ANOMALIES IN THE MODULUS OF ELASTICITY AND IN INTERNAL FRICTION IN THE ALLOY Fe_3Pt

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Results are presented of measurement of the temperature dependence of Young's modulus and of internal friction of a disordered alloy with a composition close to that of Fe_3Pt. A very large anomaly in Young's modulus and a sharp internal friction peak are observed in the vicinity of the ferromagnetic Curie point (71° C). On application of a magnetic field, two types of ΔE effect (of different sign) are produced, due to the domain structure and to a decrease in the dynamic Young's modulus near the Curie point as a result of intra-domain spin ordering. The experimental variation of Young's modulus is compared with the corresponding temperature dependence of the modulus, deduced on the basis of magnetic data from relaxation thermodynamic theory.

1. Alloys of the Fe-Pt system, close to Fe_3Pt in composition, have a very large volume magnetostriction by the paraprocess, especially in the disordered state.[1] This has led to the suggestion that there should be an exceptionally large anomaly in the elastic and inelastic properties of such alloys near the Curie point, related not to the ordering of the magnetic moments of the domains when a load is applied, but to the ordering of the spins within the domains.[2] The aim of the present work was to study such anomalies in the alloy Fe_3Pt.

2. The measurements were made on the same 58 wt % Pt, 42 wt % Fe specimen as before,[1] i.e., on a 3 mm diameter rod, 187 mm long, produced by drawing the melt out of an induction furnace in a quartz tube under vacuum. The specimen was homogenized before the measurements by heating at 1020° C, followed by quenching in water to fix the disordered state (the Kurnakov point of this alloy is between 900 and 1000° C).

Young's modulus E and the logarithmic decrement δ, proportional to the internal friction, were measured at frequencies between 1200 and 1300 cps, corresponding to the third flexural mode of vibration of the specimen; we have described previously[3] the apparatus for measuring the relative modulus to 0.004% and the decrement to 1%.

3. The variation of Young's modulus with temperature for the alloy in the disordered state is shown in Fig. 1. An anomalous increase in modulus with temperature is found up to 220° C, but the steepest part of the curve is in the region of the Curie point (71° C).

The anomaly at room temperature is 31.4% of the value of E_0 at that temperature, i.e., of the modulus when the effect of ferromagnetic interaction is discounted (the value of E_0 is derived by extrapolating the linear part of the curve, in the paramagnetic state, down to room temperature). It can be seen that the anomaly, $E_0 - E_1$ tends to increase further below room temperature. So large an anomaly of the elastic modulus, which does not disappear in a saturating field, has not been observed before in ferromagnets, and is comparable in magnitude only with the anomaly in the oxide antiferromagnets NiO and CoO.[4] The "technical" saturation magnetic field reduces the anomaly, but only very little — to 29.7% of E_0; from this it follows that the predominant part of the anomaly is due to the volume magnetostriction by the paraprocess. This is the same phenomenon observed (but less clearly) by Engler[5] in a 42% Ni, 58% Fe alloy and by Belov et al.[2] in elinvar-type alloys. The temperature variation of the logarithmic decrement in the unmagnetized alloy is also shown in Fig. 1. The decrement has a fairly sharp and high peak a few degrees below the Curie point. Similar, but lower and broader peaks were found near the Curie point in elinvar-type alloys.[2]

4. Figure 2 shows the temperature dependence of the ΔE-effect for five magnetic field values between 8.4 and 839 oe. The usual ΔE-effect, due

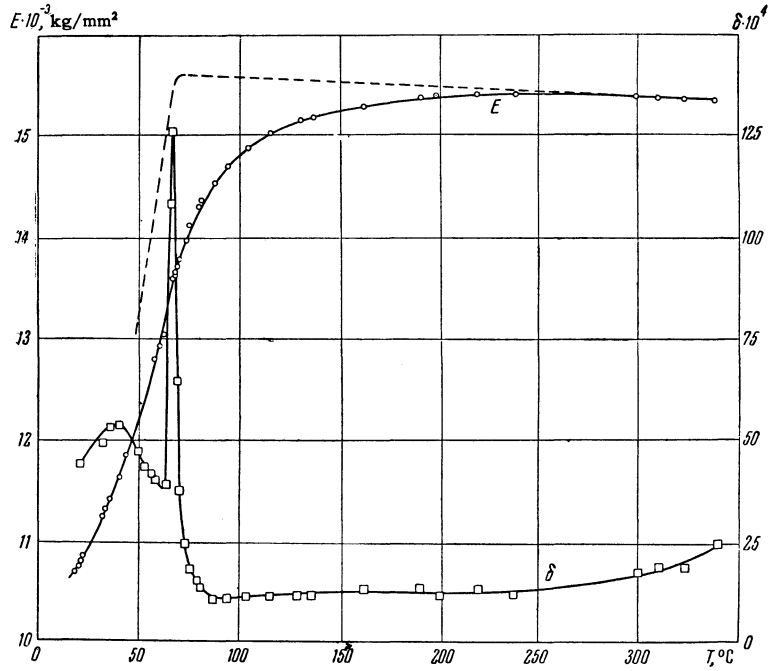

FIG. 1. Temperature dependence of Young's modulus E and logarithmic decrement δ for the disordered alloy 58 wt % Pt, 42 wt % Fe in the unmagnetized state. The dashed curve shows E, calculated from magnetic data.

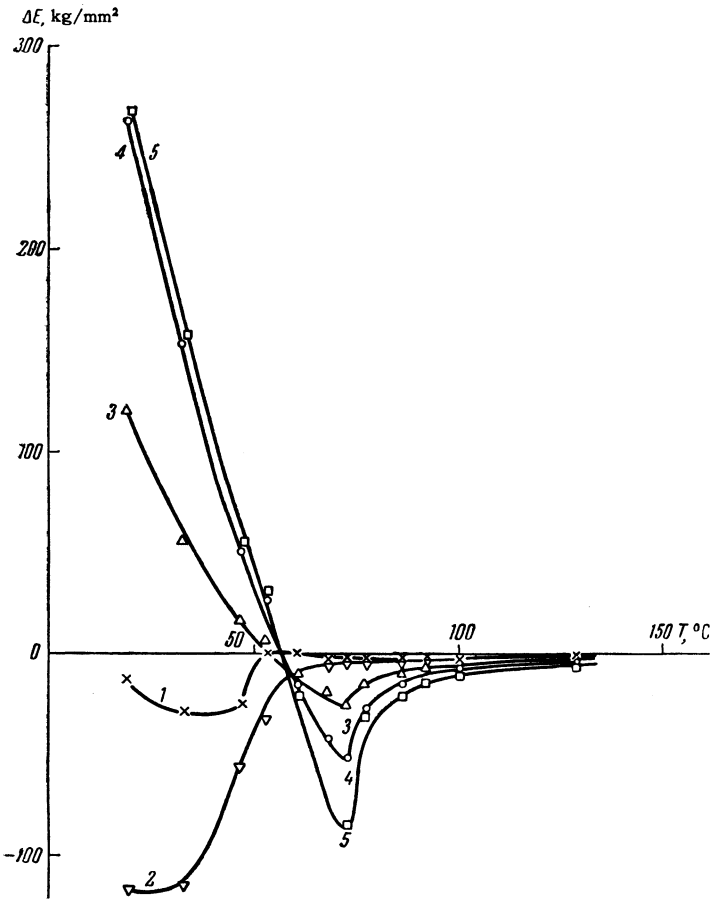

FIG. 2. Temperature dependence of the change in Young's modulus as a function of field, for various magnetic fields: 1 – 8.4, 2 – 84, 3 – 252, 4 – 503, 5 – 839 oe.

to the alteration of the domain structure in a magnetic field is observed at 19–55°C. The normal saturation of the ΔE-effect occurs if fields of 500–800oe, but the ΔE-effect is negative in fields below 100 oe. The latter phenomenon, i.e., the reduction in Young's modulus in weak fields, was observed in alloys, but only at room temperature, by Williams et al.[6] and also by several Japanese workers (see, for example, Yamamoto and Taniguchi[7]), but has not yet been explained.

The non-saturating reduction in the modulus ΔE for all fields in the immediate vicinity of the Curie point (in the paraprocess region) has a

relaxation character, as has been shown earlier.[2] Its dependence on the angular frequency of the specimen, ω, is given by the relation:

$$\frac{1}{\Delta E} = \frac{3\beta\rho}{\gamma^2 E_0^2} + \frac{\omega^2\beta^{1/3}\rho}{3\gamma^2 k^2 E_0^2 H^{4/3}} \qquad (1)$$

where β is the thermodynamic coefficient in the expansion for the specific thermodynamic potential of the ferromagnet near the Curie point (in powers of the magnetization and the elastic stresses), γ is the magnetostriction constant (in the paraprocess region), k is a kinetic coefficient that determines the rate at which the ferromagnet reaches the equilibrium state of magnetization, and ρ is the density (12.2 g/cm^3). It can be seen from Fig. 3 that at 73° C the experimental points for ΔE, plotted as $(\Delta E)^{-1}$ vs. $H^{-4/3}$, fit a straight line well.

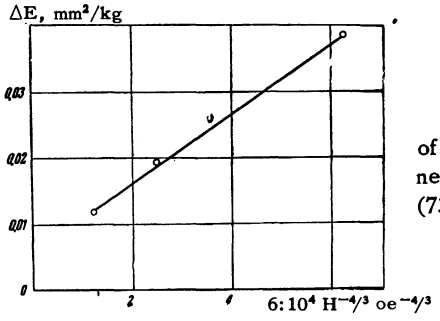

FIG. 3. Dependence of $(\Delta E)^{-1}$ on $H^{-4/3}$ near the Curie point (73°C).

5. The following relations were derived previously[2] from the theory of second-order phase transitions and the thermodynamics of irreversible processes, taking account of relaxation:

$$E = E_0[1 - \Delta_E/(1 + \omega^2\tau^2)], \qquad (2)$$

$$\delta = \pi\Delta_E\omega\tau/(1 + \omega^2\tau^2), \qquad (3)$$

$$\tau = 1/k[(H/\sigma) + 2\beta\sigma^2], \qquad (4)$$

$$\Delta_E = E_0\gamma^2\sigma^2/\rho[(H/\sigma) + 2\beta\sigma^2], \qquad (5)$$

where τ is the relaxation time, Δ_E the degree of relaxation of Young's modulus, and σ the equilibrium magnetization.*

Equations (1) to (5) are derived on the assumption of a one-domain specimen and for $\Delta_E \ll 1$. It is easy to show that to apply these expressions to an alloy with a large anomaly in the modulus it is better to replace Δ_E by

$$\Delta'_E = \Delta_E/(1 + \Delta_E).$$

*Equations (1) and (5) differ from the corresponding expressions of reference 2 in the inclusion of the factor ρ (the density) which was omitted there; because of this, the jump in Young's modulus at the Curie point, as calculated in that paper (dotted curve in Fig. 1a), should be reduced by a factor equal to ρ (about 8).

The thermodynamic coefficients α, β, γ, and the equilibrium magnetization σ are calculated from the experimental data of reference 1. Figure 4 shows this temperature dependence (the Curie point, Θ = 71° C, is determined from the condition $\alpha = 0$, cf. reference 8).

In order to calculate the relaxation time τ from Eq. (4) one must know the kinetic coefficient

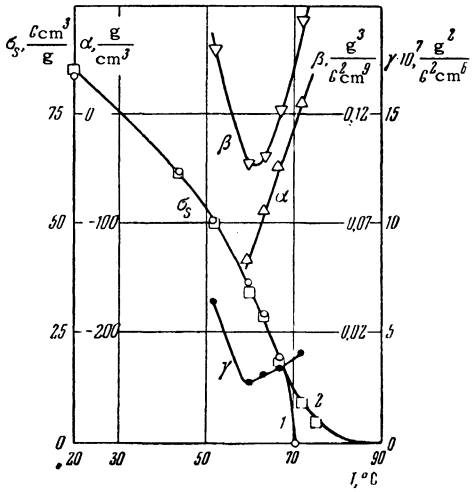

FIG. 4. Temperature dependence of spontaneous magnetization σ_s and thermodynamic coefficients α, β, γ: $1-\sigma_s$ calculated from the thermodynamic coefficients, $2-\sigma_s$ from data on the paraprocess magnetostriction.

k. This was determined at the temperature of the maximum decrement T_{max} = 66.5° C by two means: a) from the slope of the line in Fig. 3 and Eq. (1), since this slope is almost the same at 73° C as at 66.5° C; b) from the relation

$$\Theta - T_{max} = \omega/2k\alpha'_\Theta, \qquad (6)$$

which follows from (4) for H = 0 and under the condition for maximum internal friction, $\omega\tau = 1$, taking $\beta\sigma^2 = -\alpha = \alpha'_\Theta(\Theta - T)$ (see Belov[8]); from the plot of δ in Fig. 1 we obtain $\Theta - T_{max} = 4.5°$. The kinetic coefficient derived by both means comes out as 72 cm^3/g-sec.

This value was used to calculate the temperature variation of E near the Curie point, shown by the dashed line in Fig. 1. The calculated curve for E reaches the value $E = E_0$ at the Curie point. Instead of this, the experimental curve shows a relatively steep rise above the Curie point up to 220° C. This may be explained as the existence of a tail of the spontaneous magnetization of the structurally disordered specimen, which spreads out the ferromagnetic transition, and also as the influence of short-range order, which is not considered in the present theory. The decrement in the region of the maximum, calculated from Eq. (3), is one order of magnitude larger, and the maximum is somewhat broader, than that observed,

which cannot yet be explained satisfactorily.

In conclusion it is a pleasure to express our thanks to Professor K. P. Belov for his interest in the present work.

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