HIGH-TEMPERATURE INTERNAL-FRICTION PEAK IN 99.999 wt % SINGLE-CRYSTAL ALUMINIUM

C. Su, T. Kê

To cite this version:

HAL Id: jpa-00225465
https://hal.archives-ouvertes.fr/jpa-00225465
Submitted on 1 Jan 1985

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L’archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.
HIGH-TEMPERATURE INTERNAL-FRICTION PEAK IN 99.999 wt % SINGLE-CRYSTAL ALUMINIUM

C.M. SU AND T.S. KÊ

Institute of Solid State Physics, Academia Sinica, Hefei, China

Abstract - An internal-friction peak situated at 365°C (f = 1 Hz) was recently observed by Kê et al. in 99.991 and 99.999 wt % aluminium single crystals prepared by the dynamic-annealing method and was considered as originating from the climbing of dispersive dislocations in aluminium. In this report, the condition for the appearance and disappearance as well as the peculiarities of this 365°C peak were studied systematically with 99.999 wt % aluminium single crystals subjected to various mechanical and thermal treatments.

I. Preparation of the Specimens - The 99.999 % aluminium was produced in China containing a very small amount of Mg and Si, and traces of Cu, Fe, Mn and Sn, and its nominal purity is 99.9993 %. Heavily cold-worked (swaging and drawing) 99.999 % aluminium wires (about 1 mm diameter) were annealed at 380°C for 2 h. They were deformed about 3 % by stretching at room temperature and put inside a tube furnace having a temperature gradient about 200°C/cm along the tube. The specimen was displaced in the furnace with a uniform speed of 2.5 cm/h. When the hottest part of the specimen inside the furnace was kept at a temperature about 560°C, single-crystal wire was obtained without containing any grain boundaries. The variation of the angle between the crystal plane and the specimen axis is smaller than 1° along the whole length of the specimen (12 cm). When the hottest part of the specimen was lowered to 460°C, "single-crystal" wire containing several bamboo grains of several cm long can also be obtained, and there are some small-angle grain boundaries with a deflection angle of about 5°.

II. Experimental Results - Internal friction was measured with a low frequency inverted torsion pendulum. The length of the wire specimen was 12 cm. The maximum strain amplitude on the surface of the specimen was lower than 10⁻³. All the internal friction curves (versus temperature) were obtained by measurements with descending temperatures.

II. 1. Effect of the method of growth and the procedure of heat treatment on the appearance of the 365°C peak.

1. Crystal grown by low-temperature dynamic annealing (460°C)

A specimen containing 4--5 bamboo boundaries in a length of 12 cm was annealed at 430°C for 2 h. The internal friction measured in descending temperatures is shown by curve 1 of Fig. 1. A low internal-friction peak appeared around 500°C which has been shown to be the macrocrystalline internal-friction peak. The specimen was then annealed in situ of the torsion apparatus at 600°C for 2 h. Then the temperature was lowered to 450°C and kept there for 2 h. Internal friction measurements were taken with descending temperatures and the internal friction curve obtained is shown by curve 2 of Fig. 1. It can

Article published online by EDP Sciences and available at http://dx.doi.org/10.1051/jphyscol:19851080
be seen that the 600°C annealing led to the appearance of a pronounced 365°C peak.

Figure 2 shows the internal friction curves of a crystal grown by low-temperature static annealing, which contains about 10 bamboo boundaries after an annealing at various temperatures. It is seen that the 365°C peak appears only after an annealing at 550°C.

2. Crystal grown by high-temperature dynamic annealing (560°C)
For such a crystal, the 365°C peak appeared after an annealing at 430°C as shown by curve 1 of Fig. 3. This happens because the crystal has been treated at a temperature higher than 550°C during its growth.

Previous experiments /1/ showed that the 365°C peak did not appear in a single crystal grown by zone-melting. This means that the condition for the appearance of the 365°C peak is that the specimen must be stretched (about 3% or so) and then subjected to static or dynamic...
annealing so that the specimen was heated up to a temperature above 550°C. In the case of growth by zone-melting, the growth process was proceeded by localized transformation between liquid and solid states so that the defect state in the single crystal grown should be quite different from those in the crystal which had not been subjected to local melting.

II. 2. Effect of tensile deformation on the height of the 365°C peak

In curve 2 of Fig. 3, the internal friction was measured from 430°C with descending temperatures down to the peak temperature (365°C) and then a tensile stress of \(2.9 \times 10^7\) dyne/cm\(^2\) was applied to the specimen in situ of the torsion apparatus for 150 s to reach an elongation of 5%. It is seen that the internal friction at 365°C dropped from A to B after this creep treatment. Then the temperature was raised to 620°C and kept there for 1.5 h, and the internal friction measured with descending temperatures is shown by curve 3. It is seen that the 365°C peak completely disappeared and the "macrocrystalline peak" reappeared. Laue analysis showed that the specimen was polygonized but there was no trace of fine grains formed by recrystallization.

Tensile deformation at room temperature has the same effect as creep deformation in suppressing the height of the 365°C peak. For very small deformation at room temperature or by creep, the 365°C peak can be partially recovered by a subsequent annealing at 600°C.

II. 3. Activation energy associated with the 365°C peak

The activation energy was determined by the method of change of frequency. Cautions were taken for avoiding the specimen to be subjected to deformation during the change of frequency. The average value of several measurements on different specimens is \(H = 1.84 \pm 0.1\) eV and \(\nu_0 = 1.4 \times 10^{14}\) Hz. Determination of the activation energy by using a force vibration pendulum in which the \(Q^{-1} - f\) curves were measured at various temperatures (T) gave similar results \((H = 1.81\) eV\) as those determined by measuring the \(Q^{-1} - T\) curves at various frequencies \((f)\). Curves 1--4 of Fig. 4 show the internal friction curves measured with 1, 0.464, 0.215, 0.100 Hz in the temperature range of 430 to 130°C.

II. 4. Amplitude dependence of the 365°C peak

In Fig. 5 is shown the amplitude effect of the internal friction curves of a crystal grown by low-temperature dynamic annealing with subsequent annealing at 430°C and at 600°C for 2 h. Curves 1 and 2. 450°C anneal, with strain amplitude \((A_\varepsilon)\): \(9.1 \times 10^{-6}\) and \(2.5 \times 10^{-6}\). Curves 3, 4, 5. 600°C anneal, with \(A_\varepsilon : 9.1 \times 10^{-6}\), \(6.5 \times 10^{-6}\) and \(4.5 \times 10^{-6}\). It is shown that, there is no amplitude effect for the macro-crystalline peak as shown by curves 1 and 2. Whereas anomalous amplitude effect appeared for the 365°C peak as shown by curves 3, 4, 5.
Fig. 5. The amplitude dependence of the macro-crystalline peak and the 365°C peak. Curves 1, 2: 430°C anneal for 2 h, for the macro-crystalline peak with $A_\varepsilon = 9.1$ and $2.5 \times 10^{-5}$. Curves 3, 4, 5: 600°C anneal for 2 h, for the 365°C peak, with $A_\varepsilon = 9.1$, 6.5, and $4.5 \times 10^{-5}$.

Fig. 6. The anomalous amplitude effect of the 365°C peak. Curve A, B, C corresponds respectively to the temperature marked on curve 3 of Fig. 5.

In Fig. 6 are shown the $Q^{-1} - A_\varepsilon$ curves at the three temperatures marked A, B and C on curve 3 of Fig. 5. It is seen that anomalous amplitude effect appears most pronouncedly near the peak temperature of the 365°C peak.

III. Discussions - Electron microscopic observations showed that under the conditions when only the 365°C peak appears, the dislocations in the specimen are arranged in an irregular spatial network in a dispersive and homogeneous mode. This is quite different from the highly inhomogeneous dislocation configuration in cell structures or polygonization boundaries.

In consideration of the magnitude of the activation energy and the attempted frequency associated with the 365°C peak as determined in the present experiments, this 365°C peak is considered as originating from the formation and the movement (climbing) of the jogs on the dislocations constituting the spatial network, and the anomalously amplitude-dependent effect is explained as due to the piling up of the jogs and the subsequent release because of the shift or the broken down of nodes of the dislocation network.

References