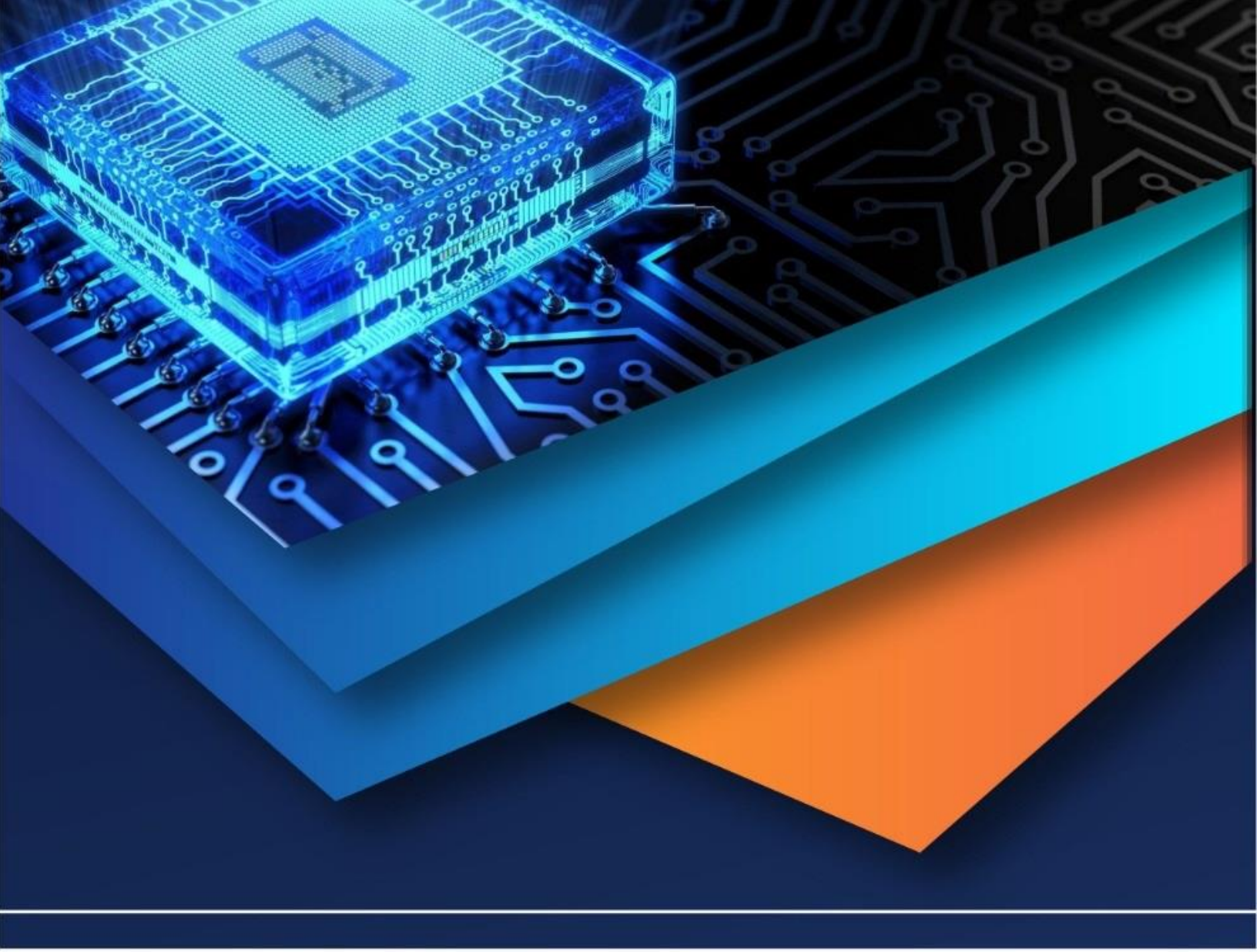

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