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HAL Id: jpa-00223437
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Submitted on 1 Jan 1983

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INTERNAL FRICTION IN DEFORMED CuAl SOLID SOLUTIONS

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Abstract - The internal friction of deformed (ε ≤ 2.5 %) CuAl single crystals (0.07 to 0.8 at % Al) was investigated in the temperature range 100 - 650 K at 90 Kc.

Two small peaks and a larger one were observed below and just above room temperature. Their peak temperatures depended systematically on the Al content and slightly on the degree of deformation. The height of the smaller peaks was very sensitive to the thermal treatment of the specimens. These dependencies can be explained within the framework of the Labusch-Haasen theory if one assumes an interaction between dislocations and Al-atoms and Al-vacancy complexes, respectively, for the small peaks. An interaction energy of about 0.6 eV is derived in the former case.

1. INTRODUCTION

In a number of papers /1,2,3/ Labusch and Haasen have developed a statistical theory of the solid solution hardening of dilute alloys. An important aspect in their model is the interaction between dislocations and the point defects. The authors have shown in a recent paper /4/ that it may eventually be possible to study this effect separately by internal friction measurements. The theory predicts that a dislocation in the vicinity of an obstacle due to the repulsive interaction can assume two equilibrium positions (y', y'') (s. Fig. 1).

Fig. 1 - The two equilibrium positions (y', y'') of a dislocation near a repulsive obstacle

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Thermally activated jumps between these two positions can be treated as a relaxation process and should lead to an internal friction maximum at low temperatures in the kilicycle range. An important prediction of the model is a dependency of the activation energy on the defect concentration.

To confirm their model internal friction measurements in deformed CuAl solid solutions were carried out in the kc range.

2. EXPERIMENTAL PROCEDURE

For the internal friction measurement in the kc range a technique was employed originally developed by Schwarz /5,6,7/. Rod-like specimens with a square cross section are glued to a single quartz transducer with a matching frequency of approximately 90 kc. This two component oscillator is hung between two thin copper wires and excited to vibrations by an electronic feedback circuit. The measurements are carried out at a constant amplitude and allow a low background damping (Fig.2). The CuAl single crystals were grown by the Bridgman technique with a <100> direction parallel to the long axis and their exact length was cut by spark erosion. The crystals with an Al-content varying between 0.07 and 0.8 at % were deformed under pressure at room temperature to a maximum strain ε ≤ 2.5 % and then glued to the quartz crystal. The internal friction was measured in the temperature range 100 - 650 K. The background damping mainly due to the glue and the friction between the quartz crystal and the supporting wires is shown in Fig. 2. Samples showing an internal friction peak were successively deformed again together with the quartz crystal in order to study the dependency of the peaks on the degree of deformation.

3. EXPERIMENTAL RESULTS

It is an essential feature of the measurements that the specimens behave quite different below and above room temperature, therefore the results shall be discussed separately. The internal friction of the specimens which were deformed at room temperature and then heated to a temperature above room temperature decreased approximately exponentially with time. Therefore during one heating cycle the

![Fig. 2 - Internal friction measurement of a deformed CuAl sample (11.3 MPa, 0.8 at %) which shows a peak at 80 °C (P). Cementing two quartzes together (99 and 96 kc) the underground (glue) was measured.](image1)

![Fig. 3 - Second measurement of the peak. Frequency curve with a small step and the numeric differentiated frequency curve with a maximum at the same temperature.](image2)
Damping was usually much lower cooling down the specimens (Fig. 2). Keeping the samples at 150 °C for about one hour was usually sufficient to reach the saturation level of the internal friction. It is assumed that some point defects may be created during the deformation procedure migrate toward the dislocations and decrease the average dislocations length L.

Apart from this time dependent decrease of the damping an internal friction maximum (P2) is observed both during heating-up and cooling-down. A typical measurement of a newly deformed specimen with an Al-content c = 0.8 at % is given in Fig. 2. After a heat treatment at 150 °C the peak shape is given in Fig. 3. The corresponding frequency versus temperature curve shows a small step at the same temperature typical for a single relaxations process.

Below room temperatures two smaller peaks (P1, P2) can be observed with peak heights varying between (1 - 50) \cdot 10^{-5}. They were not very reproducible and their occurrence and height was sensitive to the thermal treatment of the samples before and after the deformation (holding the specimen above room temperature). A typical measurement is shown in Figure 4.

![Image of Figure 4: The two small peaks P1 and P2](image1)

![Image of Figure 5: Dependency on the peak height from deformation](image2)

The temperatures at which all the peaks (P1, P2, P3) appear are only slightly and the peak heights, however, strongly depending on the degree of deformation (Fig. 5). Since with increasing deformation the dislocation density N increases, the average dislocation loop length L, however, decreases. One may explain the observed maximum if \( \frac{1}{Q_{\text{max}}} \) follows the frequently derived relation /4,6/.

\[ Q_{\text{max}}^{-1} \sim NL^2 \]

A quantitative comparison involving the determination of both N and L has not been tried.

The most important feature of each peak is, however, that the maximum temperature is depending on the concentration of Al-atoms. Some typical results are given in Fig. 6 for the peaks P1, P2, P3.
4. DISCUSSION

The dependence of the peak temperatures and heights on the degree of deformation and the Al-content suggests that the underlying process is the interaction of dislocations with some point defects involving the aluminium substitutional atoms. The dependence of the peak temperature on the Al-content is in accordance with the predictions of the Labusch-Haasen theory which is approximately given by /4,6/

\[ T_{\text{max}}^{-1} = \frac{k}{E} \ln \left( \frac{\omega}{2 \nu_0} \frac{S_0 + S}{S_0} \right) \]  (1)

\( E \) is the activation energy of the relaxation process with a jump frequency \( \nu = \nu_0 \exp(-E/kT) \). \( E \) is depending on the obstacle concentration \( c \)

\[ E = E_{\text{max}} (1-0.595 \eta_0^{1/3})^2 \]  (2)

with \( \eta_0 \) the normalized obstacle width

\[ \eta_0 = \left( \frac{4/3 \, \mu \, w^3}{E_{\text{max}}} \right)^{1/2} \]  (3)

\( E_{\text{max}} \) maximal interaction energy, \( \mu \) shear modulus, \( w \) obstacle width. \( S \) and \( S_0 \) are defined in the Labusch-Haasen theory /4/ as follows (\( b \) Burgers vector)

\[ S_0 = 4/3 \, b \, L^2 \] and

\[ S = 0.816 \, \frac{E_{\text{max}} c}{w \, b} \eta_0^{1/2} (1.68-\eta_0^{1/3})^{1/2} \]  (4)

Since our observations prove that the large peak \( P_3 \) is very reproducible we assume that it is this one which is due to the interaction with the aluminium atoms. Equation (1) was therefore fitted to all experimental data yielding three parameters \( E_{\text{max}}, \nu, \omega \) (Fig. 6). The maxima \( P_1, P_2 \) were very sensitive to the thermal treatment of the specimens therefore one may conclude that the interaction of dislocations with an aluminium - vacancy complex is responsible for their occurrence. Given that this interaction can still be described by the Labusch and Haasen theory one can again apply equation /1/ to describe the data. All resulting parameters are given in Table 1 for different degrees of deformation and agree quite reasonable with each other. The derived interaction energies \( E_{\text{max}} \) are on the order of half an electron volt and smaller for the dislocation interaction with an aluminium-vacancy complex. One may speculate whether the two peaks \( P_1, P_2 \) arise because of two types of dislocations (screw and edge) or two different aluminium complexes, however, that point shall not be discussed further.

One may add that equation /1/ yields a slight dependence on the degree of deformation \( \tau \) if \( L \sim 1/\tau \) as has actually been observed /6,7/.
Summarizing the results we have demonstrated occurrence of an internal friction peak in the Kc range which shows all features of a dislocation point defect interaction process as predicted by the Labusch-Haasen theory.

<table>
<thead>
<tr>
<th>ε(%)</th>
<th>σ(MPa)</th>
<th>Parameter</th>
<th>( P_1 )</th>
<th>( P_2 )</th>
<th>( P_3 )</th>
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<tr>
<td>0.1</td>
<td>1.8</td>
<td>( E_{\text{ww}} ) (eV)</td>
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<td>2.0</td>
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<td></td>
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<td>( N ) (b)</td>
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<td></td>
<td></td>
<td>( v_0 ) (Hz)</td>
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<td>1.1</td>
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<tr>
<td></td>
<td></td>
<td>( E_{\text{ww}} )</td>
<td>0.36</td>
<td>0.51</td>
<td>0.62</td>
</tr>
</tbody>
</table>

REFERENCES

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/4/ Labusch, Haasen, Proceed. ICSMA 4, (1976) p. 246

