Unidirectional anisotropy in Invar

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It is found that unidirectional anisotropy exists in Invar alloys containing 32% Ni, 62% Fe, and 6% Si at temperatures below 50°K. This confirms the suggestion that antiferromagnetic and ferromagnetic phases coexist in Invar alloys.

Alloys with invar composition are of interest to investigators because of their unusual physical properties. In 1960 Sedov and one of the authors [1] advanced first the hypothesis that the anomalies of the magnetic properties of the invar alloys can be attributed to the so-called "latent antiferromagnetism." It was assumed that in the γ phase of the invar alloy FeNi, the parameters of the exchange interaction energy of the electrons of the neighboring atoms, Ni—Ni and Ni—Fe, have opposite signs, negative for the Fe—Fe atoms. The possible occurrence of antiferromagnetism in the γ-iron lattice was confirmed experimentally by the characteristic temperature dependence of the susceptibility of the paraprocess [1,2] and by the temperature dependence of the Mössbauer spectra [3,4]. Using the results of the measurements of the rotational hysteresis of Fe—Ni alloys, Nakamura [3] estimated T_N of the antiferromagnetically ordered regions. It turned out that they lie in the temperature region 35—50°K. Neutron-diffraction investigations carried out by Dubinin et al. [5] confirmed the coexistence of paramagnetic and antiferromagnetic phases in Invar.

The purpose of the present study was to investigate the hysteresis loops of invar alloys at low temperatures (below 50°K) after cooling in a sufficiently strong magnetic field. In this case, if a shifted hysteresis loop were to be obtained, this would be new proof of the coexistence of ferromagnetically- and antiferromagnetically-ordered regions in the alloy.

The magnetization measurements were carried out by a ballistic method. To increase the sensitivity of the setup, we developed a compensation system that made it possible to receive simultaneously a signal from the sample in the measuring coil and to offset it by a signal from a secondary mutual-inductance coil. The signal from the sample was not completely compensated, and the signal difference was measured with an F190 high-sensitivity microweber meter. To decrease the measurement errors, particular attention was paid to stabilization of the current through the mutual inductance coil and through the solenoid in which the measurements were made. A current up to 500 mA was maintained constant within one μA. The compensation of the signal from the sample has made it possible to measure magnetizations on the order of hundreds of gausses with accuracy up to 0.1 G. The magnetic field was produced with a solenoid. An additional winding was wound on the solenoid to compensate for the earth's magnetic field. Experience has shown that in our experiments it is impossible to use a superconducting solenoid, since its residual field would distort the shape of the hysteresis loop and would introduce an error in the measured value of the coercive force.

The sample was prepared at the Precision-Alloy Institute of the Central Research Institute for Ferrous Metallurgy, in the laboratory of I. M. Puzeĭ, and its composition was 32% Ni, 6% Si, and the rest Fe. The silicon was introduced into the alloy to stabilize the γ phase upon cooling [6]. The sample was annealed for three hours at 1100° C and was then quenched in water.

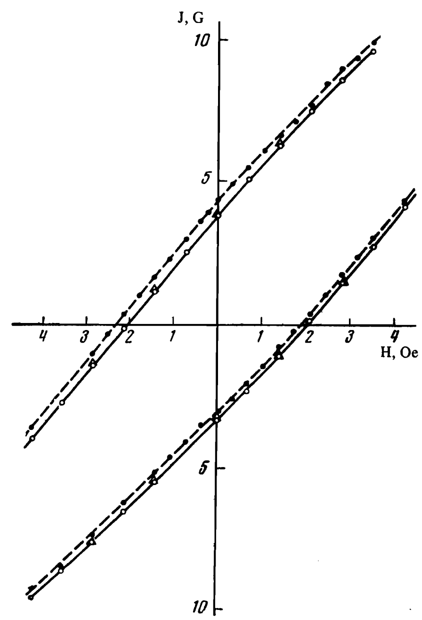

FIG. 1. Sections of hysteresis loops: the solid curve was obtained at 4.2°K for a sample cooled in a zero field, H_{max} = 106 Oe; the dashed curve was obtained after cooling the sample from 50 to 4.2°K in a magnetic field H_{cool} = 106 Oe = H_{max}; Δ—points of hysteresis loop obtained after secondary heating and cooling in a zero field from 50 to 4.2°K.

Nakamura [3] was unable to obtain a displaced hysteresis loop by using magnetic fields exceeding 15 kOe. Our earlier investigations of unidirectional anisotropy of high-coercivity Cu—Mn alloys have shown that a displaced hysteresis loop of alloys with small percentage content of Mn is obtained only up to definite values of the field. In strong magnetic fields, reorientation of the antiferromagnetic regions takes place. One might assume that the foregoing pertains to an even greater degree to the invar sample. Therefore measurements of the hysteresis loop were carried out in magnetic fields not exceeding 650 Oe.

Figure 1 shows sections of the hysteresis loops for the maximum field H_{max} = 106 Oe; these loops were obtained at 4.2°K after cooling the sample in a zero magnetic field and after cooling it from 50°K in a magnetic field H_{cool} = 106 Oe. The figure shows clearly the displacement of the second loop along the magnetic-field axis, amounting to 0.2 Oe. The hysteresis loop returned to its initial position after the sample was again heated to 50°K and cooled in a zero field.

Figure 2 shows hysteresis loops (H_{max} = 106 Oe) obtained at 50°K after cooling the sample from 120°K in a zero field and in a magnetic field of 106 Oe. In this case,

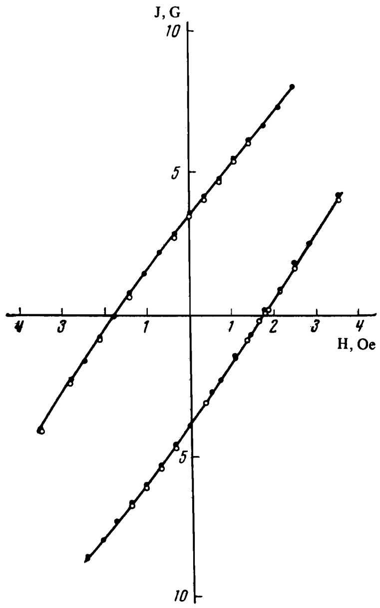

FIG. 2. Hysteresis loops at 50°K: O—for $H_{cool} = 0$, ●—after cooling from 120°K in a field $H_{cool} = 106$ Oe (in both cases, $H_{max} = 106$ Oe).

the hysteresis loops coincide. The same occurs at all temperatures above 50°K. Thus, the hysteresis loop of an invar alloy is displaced only at temperatures below the assumed Néel point of the γ-phase of the iron. These results agree with conclusions drawn in [1-3].

It should be pointed out that the hysteresis loops at a high value of the magnetic field ($H_{max} = 650$ Oe) turn out to be symmetrical regardless of whether the magnetic field is applied during cooling or not. The reason may be that the 650 Oe field is sufficient to reverse the orientation of the antiferromagnetically-ordered regions.

Figure 3 shows the change of the magnetization of the sample as a function of the temperature in a constant

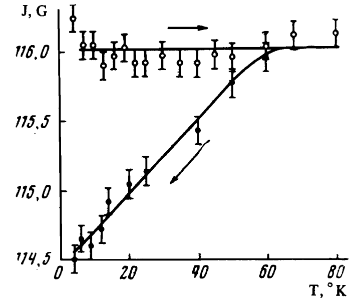

FIG. 3. The dependence of the magnetization on the temperature in a field H = 19 Oe. The upper curve was obtained as the sample was heated and the lower as it was cooled. Prior to the measurement, the sample was cooled from 50 to 4.2°K in a field $H_{cool} = 106$ Oe. The field H was applied in the direction of H_{cool}.

magnetic field H = 19 Oe. The upper curve corresponds to heating of the sample, and the lower to cooling. Prior to the measurements, to induce unidirectional anisotropy, the sample was cooled in a magnetic field $H_{cool} = 106$ Oe from 50 to 4.2°K. A magnetic field H = 19 Oe was applied in the direction H_{cool}. As seen from the figure, the unidirectional anisotropy is destroyed by heating in a weak magnetic field.

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Translated by J. G. Adashko
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