Internal Friction in Commercial Aluminium Alloy AW-2007

Peter Palček\textsuperscript{a}, Jakub Porubčan\textsuperscript{a,∗}, Dalibor Blažek\textsuperscript{a} and Zuzanka Trojanová\textsuperscript{b}

\textsuperscript{a}University of Žilina, Faculty of Mechanical Engineering, Department of Material Science, Univerzitná 1, SK-010 26 Žilina, Slovak Republic

\textsuperscript{b}Charles University in Prague, Faculty of Mathematics and Physics, Department of Physics of Materials, Ke Karlovu 5, CZ-121 16 Praha 2, Czech Republic

Abstract

The aim of this work is to state internal friction on stress amplitude dependence in an experimental aluminium alloy AW - 2007. Dependence was examined on sample made of extruded material after annealing at the temperatures of 200 °C and 250 °C. Annealing at the increased temperature has significant effect on dislocation structure. All slip systems are activated in material and thermally activated dislocation transport also occurs. At the same time the annihilation of dislocations with opposite direction occurs. The Frank-Read sources are removed. After quenching at the room temperature the relatively immobile dislocation forest is present in the material that does not contribute to the internal friction and does not generate new dislocations. The amplitude dependence of internal friction can be described by Granato and Lücke model, which presumes the existence of weak attached barriers in slip plane of dislocation. This model involves average dislocation length, Young's elasticity modulus, interaction energy between dislocations and pinning points, magnitude of Burgers vector.

The method of quality of resonant system was used to measure the internal damping. All experiments were carried out at the frequency range of 20 kHz at the room temperature.

Keywords: Internal friction; Aluminium alloy; AW – 2007; Annealing; Dislocation

1. Introduction

Aluminium alloys are one of the most important non-ferrous metals today. They have very useful properties and they are widely used in many fields. These materials become of special importance in many applications, especially in the automotive and aviations industry. Engineering importance of aluminium alloys has risen recently. The automotive industry has a growing interest in aluminium alloys as a structural material that may reduce fuel consumption of cars and exhaust emissions. Aluminium

\[ \text{Jakub Porubčan. Tel.: +421 41 513 2632; fax: +421 41 565 2940.} \]
\[ \text{E-mail address: jakub.porubcan@fstroj.uniza.sk.} \]
materials are promising materials because of their low density, high specific strength and high corrosion resistance. Aluminium alloys are easy to recycle; consequently their production is economic and ecological [1].

The internal friction (IF) is an energy dissipation, connected with deviations from Hooke’s law, which is manifested by stress-strain hysteresis, in the case of cyclic loading. The corresponding energy absorption $\Delta W$ during one cycle, divided by the maximum elastic stored energy $W$ during that cycle, defines the specific damping capacity $\Psi = \Delta W/W$, or the loss factor $\Delta W/2\pi W$, as the most general measures of internal friction, for which no further assumptions are required. The reciprocal loss factor is also called the quality factor $Q = 2\pi W/\Delta W$, so that internal friction (or damping) can generally be written as [2, 3]

$$Q^{-1} = \Delta W/2\pi W = \Psi/2\pi.$$

(1)

This contribution is about the amplitude dependent internal friction in commercial aluminium alloy AW-2007 after annealing in different temperatures (200 °C and 250 °C) measured at room temperatures. This method is very efficient in studies of dislocation properties, as shown for other aluminium alloys [4, 5, 6, and 7]. The most important mechanisms that contribute to IF are dislocation movement, slip on grains boundary and twinning. Among these anelastic processes the microplasticity and dynamic modulus changes can be observed.

2. Experimental

2.1. Microstructure

The aluminium alloys EN AW-2007 was used for IF measurement. Experimental alloy was founded on the Al-Cu-Mg base with addition of lead to improve machining. Internal friction specimens were machined out of extruded rods without heat treatment. The chemical compositions of this material are given in Table 1.

The microstructure of experimental alloy in as cast state consists of substitute solid $\alpha$ phase and some intermetallic phases, primarily based on: Al-Cu (MgPb), Al$_2$Cu, Al-Cu (FeSiMn) (Fig. 1a) [8, 9]. The extruded material has been squeezed by very high speed. In material, plastic deformation arises and new deformed structure (fibrous structure) emerges (Fig. 1b).

![Microstructure of experimental material EN AW-2007](image1.png)

Fig.1 Microstructure of experimental material EN AW-2007 (a) as cast, non-etched, (b) as extruded, longitudinal direct, etched HF.
2.2. Internal friction method

The method of resonant system quality was used for the internal damping measurement. For this method it is necessary to use a specimen, frequency of which is similar to the frequency of the whole resonant system, which was 20.4 kHz. During the measurement, the resonant frequency of specimen little decreased due to microplastic deformations. The resonant system was actuated by piezoceramic elements. The vibration amplitudes of specimen were controlled by loading voltage amplitude and measured by electric current in circuit. The experiment was controlled by computer [10].

The specimens were investigated in extruded state after annealing at the temperatures of 200 °C and 250 °C.

3. Results and discussion

The dependence of internal friction on applied stress was measured with the goal to investigate the influence of temperature on material properties.

In Fig. 2a the characteristic process of one ADID curve measurement is presented. First, the stress amplitude is rising from zero up to the maximum load. Next, the specimen is hold at maximum stress amplitude for about 5 minutes. Last, the stress amplitude decreases. In Fig. 2b and Fig. 2c the measured internal friction is presented. Different regimes of dislocation behavior were observed. First the little drop until the critical amplitude is reached (A), next the damping is growing up due to movement of unpinned dislocations. If the maximum vibrations amplitude of previous experiments is exceeded (B), the microplastic deformation occurs. At this moment the measured internal damping becomes unstable. When the amplitude of vibrations is held constant, the dislocations multiply it and hysteresis abolishes (C). If the amplitude of vibrations decreases, the internal friction decreases too (D). Next run follows after 30 minutes break.

Fig. 3a shows characteristic dependence of IF on applied stress for specimen which has been annealed at the temperatures of 200 °C. Measurement method is showed in Fig. 2. The initial IF of all measured cycles was the same. The consecutive decrease was measured in all runs. Short plateau follows next till the maximum amplitude of vibrations was reached. The microplastic deformation was not observed. It was caused by high dislocation density forest and residual stress after previous mechanical treatment. If
applied temperature was not high enough, immobile dislocation predominate in material. These dislocations do not move and also do not contribute to IF. At last, the stress amplitude decreases with decreasing amplitude of deformation.

In every run the drop of basic value of IF was evident. It is influence of cyclic loading on dislocations in material. Dislocations probably keep rising their density after each cycle. Next run follows 30 minutes after last run. Dislocations which are in material have enough time to relax. Thus the start points were in each cycle on the same place. One can see that 200 °C was a low temperature that did not removed deformation and residual stress away.

Fig.3 Amplitude dependent internal friction measurements on samples which were annealing at the (a) 200 °C/2 hours, (b) 250 °C/2 hours.

The behaviours of amplitude dependent IF were also measured after annealing at 250 °C. Fig. 3b shows characteristic ADID loops measured in cycles. Temperature at 250 °C was sufficiently high to partially remove deformation and residual stress after mechanical treatment. After this heat treatment it was possible to study changes in amplitude dependent IF.

Annealing at this temperature has significant effect on dislocation structure. All slip systems are activated in material and thermally activated dislocation transport also occurs. At the same time the annihilation of dislocations with opposite direction occurs. Decreasing the length of dislocations result to the end of Frank - Read source. After quenching at the room temperature non-transportable dislocation forest is present in the material that does not contribute to the internal friction and does not generate new dislocations.

On curves, the displacement of characteristic triangle progress, which appear when microplastic deformation take place was observed. This displacement into higher deformation amplitudes was linked with changes of dislocation forest structure and mainly with pinned and unpinned dislocations. Dislocations unpinned in previous cycle at the critical stress amplitude $\varepsilon_{cr2}$ were pinned at the points which must overcome as last. Reverse move of dislocations was possible only if the stress amplitude to overcome obstacles in the opposite direction. This behaviour describe Granato and Lücke model [11, 12].

If the stress amplitude achieves critical stress amplitude $\varepsilon_{cr2}$, the cyclic microplasticity in suitable oriented grains occurs. If the amplitude of vibrations is held constant, the density of dislocations grows up and the dislocation forest saturates itself. The IF is falling down and critical stress amplitude $\varepsilon_{cr2}$ grows up to the actual amplitude of deformations. In the first cycles the increases of dislocation forest density were
relative small, because microplasticity deformation was observed only in some grains. In the next cycles, 
the number of grains, where amplitude of deformation overcomes the critical value, gradually increases 
[13]. The maximum of IF is higher too.

During measurement specimens passed through fatigue process. One run of measurement takes about 
700s which present 1,4x10^7 cycles, at the maximum stress amplitude it is about 6x10^6 cycles. In the Fig. 
2 b one sample which reaches fatigue life in the fifth cycle, is also shown.

4. Conclusions

- The amplitude dependence of internal friction after annealing (at 200 °C and 250 °C/2 hours) 
  was measured and the evolution of ADID curve was observed on extruded commercial aluminium alloy EN AW – 2007.
- The annealing temperature has significant influence of dislocations density, structure of 
  dislocation forest and also their mobility. With higher temperature of annealing density of 
  dislocation and residual stress decreases.
- It was not possible to confirm validity of Granato and Lücke model mathematically, because 
  critical stress amplitude was near that model.
- During measurement the displacement of characteristic triangle progress was observed. This 
  displacement is linked with cyclic microplastic deformation of experimental material and 
  increases of critical amplitude of vibrations \( \varepsilon_{cr2} \).
- Cyclic microplasticity does not influence the basic value of internal friction only when the 
  samples was annealing at 250 °C, for samples annealing at 200 °C the basic value of internal 
  friction gradually decrease in each measured run.
- Specimens pass through fatigue process during measurement. They were loaded 
  approximately 1x10^7 cycles in each measured run.

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