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Forced Magnetostriction in Ferromagnetic Alloys with the Order-Disorder Transition

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Forced magnetostriction of iron alloys with nickel, cobalt and platinum was measured in both the ordered and disordered states. In the disordered states, the thermodynamical relation relating the volume magnetostriction to the change of saturation magnetization with pressure is valid for all three alloys. The volume magnetostriction in the ordered states is smaller than the one in the disordered in iron-nickel and iron-platinum alloys. In iron-platinum alloys the large volume magnetostriction was observed, especially in the disordered state. The temperature dependence of volume magnetostriction of iron-platinum alloys also shows larger volume magnetostriction in the disordered state than in the ordered. This large change in volume magnetostriction between the ordered and disordered states may be explained by the molecular field approximation.

Introduction

It is well known that the forced magnetostriction, namely, the change of volume in ferromagnetic alloys at high magnetic fields is closely related to the magnetic properties such as saturation magnetization and Curie temperature. Ferromagnetic alloys with order-disorder transition are very interesting to study, because the magnetic properties in these alloys strongly depend upon the order-disorder transition. The measurements have, therefore, been performed systematically on the forced magnetostriction of several ferromagnetic alloys which have ordered and disordered states.

Experimental Results and Discussion

To measure the volume magnetostriction the strain gauge technique has been employed and the measurement was done up to 23,000 Oe. by use of an electromagnet.

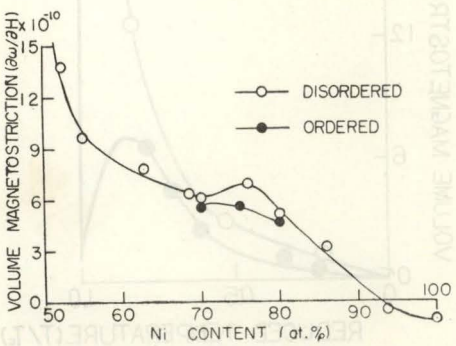

Fig. 1. Volume magnetostriction in nickel iron alloys measured at room temperature.

The results of iron-nickel alloys in γ-phase is shown in Fig. 1 in which the volume magnetostriction in the ordered state is smaller than in the disordered one. To obtain the ordered sample, the specimen was annealed in vacuum at 490°C for one week. The measured volume magnetostriction is very small being of the order of magnitude of 10^{-10}, so that the measurement of the reliable temperature dependence could not be performed.

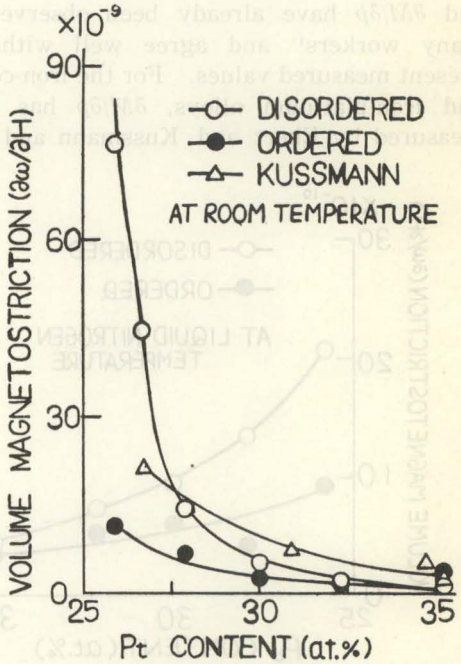

Fig. 2. Volume magnetostriction in iron platinum alloys measured at room temperature.

In iron-cobalt alloys, the volume magnetostriction is very small for all compositions, namely the order of magnitude is less than 10^{-10} so that the systematic relation between the volume magnetostriction and the composition could not be found and neither the effect of ordering nor the temperature dependence could be measured.

The same measurement has also been made on iron-platinum alloys which contain platinum from 25 to 35 atomic percents. The experimental result of iron-platinum alloys at room temperature is shown in Fig. 2, which shows the very large volume magnetostriction, especially in the disordered states. To obtain the ordered sample, the specimen was prepared by quenching the sample from 650°C to 0°C.

Several theoretical treatments have been given for the volume magnetostriction. One of them is based on the thermodynamical relation connecting the volume magnetostriction with the change of saturation magnetization with pressure as follows:

$$(\partial\omega/\partial H)_{P.T.} = -(\partial M/\partial p)_{H.T.}\,, \qquad (1)$$

where $\partial\omega/\partial H$ is the volume magnetostriction, M the saturation magnetization per unit volume and p the pressure. For the iron-nickel alloys in the disordered state, $\partial\omega/\partial H$ and $\partial M/\partial p$ have already been observed by many workers[1] and agree well with the present measured values. For the iron-cobalt and iron-platinum alloys, $\partial M/\partial p$ has been measured by Ebert and Kussmann and also agrees well with the present measured values. Therefore, the thermodynamical relation is valid for all three alloys in the experiments.

In Fig. 3 the volume magnetostrictions at the liquid nitrogen temperature in iron-platinum alloys in the ordered and disordered

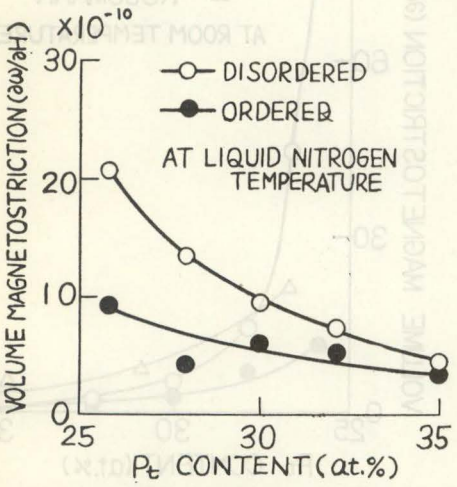

Fig. 3. Volume magnetostriction in iron platinum alloys measured at liquid nitrogen temperature.

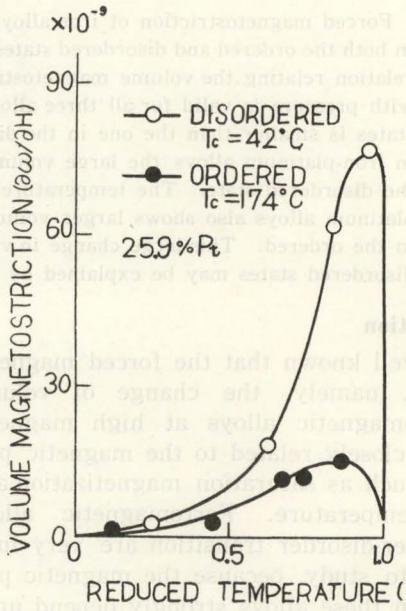

Fig. 4. Temperature dependence of volume magnetostriction in 25.9% Pt-Fe alloy.

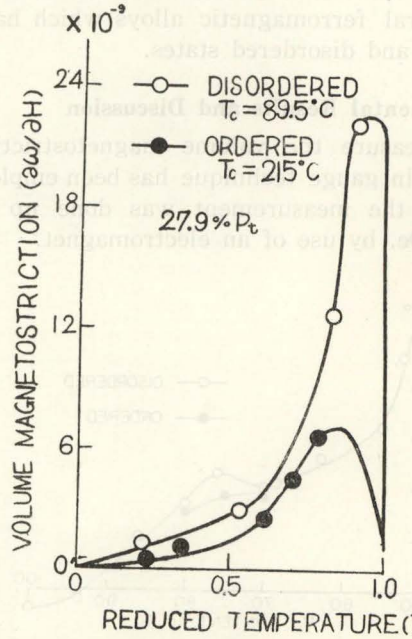

Fig. 5. Temperature dependence of volume magnetostriction in 27.9% Pt-Fe alloy.

states are shown. The temperature dependence of the volume magnetostrictions is shown in Fig. 4 and 5 for two alloys which have 25.9 and 27.9 atomic percents platinum, respectively. The abscissae are represented by the reduced temperature. It is noted, here, that the Curie temperatures in both their ordered and disordered states are far below their order-disorder transition temperatures (about 800°C), so that any change of ordering in the disordered samples should not appear by raising temperature in the experiments.

For discussing the effect of ordering upon the volume magnetostriction, the following relation will be considered:

$$\partial\omega/\partial H=(CK)(\partial J/\partial\omega)(I\partial I/\partial H)\,. \qquad (2)$$

Eq. (2) is easily obtained from Eq. (1) on the basis of the molecular field theory. Here C is the constant which depends on the numbers of the nearest neighbours, K the compressibility, I the intensity of saturation magnetization per unit volume and J the exchange integral. Now, since the fundamental change during the order-disorder transition is the change in the number of atomic pairs, the very large change of the volume magnetostriction between the ordered and disordered states would be explained by the model using pair interactions of spins, starting from the molecular field approximation. In the Eq. (2), I and K are presumed to be slightly large in the ordered state than in the disordered. J is approximately expressed as follows:

$$NZJ/2=Q_{AA}J_{AA}+Q_{BB}J_{BB}+Q_{AB}J_{AB}\,, \qquad (3)$$

where N is the total atomic number, Z the number of the nearest neighbours, $NZ/2$ the number of all pairs, Q_{AA}, Q_{BB} and Q_{AB} the numbers of A-A, B-B and A-B atomic pairs, respectively, and J_{AA}, J_{BB} and J_{AB} are the exchange integrals of these pairs, respectively. On differentiating Eq. (3) by ω,

$$(NZ/2)(\partial J/\partial\omega)$$
$$=Q_{AA}(\partial J_{AA}/\partial\omega)+Q_{BB}(\partial J_{BB}/\partial\omega)+Q_{AB}(\partial J_{AB}/\partial\omega) \qquad (4)$$

is obtained. Then, if A is an iron atom and B a platinum atom, J_{BB} is reasonably assumed to be zero. Q_{AA} and Q_{AB} change about 10 percent by the order-disorder transition. According to Sato's interaction curve[3] near the composition of Fe_3Pt, $\partial J_{AA}/\partial\omega$ is positive and $\partial J_{AB}/\partial\omega$ negative and their values scarcely change among the ordered and disordered states. The ratio of $\partial J/\partial\omega$ in the disordered state to the one in the ordered state is estimated to be 1.3 for the specimen with 25.9 atomic percents platinum roughly.

On the other hand, Néel[4] gave the following relation of the anomaly in thermal dilatation using the molecular field approximation,

$$\omega=\omega_0(I/I_0)^2 \qquad (5)$$

where ω_0 is the spontaneous volume change due to the ferromagnetism at $0°K$ and I_0 the intensity of saturation magnetization at $0°K$. From the Eq. (1)

$$(\partial\omega/\partial H)=(2\omega_0/I_0)I(\partial I/\partial H) \qquad (6)$$

is derived. From the data of the anomalies in thermal dilatation measured by Kussmann and Rittberg[5], the ratio of $(2\omega_0/I)$ in the disordered state to the one in the ordered state is roughly estimated to be 1.2 for the same composition. The value agrees with the above mentioned value of the ratio of $\partial J/\partial\omega$.

From these discussions, it turns out that $\partial I/\partial H$ in the disordered state will be about five times larger than $\partial I/\partial H$ in the ordered state for the alloy with 25.9 atomic percent platinum, so far as the molecular field treatment is valid.

References

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