INFLUENCE OF PLASTIC DEFORMATION ON INTERNAL FRICTION OF ALUMINIUM WITH OIL LAYER

B. Augustyniak, G. Fantozzi, W. Chomka

To cite this version:

HAL Id: jpa-00223423
https://hal.archives-ouvertes.fr/jpa-00223423
Submitted on 1 Jan 1983

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.
INFLUENCE OF PLASTIC DEFORMATION ON INTERNAL FRICTION OF ALUMINIUM WITH OIL LAYER

B. Augustyniak, G. Fantozzi* and W. Chomka**

Institute of Physics, Technical University of Gdańsk, 80-952 Gdańsk, Poland
*I.N.S.A. de Lyon, Bât. 502, Physique des Matériaux, 69621 Villeurbanne Cedex, France
**Centre Universitaire de Batna, Batna, Algeria

RéSUMÉ

Les spectres de frottement intérieur d'échantillons d'aluminium /99,999 %/ recouverts d'une fine couche d'huile dépendent du taux de déformation plastique de l'échantillon. Pour les échantillons recuits, le pic d'huile apparaît vers 205 K, la temperature de solidification de l'huile. La déformation plastique augmente le pic d'huile jusqu'à un taux de l'ordre de 4 % et crée un nouveau pic à plus haute température. Les résultats sont discutés en fonction de la nature de la couche superficielle.

ABSTRACT

Low temperature internal friction spectra for Al sample (99.999) with thin parafin oil layer depend on the amount of plastic deformation in the metal. For annealed samples, single oil damping peak appears at melting temperature $T_p = 205$ K. Plastic deformations up to 4% increases the oil maximum and creates a new oil peak at higher temperatures. Results are qualitatively discussed as a function of the nature of the surface layer.

INTRODUCTION

Low temperature internal friction spectrum for the samples covered with a layer of mineral oil or hydrocarbon shows one distinct peak at the melting temperature $T_p$ of the layer. This internal internal friction maximum is due to the solidification process of the layer [1, 2]. For the samples of different metals covered with the same layer of mineral oil, a simple peak or a complex spectrum of internal friction was observed [3]. Those oil peaks anneal out after heating at the decomposition temperature of tested oil.

The nature of the internal friction spectrum should be attributed to the surface layer properties and not only to the base properties of oil.

The aim of the present work is to find the condition in which the complex internal friction spectrum is obtained.

This paper presents the results of the initial measurements. The internal friction of pure Al metal with a layer of the mineral oil for diffusion pump was measured. Aluminium was chosen for the
study because it has a simple microstructure. The internal friction was measured as a function of the temperature after different mechanical and thermal treatments of the specimens.

**EXPERIMENTAL PROCEDURE**

The measurements of the internal friction were performed with a torsional pendulum oscillating at 0.5 to 2 Hz [4]. The vibration amplitude was constant and the energy loss due to the internal friction was automatically recorded. The heating rate was 0.2 K/min. The range at the temperature change was 80 to 300 K.

High purity samples of Al (99.999) had a form of plate (1. 4. 50 mm). They were annealed at 730 K for 3 hours. The annealing process was performed in argon atmosphere.

The thin layer of the mineral oil was put on the metal surface by greasing with a brush.

It is known that similar internal friction spectra were obtained with the samples either immersed or quenched in oil [3]. Generally, the oil internal friction spectrum does not depend on the method of coating.

During cleaning, the samples were removed from the apparatus. They were cleaned with a ethyl ether in an ultrasound cleaning machine for 20 to 30 min. The aluminium specimens were electrolytically polished too.

Plastic deformation of the aluminium samples, at room temperature, was obtained by twisting in the pendulum [5].

The internal friction measurements were made as a function of the temperature for different amplitudes of vibration. In order to study the internal friction spectrum as a function of the surface condition of the sample, the annealed aluminium samples were plastically deformed.

The first experiment was made with the non-polished aluminium sample. The internal friction spectrum was examined for the different vibration amplitudes. The results are plotted in Fig. 1.

The internal friction spectrum for the annealed aluminium is well known [6, 7]. At low temperatures the Bordoni internal friction peaks appear and at high temperatures the background internal friction increases exponentially. In the present work the measurements were carried out in a temperature range where no peak is observed.

At first, the internal friction for the non-coated sample was measured. The results, illustrated by curve a in figure 1, agree with the known internal friction spectrum [6]. After coating the oil damping peak appears at $T_D = 205 \pm 3$ K, as shown in Fig. 1 by curve b. At higher vibration amplitude, this peak appears also but it is mixed with the high internal friction background (curve c in Fig. 1). Secondly, this sample was plastically deformed ($\varepsilon = 2\%$) in situ. After this, an additional internal friction peak appears (curve d Fig. 1). This new peak is linked to an interaction of the oil layer with the deformed metal surface. This supposition was confirmed experimentally as follow. At first, the vibration amplitude is decreased and so the two peaks are better defined (curve e in Fig. 1). These peaks disappear after a cleaning procedure (curve f) but they appear again when the sample is covered by the oil (curve g in Fig. 1). Quantitatively,
the same results are obtained for the electrolitically polished aluminium sample.

To study more quantitatively these phenomena, new experiments were carried out for different plastic deformation ratios. An annealed and polished aluminium sample was first coated and then gradually deformed up to $\varepsilon = 4\%$. The results of these experiments are plotted in Fig. 2. As usually, the first spectrum was measured for the non-coated sample (curve a in Fig. 2), and the next peak increases during additional plastic deformation as shown by curves c through g in Fig. 2. The plastic deformation increases the background internal friction too. The curve h in Fig. 2 shows the internal friction spectrum after cleaning. The background internal friction is higher than for the undeformed sample (curve a). The plastic deformation also influences the shear modulus variations, as shown in Fig. 3. For better comparison the experimental results are calculated with respect to the room temperature values of the coated annealed sample (curve b in Fig. 3).

The plastic deformation causes a negative shear modulus defect for the pure aluminium sample [7]. This modulus defect increases with temperature and with plastic deformation, as shown by Fig. 3. Shift of the curves a and b or h and g (Fig. 3) is caused by dismantling of the pendulum for coating and cleaning the sample, respectively.

**DISCUSSION**

Results presented above show that oil internal friction spectra depend mainly on the surface state of the sample. In the case of aluminium the plastic deformation creates a new internal friction peak.

Let us present some features of the oil internal friction which have been revealed. At first, we have examined the relationship between the height of the oil damping maximum and the vibration amplitude value. The heights values $q_m$ were estimated as above and only when this maximum is well defined. The results show that the oil internal friction does not depend on the vibrational amplitude. We think that the applied stress does not change the surface metal layer because it is lower than the microelastic limit.

Figure 4 shows the oil damping maximum heights $q_m^{-1}$ as a function of the shear modulus defect value $\Delta G$. The modulus defect $\Delta G$, due to the oil layer, was calculated from the relation:

$$\Delta G = G/G_0 - 1,$$

where $G$ and $G_0$ are shear modulus of a coated and noncoated sample, respectively. This defect is calculated for a temperature below $T_D$. It is important to know the relationship $q_m^{-1}(\Delta G)$ for a better physical interpretation of the observed oil maximum. It should be emphasized that this relationship is independent of the metal sample. Some aluminium results differ from the linear dependence but these results have been calculated for highly coldworked sample (curves f, g and h in Fig. 2). In this case, we observe a shear modulus defect greater than as expected. Probably that is the result of superposition of the two processes linked to the two oil internal friction peaks.
For the low shear modulus defect values, the relationship was estimated by the linear expression: \( Q_m^{-1} = (0.2 \pm 0.05) \Delta G \). The factor value is smaller than as for a single relaxation process. This difference suggests that the oil internal friction can be treated phenomenologically as a result of one relaxation process with a relatively broad relaxation time spectrum. It is important to emphasize that such low factor values are equally obtained for another oil or hydrocarbon layers and another metal samples [1, 2, 3].

The last relationship concerns the influence of the plastic deformation ratios on the oil internal friction spectrum. The internal friction spectra, as shown by Fig. 2, were examined in order to find the heights of the two oil peaks. Results of the calculation are plotted in Fig. 5. It can be seen that in each case, the plastic deformation increases oil damping. The amount of plastic deformation above 3 to 4% does not increase more results in a further of \( Q^{-1} \) values. It is known that such high plastic deformation leads to a stable microstructure of aluminium [7], and it changes also the surface properties of the sample [6].

The thin oxide film is mechanically much stronger and tolerates much more plastic deformation before failure than the corresponding oxide in bulk. With a strain of about 2%, the thin oxide film on aluminium is still be having elastically but it was shown that the oxide film of thickness of about 400 Å fractures at strain higher than 2.5% [9]. We think that the features of the \( Q^{-1} \) dependence as presented by figure 5, can be correlated with the fracture of an oxide layer on metal surface.

The oil damping spectra obtained for the annealed samples seem to result from one process which leads to the single asymmetrical maximum. For describing this process, only qualitatively, we suppose at first that the oil layer is put on the clean elastic metal surface. Near by, the \( T_f \) temperature during cooling, the oil layer can be treated as viscous. The rheological properties of such simple composite can be described by the Zener model [11]. More detailed theoretical calculations for the glass-metal composite were carried too [12]. These mathematical treatments lead to the conclusion that the height of oil maximum is dependent on the layer thickness and on the metal sample diameters. The experimental results for the thin oil layers show that the oil damping maximum is not dependent on the layer thickness but, as was shown above, rather on the microstructure of the metal surface. This discrepancy can be eliminated by the assumption that the oil damping is linked only to an effective surface layer, with a thickness much smaller than the real thickness of the oil layer. Probably, only the nearest oil layer part interacts with the oxide metal surface and participates in the internal friction phenomena. The effective thickness of the external layer is not precisely defined. This layer is composed mainly of the oxide layer which is saturated by the oil molecules. By the plastic deformation we increase the effective thickness of the external layer. This leads, with the agreement to the phenomenological model to an increase of the oil damping maximum. The new oil damping maximum appears for plastically deformed aluminium samples. This new maximum dependent on the deformation ratio as shown by Fig. 5 and does not depend on the vibration amplitude. It can also be seen that the new oil damping maximum is followed by the relatively small shear modulus defect, as shown by Fig. 3. Presently, we cannot give the real
physical model for this phenomena. We suppose that the new internal friction peak is due to the irreversible motions of the oil molecules between the surface steps in oxide layer. Plastic deformation creates the steps by the partial fracture of the metal oxide layer. These steps are the sources of electrostatic forces which influence the condition of interaction between the oil molecules and the metal atoms.

CONCLUSIONS

The object of this paper is to examine the properties of the low temperature internal friction spectra of the Al metal samples as covered with the mineral oil layer. From this study the following conclusions may be drawn.

1. For the annealed samples the single asymmetrical oil internal friction maximum appears. It is independent of the vibration amplitude of the sample up to \( \gamma = 10^{-4} \). The damping maximum is followed by the shear modulus defect. It is found a linear relationship between the height of the internal friction maximum \( Q_m^{-1} \) and the modulus defect value \( \Delta G \): 
\[ Q_m^{-1} = 0.2 \Delta G. \]
The low value of the factor indicates that the oil damping can be phenomenologically described by the relaxation process with the broad relaxation time spectrum.

2. The complex internal friction spectra were obtained for the coldworked samples. The plastic deformation of the Al-sample is the causes of the new oil damping maximum at higher temperatures. Probably this internal friction is due to the irreversible movements of the oil molecules on the surface oxide steps which are created during plastic deformation.

Acknowledgments

These experiments were made during the stage supported by C.I.E.S. in the I.N.S.A. Laboratory. The authors wish to thank Mr. J. Perez and Mrs. E Denga for many helpful discussions.

REFERENCES

5. FANTOZZI G., Thése, INSA Lyon, 1971.
Fig. 1. Internal friction spectra of aluminium: a,f-uncoated, d - ε = 2%.

Fig. 2. Internal friction spectra of gradually deformed sample: a,h - uncoated.

Fig. 3. Shear modulus spectra of gradually deformed sample.

Fig. 4. Low temperature oil maximum height vs. modulus defect.

Fig. 5. Low /a/ and high /b/ temperature oil damping vs. plastic deformation.