INTERNAL FRICTION OF SUBMICROCRYSTALLINE METAL

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The results of a study of the structure of submicrocrystalline metals conducted with the help of transmission electron microscopy, Mössbauer spectroscopy, and calorimetric measurements are presented. The effect of the special features of the microstructure on the amplitude and temperature dependences of the internal friction in submicrocrystalline copper and steel 12Kh18N10T is estimated.

In recent years physicists and materials technologists have devoted much attention to new materials with ultrafine grains [1 - 4]. Such are nanocrystalline alloys with a mean grain size of about 10 nm and submicrocrystalline (SMC) alloys with a mean grain size of about 100 nm. The great interest in ultrafine-grained alloys is due to the fact that their physical properties differ quite substantially from those of conventional materials with coarser grains. This opens new possibilities in the creation of materials with unique combinations of properties.

The internal friction is a very important property of metallic materials and has a theoretical and practical significance [5 - 7]. The problem of damping the vibrations of materials has to be solved in industry and in transport. However, the use of traditional methods for manufacturing high-damping materials (correction of the composition of the alloy, use of alloys with magnetomechanical energy dissipation, etc.) diminishes their strength properties [7].

We devoted the present study to the structure of SMC metals (Cu, Co, Fe, Ni, Pd) and the internal friction of SMC copper and corrosion-resistant steel 12Kh18N10T (<0.12% C, 17 - 19% Cr, 9 - 11% Ni, 0.4 - 0.7% Ti, <2% Mn, <0.8% Si).

The SMC structure of the metals was studied by the methods of electron microscopic Mössbauer and calorimetric analyses.

In [12] copper specimens were tested after an intense plastic deformation in a differential scanning Perkin Elmer DSC calorimeter with plotting of the DSC curves. The DSC curves of copper exhibited an exothermic peak near 200°C. An analysis of the experimental data with allowance for the results of a microdiffraction study has shown that the liberation of heat from the specimen is mainly provided by two processes, namely, the collective recrystallization and the transformation of the boundaries from a nonequilibrium state to an equilibrium one. The first process is responsible for about 0.34 J/g of the liberated heat, and the second one provides 0.20 J/g.
Fig. 1. Microstructure and an electron diffraction pattern (of a region with an area of 0.5 µm²) of copper specimens subjected to equichannel angular pressing (a) and subsequent annealing at 175°C for 1 h (b).

A Mössbauer study of SMC iron conducted with the help of a YaGRS-4 spectrometer in a regime of constant acceleration [13, 14] has shown that the superfine electric and magnetic structure of the SMC specimen has a composite nature that indicates the presence of metal atoms in two well-distinguishable states. In the first case the parameters typical for a conventional crystallographic state characterize the atoms inside the grains. The second state with changed (and, what is important, determinable) parameters is typical for atoms positioned in the neighborhood of grain boundaries at a distance of 11 ± 1.5 nm. The Debye temperature of these atoms is 200 K lower than that of the atoms inside the grains. This means that the atoms in the neighborhood of grain boundaries have an elevated dynamic activity.

Due to the special features of their structure, SMC materials have physical properties and, in particular, internal friction, that different from those of conventional materials with coarser grains.

We measured the internal friction δ of copper specimens and specimens of steel 12Kh18N10T using direct and inverse torsional pendulums; the deformation curves were obtained using an Instron testing machine. In order to form various structural states in the specimens of SMC copper, they were annealed at various temperatures after the plastic deformation.

Fig. 2. Amplitude dependences of the internal friction of copper subjected to intense plastic deformation (1) and subsequent annealing for 1 h at 150 (2), 175 (3), 250 (4), and 350°C (5) [15].

It has been established (Fig. 2) that the behavior of the amplitude dependence δ = f(δ) of the internal friction of copper specimens is affected considerably by the annealing temperature. The level of the background (the amplitude-independent part) of the internal friction is high and the amplitude dependence δ of specimens deformed (without annealing) and annealed at 150°C is rather weak. The background level in these specimens is 4.5 times higher than in coarse-grained specimens obtained by annealing at a high temperature. This level is 3 times higher than the damping level of gray cast iron (50 × 10⁻⁴), which is a criterion in determining the conventional limit [7] of high damping. The mean grain size in such specimens is 0.20 µm and the majority of the grain boundaries are in a nonequilibrium state (Fig. 1a). The most substantial changes in the internal friction occur in specimens after annealing at 175°C; the amplitude dependence increases markedly, and the background level diminishes to a value typical for coarse-grained copper. The mean grain size grows weakly, attaining d = 0.25 – 0.30 µm, and the fraction of boundaries having a strip contrast on the electron microscopic images typical for equilibrium boundaries increases (to 70 – 80%) (Fig. 1b). Annealing at 250 and 350°C causes the growth of the mean grain size to 1 and 5 µm, respectively, which is accompanied by a gradual return of the amplitude dependence of the internal friction to a form typical for coarse-grained copper.

When determining the temperature dependence of the internal friction (TDIF) [16] the specimen of the studied material was first heated from 4 to 400 K, then cooled to 4 K, and then the TDIF was measured in heating the specimen to a higher temperature (500 K). This experimental procedure was realized several times with increase of the maximum temperature to 500, 600, and 650 K, i.e., the measurements were conducted in several cycles.

Analyzing the data of Fig. 3 we can see that curve 4 is the closest to the TDIF of a conventional polycrystalline copper [17]. In this case the mean grain size in the copper specimen d = 8 µm. Curve 4 has a relatively weak low-temperature