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Thermo-magnetic memorization effect in amorphous ferromagnetic ribbons

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Abstract The results of experiments done on soft magnetic amorphous alloy ribbons of $Co_{70.4}Fe_{4.6}Si_{15}B_{10}$ are presented and discussed. They give the behaviour of the initial ac permeability as a function of temperature for several values of the amplitude and frequency of the driving field. A frequency memorization effect, already reported, is seen to be dependent not only on the frequency but also on the amplitude of the field applied during the previous thermal treatment. The kinetics of domain wall motion driven by temperature and applied field is suggested as the mechanism responsible for the memorization effect.

1. Introduction

Soft ferromagnetism is observed in certain amorphous alloys[1]. Cobalt rich amorphous alloys with zero magnetostriction and high permeabilities are excellent materials for transformer cores and magnetic heads[2], due to their high resistivities.

The initial value of the permeability of such alloys depends on the quenching rate and on the presence of an externa1 applied field.

In a previous paper[3] a frequency dependent memory effect related to the thermal history of the ac magnetic permeability in the as quenched $Co_{70.4}Fe_{4.6}Si_{15}B_{10}$ alloy was reported. This effect was discussed in terms of a model for the time response of the magnetic permeability based on the domain structure of amorphous materials. In this work we present several new results related to the frequency dependent thermo-magnetic memorization effect (FDTMME). They lead us to consider that it is basically due to the kinetics of the domain walls (DW) motion.

2. Experimental

Samples of the amorphous alloy $Co_{70.4}Fe_{4.6}Si_{15}B_{10}$ were produced by melt-spinning. Their dimensions are 1.5 mm wide, 20 μm thick with a length of a few centimeters cut from a long ribbon. The initial ac permeability, was measured with the samples inside two co-axial coils. The driving coil, formed by 40 turns, is 5 cm long. The pick-up coil is 1 cm long and contains 50 turns. The signal from the pick-up coil was recorded through a lock-in amplifier according to the scheme of fig. 1. The first series of measurements of the initial ac permeability were performed with the temperature varying from room values up to 410°C, well above the Curie temperature $T_C = 386°C$, with a rate of 6°C/min, for the as cast annealed samples. The frequency and amplitude of the driving field were varied. The frequency values were such that the skin depth was larger than the sample thickness. The second series of measurements of the initial ac permeability were done at room temperature. The samples were previously annealed, for 20 min, at 400°C, to allow for irreversible structural relaxation. They were then heated up to a certain fixed value of the temperature, which was kept constant for 3 minutes, with and without an applied ac field and quenched to room temperature by placing the sample on a copper block. Measurements of the initial ac permeability were performed for different values of the frequency of the ac applied field.

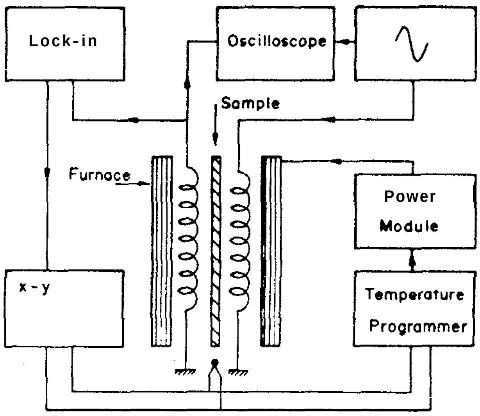


Fig. 1 - Experimental setup.

3. Results

The behaviour of the root-mean-square initial magnetic ac permeability (from now on referred to simply as permeability) $\mu(\omega) = \mu'(W) + i\mu''(\omega)$ as a function of the temperature for various frequencies of the driving field for as cast samples is shown in fig. 2.

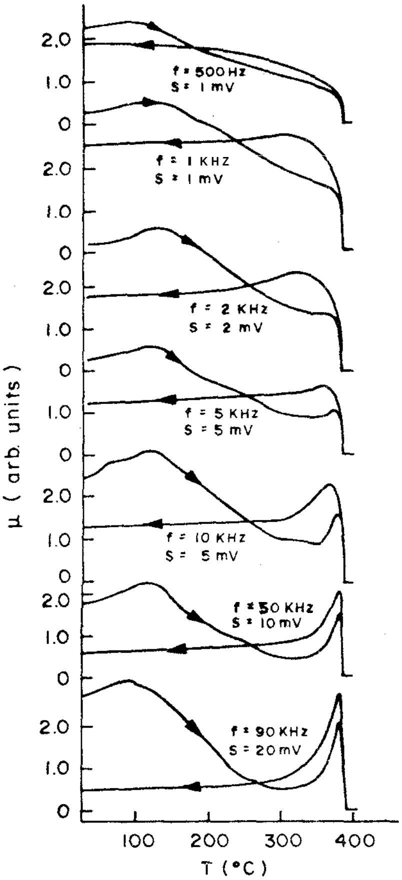


Fig. 2 - Initial ac magnetic permeability μ in aq- $Co_{70.4}Fe_{4.6}Si_{15}B_{10}$ as a function af the temperature T for different values of the driving field frequency f. S is the value of the sensitivity of the lock-in arnplifier. The arrows indicate the direction of temperature variation.

The effect of frequency memorization is shown in figs. 3, 4 and 5 [3]. In order to avoid interference of irreversible structural relaxations, the temperature range was swept in two successive cycles. Measurements were made at different settings

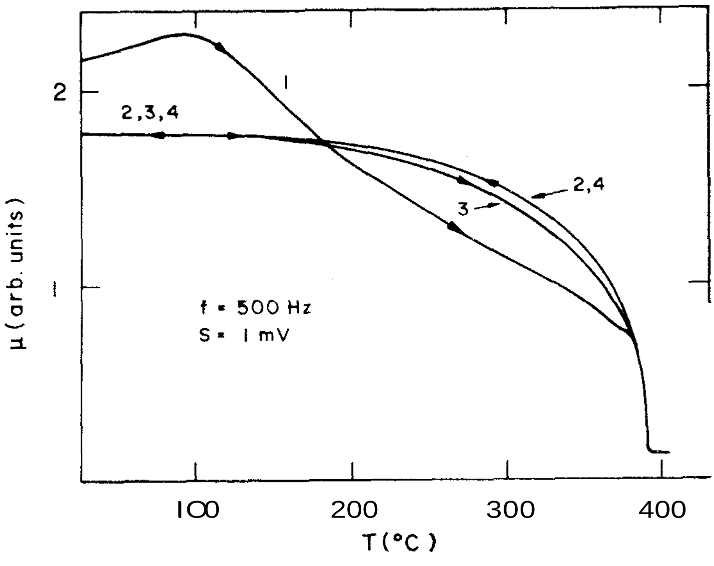

2
1
μ (arb. units)
2,3,4
1
2,4
3
f = 500 Hz
S = 1 mV
100
200
300
400
T (°C)

Fig. 3

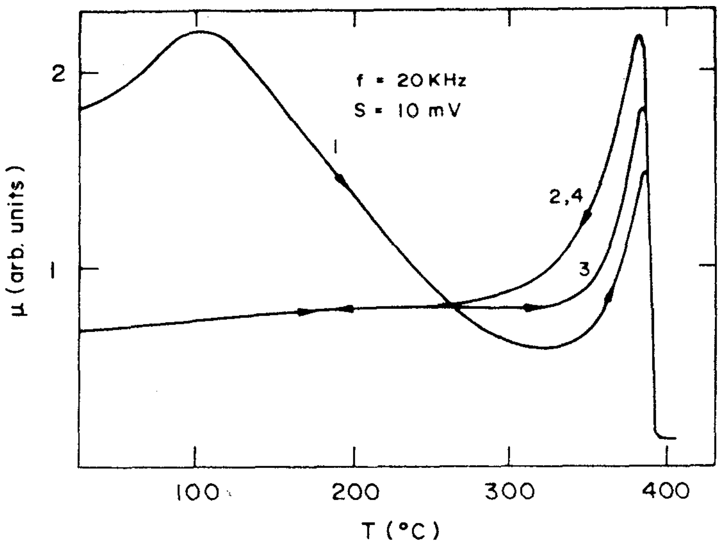
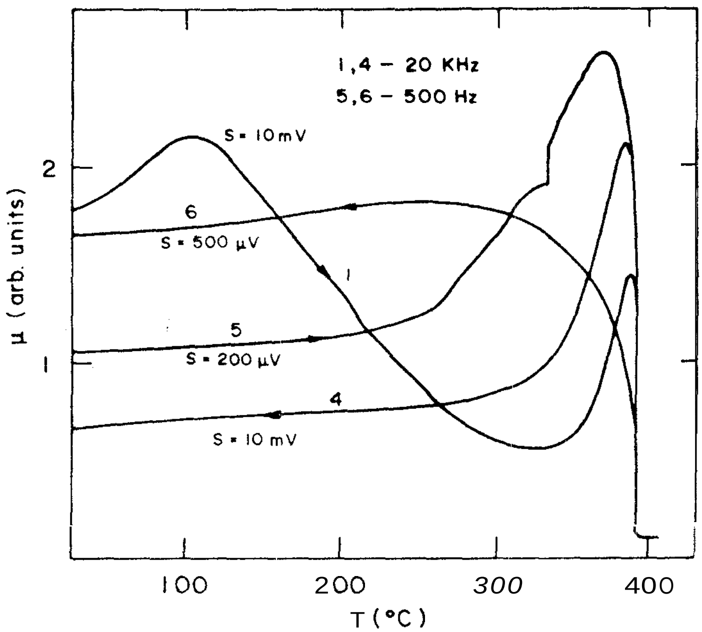

2
1
μ (arb. units)
f = 20 KHz
S = 10 mV
1
2,4
3
100
200
300
400
T (°C)

Fig. 4



Figs. 3, 4, 5 – Thermal histeresis of the ac magnetic permeability μ in aq-$Co_{70.4}Fe_{4.6}Si_{15}B_{10}$ for driving fields of frequency f and lock-in amplifier sensitivity S. The arrows indicate the direction of temperature variation.

of the sensitivity S of the lock-in amplifier and at two values of the frequency f of the driving field, which has an effective amplitude of 10 A/m.

Fig. 6 shows the permeability as a function of the temperature for a sample which had previously undergone various complete cycles of permeability measurements with driving fields of amplitude $H_{pp} = 8$ A/m, peak to peak, and frequency 500 Hz. The plotted results were obtained with driving fields of 500 Hz with different values of the amplitude.

One sample was annealed at $T_a = 200°C$ for $t_a = 10^4$ min and the permeability was measured at 500 Hz, $H_{pp} = 8$ A/m, during three temperature cycles, as shown in fig. 7. Similar results are shown in fig. 8 for a sample that had undergone a cycle $\mu \times T$ with f=500 Hz and H_{pp}=1,5 A/m.

A second series of measurements produced the results shown in Figs. 9, 10 and 11.

4. Discussion

The first studies of the variation of permeability with temperature, given in fig. 3 and 4, indicated that the second cycle (curves 3 and 4) was reproducible. The same results were obtained on repeated measurements. A dependence on frequency is evident. However, as fig. 5 shows, when two cycles were performed at 20 kHz (results are those of fig. 4, of which only curves 1 and 4 are reproduced in fig. 5) followed by a third cycle at 500 Hz (curves 5 and 6), the behaviour was different from the one obtained with the some procedure and shown in curves 3 and 4 of fig. 3. This was interpreted as a frequency memorization effect[3]. Can this effect occur at different frequencies? It is dependent on the amplitude of the driving field? Trying to answer, at least partially, those questions a few cycles of measurements of the permeability as a function of the temperature were made at different frequencies with 10 A/m effective amplitude for the driving field on as cast samples and are given in fig. 2. Any sample submitted to a second cycle will yield basically the same results as given in the curves with decreasing temperature.

The cycle with H_{pp}=8 A/m and f = 500 Hz, curves 1 and 2 of fig. 6, is different from the corresponding cycle, curves 3 and 4 of fig. 3, which was obtained with a higher value of H_{pp}. The next cycles, with f=50 kHz and H_{pp}=0,5 A/m, seemed to show a FDTMME, however this is questionable since cycle 5,6 is similar to 3,4 in spite of including temperature values above T_C. Nevertheless, it should be noted that the behaviour of the permeability in one cycle depends on the value of H_{pp} in the previous one. To see this observe the sequence of cycles 3, 4; 5, 6 and 7, 8.

When an as cast sample was annealed, with no applied field, at T_a = 200°C for 10^4 min, the first part of the first cycle $\mu \times$ T exhbited substantially smaller permeability values than the second part, fig. 7. Another feature is the sudden rise in the value of the permeability near 230°C, in curve 1.

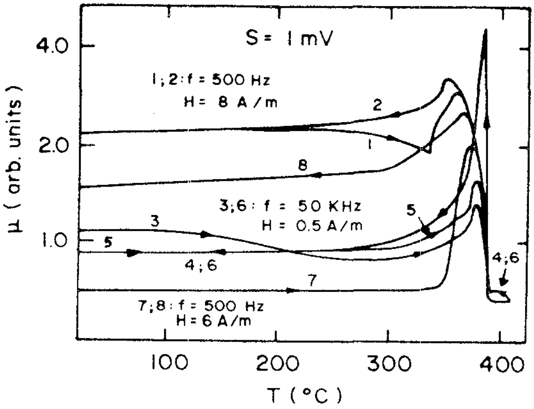


Fig. 6 - Various cycles of $\mu \times T$ measurements were made at the indicated amplitudes and frequencies of the driving field. The sample was subjected to several such cycles, at f = 500 *Hz*, H_{pp}=8 A/m, before the shown results were obtained. The numbers indicate the order at which the measurements were made.

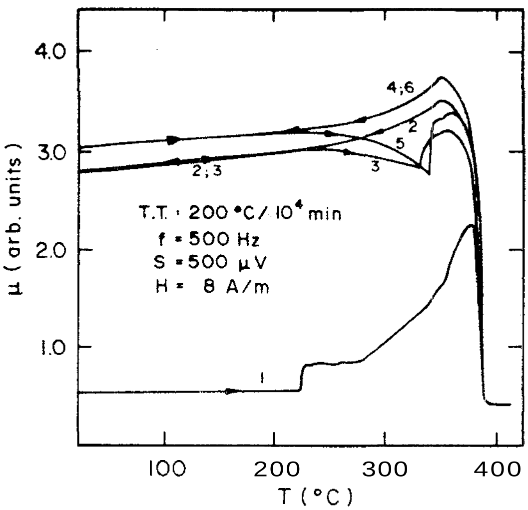


Fig. 7 - Cycles of $\mu \times T$ obtained from a sample annealed for 10^4 min at $T_\alpha = 200°C$. The measurements were made with a field of $H_{pp} = 8$ A/m and f = 500 Hz.

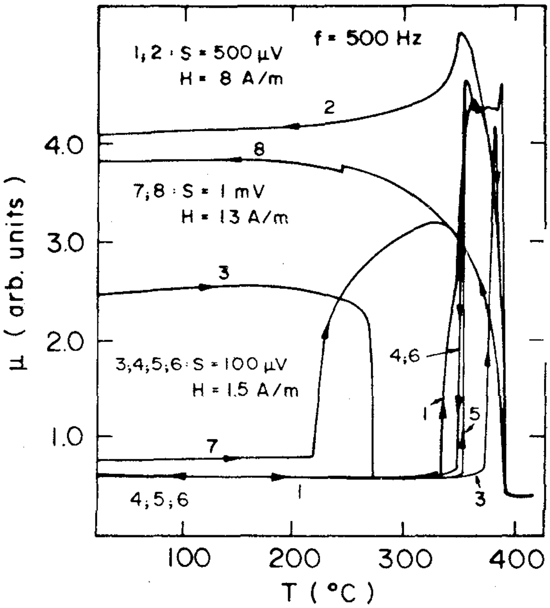


Fig. 8 – The $\mu \times T$ cycles were obtained from a sample that had gone previously through one cycle with $H_{pp} = 1,55$ A/m and f = 500 Hz.

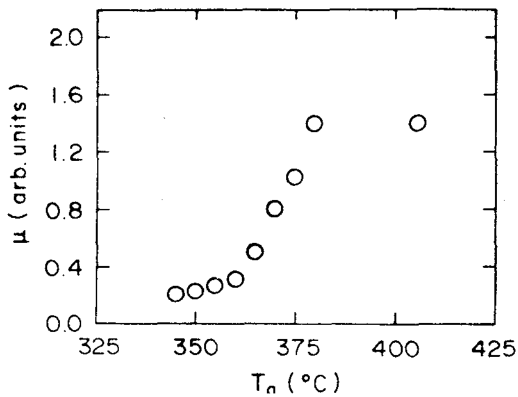


Fig. 9 – μ measured at room temperature as a function of the annealing temperature T_a. The temperature was kept at T_a for 3 minutes then quenched to room values.

Fig. 8 contains the results of several cycles of μ r T, with f=500 Hz, for various values of H_{pp}, from a sample that had been through a previous cycle similar to 5,6 with H_{pp}=1,5 A/m. It is quite evident that the behaviour depends strongly on the excitation intensity. A sudden increase of the permeability, at about 340°C was observed when H_{pp} was increased to 8 A/m, curve 1. When the amplitude was lowered back to 1.5 A/m, a sudden decrease in the permeability at about 280°C was measured, curve 3. A sudden increase is also seen in curve 7, at about 210°. There seems to be an interplay between the thermal agitation and the driving field that determines critica1 points, where μ undergoes sudden changes. The position of the critica1 points is probably determined by both the temperature and H_{pp}.

Finally figs. 9, 10, 11 show the results of s study of the dependence of the permeability, at room temperature, with thermal treatment with and without an ac driving field. Larger permeability values were obtained with higher annealing temperatures, with ac applied fields, for higher values of the field frequency. This is due to the fact that by quenching of the sample, the state of isotropy, reached at higher temperatures with an applied field, is memorized.

5. Final Remark

Further experiments are in progress in order to understand more deeply the kinetics of domain wall motion driven by the ac field and by temperature. Samples with non-zero magnetostriction are also being measured. The possible influence of oxidation on the sample surface upon wall motion is also being analysed through measurements in an inert atmosphere.

Acknowledgement

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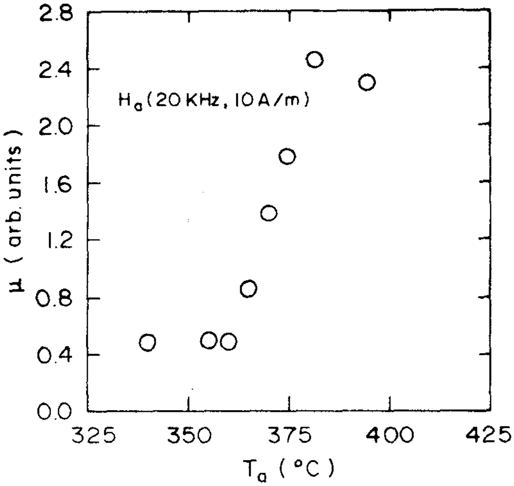

Fig. 10 – μ measured at room temperature as a function of the annealing temperature T_a. The temperature was kept at T_a for 3 minutes, with an applied field H_a, then quenched to room values.

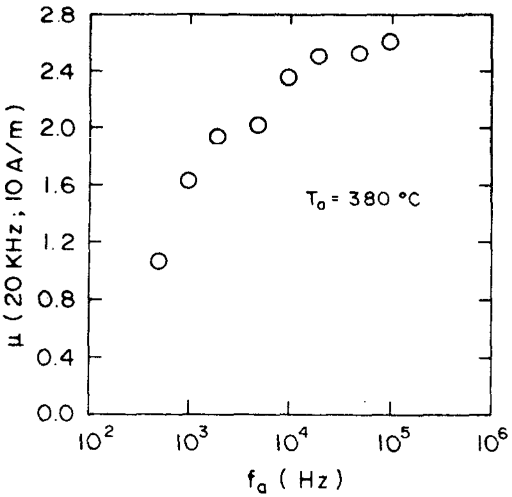

Fig. 11 – μ measured at room temperature as a function of the frequency f_a of the field applied during thermal treatnent for 3 minutes at $T_a = 380°C$.

References

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Resumo

São apresentados e discutidos novos resultados de medidas feitas em fitas amorfas da liga magnética "soft" $Co_{70.4}Fe_{4.6}Si_{15}B_{10}$. Eles consistem na variação da permeabilidade magnética inicial ac em função da temperatura, para vários valores da amplitude e da frequência do campo aplicado. Verifica-se que um efeito de memorização de frequência, já publicado anteriormente, depende não só da frequência como também da amplitude do campo magnético aplicado durante o tratamento térmico anterior. Sugere-se que a dinâmica do movimento de paredes de domínio, devido à temperatura e ao campo aplicado, seja responsável pelo efeito de memorização.