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Influence of magnetic fields on the internal friction of Ni

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Abstract

The influence of static and synchronous magnetic fields on the magnetochemical damping of a pure Ni sample was investigated to check the validity of Degaque's model of magnetomechanical damping. The experimental dependences were fitted using four parameters which were common to both dependences. It was revealed that Degaque's model describes these dependences qualitatively very well. The values of the parameters were found to be consistent with appropriate values of microscopic parameters such as the magnetostriction and magnetization vector of Ni.

1. Introduction

A phenomenological description of the hysteresis component of magnetomechanical damping in the presence of an external magnetic field has been proposed by numerous authors [1–4]. An extensive review of the effect of magnetic fields on the hysteretic magnetomechanical component has been given recently by Degaque [5]. The hysteretic damping is always found to disappear when the magnetization of the sample reaches the saturation state. At a low value of static magnetic field, hysteretic damping is sometimes found to increase and the so-called field maximum of hysteretic damping is observed. This phenomenon is described by the models of Hrianca, Kiekalo and Degauque.

The influence of alternating (a.c.) magnetic field on magnetomechanical damping depends on the frequency of the a.c. field. The hysteretic component of damping may reach its maximum value for resonance conditions when the synchronous magnetic field is applied: $f_H = f_r$, where f_H is the frequency of the applied magnetic field, and f_r is the frequency of mechanical vibration [6]. The only model describing the influence of static and synchronous magnetic fields on hysteretic damping has been proposed by Degauque [4, 6]. Degauque has measured hysteretic damping in high purity iron samples.

Degauque has compared the experimental dependences of hysteretic damping with his theoretical curves using a two-points method of fitting: the position and height of the appropriate maximum are tested and used to calculate the required values of intrinsic parameters included in the model.

The aim of the present work was to check the validity of Degauque's model in the case of Ni using another method of parameter evaluation. The experimental curves of hysteretic damping under constant and synchronous magnetic field strength were approximated by theoretical plots using a set of only four parameters for both dependences. It should be mentioned that this method makes it possible to evaluate values of intrinsic parameters which should be independent of the way the magnetic field is applied.

2. Experimental method and results

Nickel samples (99.9%) had the form of a wire (0.7 mm diameter and 24 mm long). They were annealed at 1070 K for 3 h in high vacuum and cooled slowly in the furnace.

The magnetomechanical damping was measured using an inverted pendulum of low frequency of resonant vibration ($f_r = 5$ Hz). The amplitude of vibration was varied from 1×10^{-5} up to 100×10^{-5}. The vibration was detected optically using two kinds of light spot detectors: a photomultiplier and photocell for low and high strain amplitudes respectively.

The level of internal friction was evaluated by a logarithmic decrement for a given amplitude of vibration by extrapolating the results of the logarithmic decrement for various numbers of amplitudes n to $n = 1$.

A magnetic field was applied by a solenoid surrounding the sample. A synchronous magnetic field was provided using a power amplifier with a tension to current converter. The input voltage signal was simply proportional to the shear strain of the sample. It should be mentioned that the amplitude of the magnetic field strength decreased by a few per cent owing to free

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decay of the vibration amplitude of the sample during measurement of the internal friction.

The magnetomechanical component of the total internal friction was evaluated from the total internal friction as measured at the magnetically saturated state of the sample. The field dependences of this component were measured at various levels of shear strain amplitude which was stabilized by electronic set. The amplitude of the synchronous magnetic field strength was evaluated as a mean value of the first and the last measured amplitudes of the magnetic field strength.

The effect of the constant magnetic field on magnetomechanical damping is shown in Fig. 1. These are six examples of the results obtained for various increasing values of shear strain vibration amplitude. The hysteretic damping passes through a maximum value and the position of this "field maximum" and its height depend on the vibration amplitude. The field maximum appears at a smaller static field strength for higher shear strain amplitudes; its position varies from 4 kA m^{-1} to 0.5 kA m^{-1}. For high levels of shear strain amplitude (plots 5 and 6, Fig. 1), the hysteretic damping level decreases because of saturation of the magnetomechanical hysteresis [5] and the "field maximum" disappears. Figure 2 shows the effect of synchronous magnetic field on the hysteretic damping for various shear strain amplitudes. It should be pointed out that an increase in the synchronous magnetic field strength involves the field maximum of hysteretic damping, and the level of observed internal friction is very high, about 180×10^{-3} at a synchronous field intensity of about 5 kA m^{-1} for small shear amplitudes (plot 1 in Fig. 2).

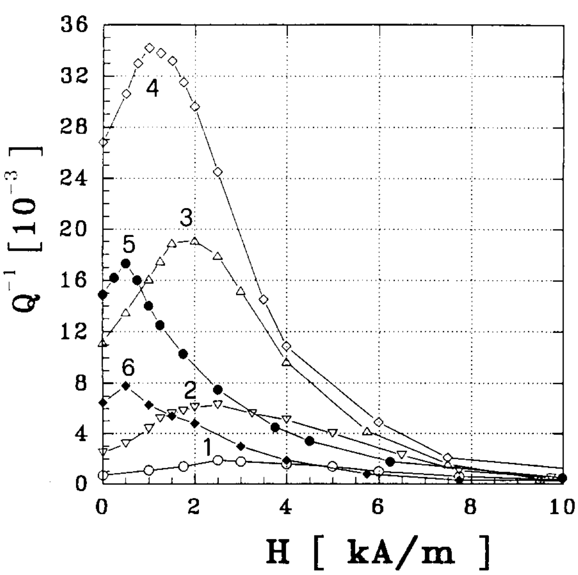

Fig. 1. Effect of static magnetic field on hysteretic damping for various shear strain amplitudes (10^{-5}): curve 1, 0.8; curve 2, 3.2; curve 3, 4.5; curve 4, 8.0; curve 5, 22; curve 6, 94.

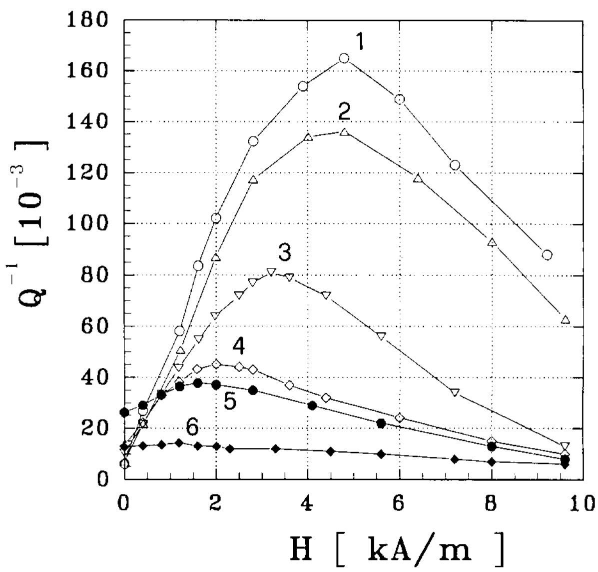

Fig. 2. Effect of synchronous magnetic field on hysteretic damping for various shear strain amplitudes (10^{-5}): curve 1, 5.4; curve 2, 6.8; curve 3, 8.0; curve 4, 11; curve 5, 21; curve 6, 63.

This synchronous field maximum is strongly reduced for shear amplitudes greater than 30×10^{-5}, as is shown by plot 6 in Fig. 2.

3. Discussion

The field maxima of hysteretic damping as shown in Figs. 1 and 2 can be explained qualitatively by the double role of the magnetic field – initiating and stabilizing [6, 7]. The initiating role is revealed better when an alternating magnetic field is applied. It is evident that the impact of the magnetic field on hysteretic damping is maximal when the magnetic field is synchronous with the external stress. Quantitative analysis of the obtained field dependences was based on Degauque's model [4, 5] because this was the only model dealing with static and synchronous magnetic fields. The field dependence of hysteretic damping was described by two functions: by F_1 for a static field and by F_2 for a synchronous magnetic field. These functions depend on two parameters Y_1 and Z_1 which are assumed to be proportional to the external field H and external stress γ. In the case of constant magnetic field, hysteretic damping is given by the function F_1:

$$F_1(Y_1, Z_1) = [\exp(-2Y_1)/Z_1^2][A[C - D\exp(-3Z_1)] + B[Y_1 + 1/3 - (Y_1 + Z_1 + 1/3)\exp(-3Z_1)]$$

where $A = 1 - \exp(-Z_1)$, $B = 1 - Y_1 - (1 - Y_1 + Z_1)\exp(-Z_1)$, $C = (Y_1 + 1/3)^2 + 1/9$.

For a synchronous magnetic field another function F_2 is used:

$$F_2(Y_1, Z_1) = [1/Z_1(Y_1+Z_1)]\{A \times [2/9 - C \exp(-3(Y_1+Z_1))] + B[1/3 - (Y_1+Z_1+1/3) \exp(-3(Y_1+Z_1))]\}$$

where $A = 1 - \exp(-Y_1 - Z_1)$, $B = 1 - (1 + Y_1 + Z_1) \exp(-Y_1 - Z_1)$, $C = (Y_1 + Z_1 + 1/3)^2 + 1/9$.

There are only four parameters (P_1, P_2, P_3, P_4) used in this description. They are defined by the following expression:

$$Y_1 = (P_1 H)/(P_2 P_4) \qquad Z_1 = \gamma/P_4$$

It was assumed that hysteretic damping should be proportional to the F_1 or F_2 function with the common factor called parameter P_3. Multiplication of P_2 by P_4 gives the mean value of internal stress level σ_i. Figures 3 and 4 show some examples of plots of functions $F_1(Y_1)$ and $F_2(Y_1)$ as calculated for increasing values of Z_1 which is proportional to the shear strain amplitude. There is an evident close correlation between the experimental and theoretical dependences of the hysteretic damping on a static magnetic field (Figs. 1 and 3) and on a synchronous magnetic field (Figs. 2 and 4). Further analysis led to numerical approximation of the experimental data. At first, the dependence on shear strain amplitude of hysteretic damping was used to calculate P_3. Figure 5 shows experimental and fitted theoretical dependences of the hysteretic damping on amplitude. These dependences can be calculated from both functions assuming that $H = 0$. The parameter P_3 was found to be equal to 0.1730 ± 0.002 and was used for further calculations where only three parameters were fitted: P_1, P_2 and P_4.

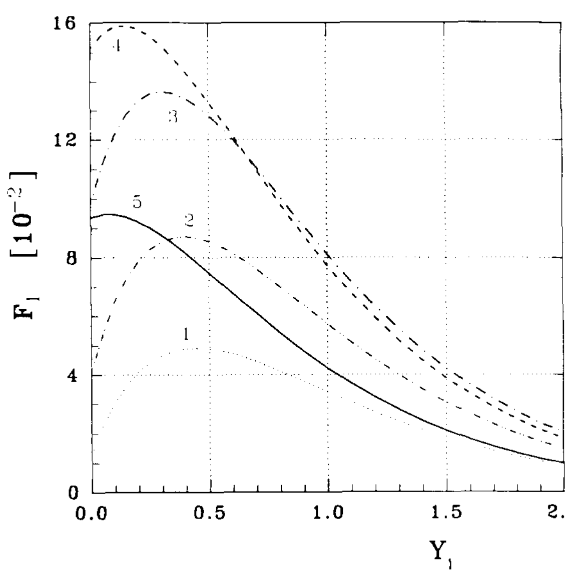

Fig. 3. Theoretical dependences of hysteretic damping on static magnetic field for various values of Z_1 parameter; curve 1, 0.1; curve 2, 0.2; curve 3, 0.4; curve 4, 1.0; curve 5, 2.0.

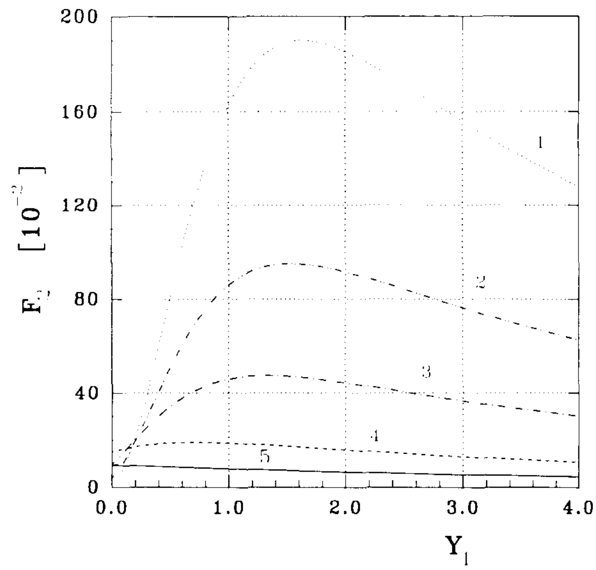

Fig. 4. Theoretical dependences of hysteretic damping on synchronous magnetic field strength amplitude for various values of Z_1 parameter; curve 1, 0.1; curve 2, 0.2; curve 3, 0.4; curve 4, 1.0; curve 5, 2.0.

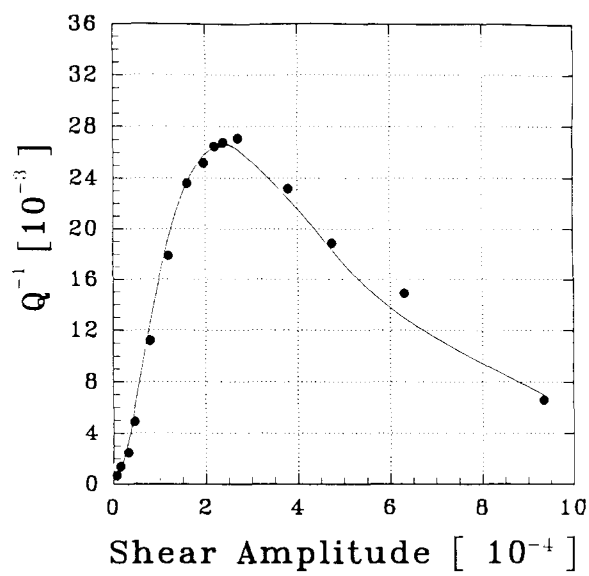

Fig. 5. Dependence on shear strain amplitude of the hysteretic damping: ● experimental, —— theoretical.

Figures 6 and 7 show plots resulting from static magnetic field dependences. The agreement between experimental points and theoretical plots is very good, mainly for low (plots 1, 2 and 3 in Fig. 6) and high (plots 1 and 2 in Fig. 7) values of shear strain amplitude. From 10 different approximations of experimental dependences the following mean values of evaluated parameters were found: $P_1 = (0.51 \pm 0.05)$ T, $P_2 = (5.8 \pm 0.5)$ MPa, $P_4 = (35 \pm 4) \times 10^{-5}$. An analogous procedure was carried out for the synchronous field dependences of hysteretic damping. Comparing Fig. 2 with Fig. 4 one can see that the hysteretic damping as measured for high values of synchronous magnetic field decreases

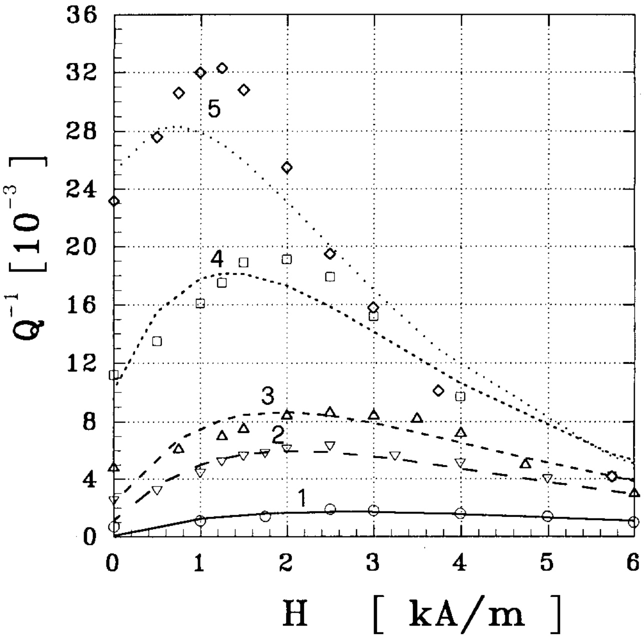

Fig. 6. Experimental (points) and theoretical (lines) dependences of the hysteretic damping on static magnetic field for various shear strain amplitudes (10^{-5}): curve 1, 0.8; curve 2, 3.2; curve 3, 4.5; curve 4, 8.0; curve 5, 22.

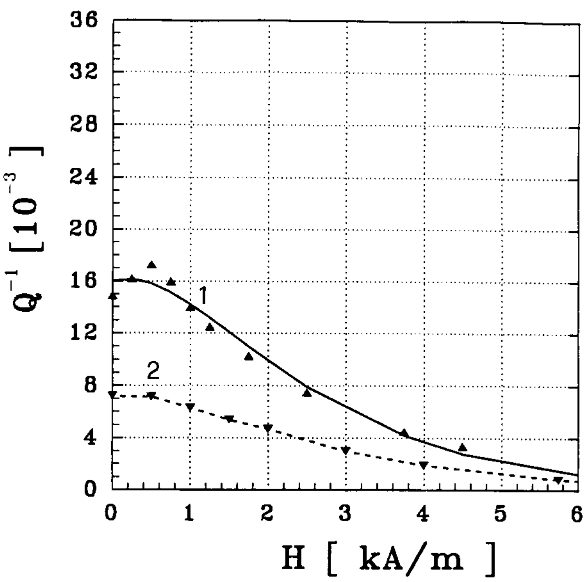

Fig. 7. Experimental (points) and theoretical (lines) dependences of the hysteretic damping on static magnetic field for various shear strain amplitudes (10^{-5}): curve 1, 63; curve 2, 93.

much more than is predicted by Degauque's model. This was why the numerical approximation was limited to the increasing part of the synchronous field maximum ($H<2.5$ kA m^{-1}). Figure 8 shows examples of such an approximation. The theoretical plots fit the experimental points very well. From 10 new approximations the following values of the three parameters were evaluated: $P_1=(0.45\pm0.06)$ T, $P_2=(5.5\pm0.8)$ MPa, $P_4=(30\pm3)\times10^{-5}$. It is easy to see that the values of

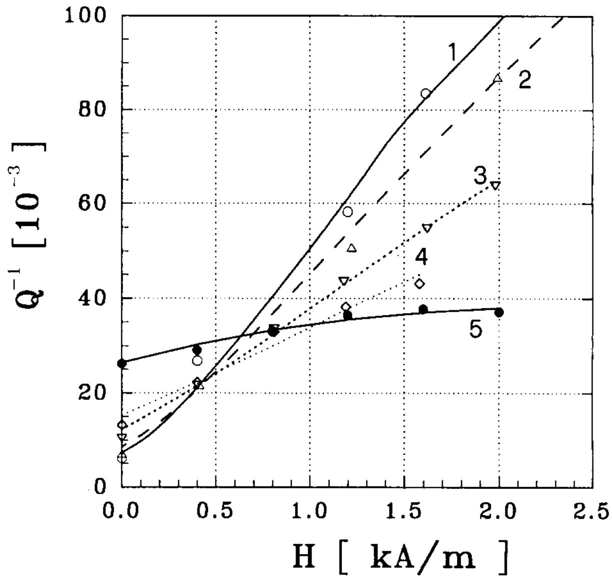

Fig. 8. Experimental (points) and theoretical (lines) dependences of the hysteretic damping on synchronous magnetic field strength amplitude for various shear strain amplitudes (10^{-5}): curve 1, 5.4; curve 2, 6.8; curve 3, 8.0; curve 4, 11; curve 5, 21.

these parameters are consistent with the values obtained above. This means that Degauque's model also describes quantitatively hysteretic damping. The final question is whether the parameters obtained can be confirmed physically. Degauque's model is based on the following relations: $P_1=1.41B_sC_1$; $P_2=1.5\lambda_sGC_2$; $\sigma_i=1.73GP_4$, where C_1 and C_2 are both constant with values dependent on the domain wall arrangement ($C_1<1$ and $C_2<1$). Taking some typical values of these microscopic parameters for Ni ($B_s=0.7$ T, $\lambda_s=-30\times10^{-6}$, $G=70$ GPa) one can find that the values of P_1 and P_2 are also well confirmed physically. The last parameter P_4 indicates the level of internal stress σ_i, which is also physically consistent: $\sigma_i=35\pm5$ MPa.

4. Conclusions

The field dependence of hysteretic damping of an Ni sample was analyzed using Degauque's model of magnetomechanical hysteresis. It was proved that this model describes our experimental results not only qualitatively but also quantitatively. Three parameters used to approximate the experimental data seem to be physically well confirmed. Some discrepancies mentioned above between experimental and theoretical field dependences for a high level of synchronous magnetic field amplitude can be explained by the fact that a synchronous magnetic field supports mechanical vibrations and can lead to a so-called "negative internal friction" phenomenon which is not included in Degauque's model [6].

Acknowledgments

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