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Deformation behavior of a modified 5083 aluminum alloy

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Abstract

The deformation behavior of a 0.2% Zr and 1.6% Mn modified 5083 aluminum alloy was studied in the temperature range of 250–570 °C over seven orders of magnitude of strain rates. It was shown that the modified 5083 alloy exhibits threshold behavior in the temperature interval of 250–500 °C. There exists a temperature dependence of threshold stress with the energy term Q_o = 18 kJ/mol. It was shown by transmission election microscopy that detachment of dislocations from dispersoids under extra force takes place. Threshold stress tends to disappear with increasing temperature at $T > 500$ °C despite the fact that evidence for interactions between mobile dislocations and dispersoids was found at these temperatures. Analysis of creep data in terms of threshold stress revealed three different types of deformation behavior. At high values of normalized strain rate, $\dot{\varepsilon}kT/(D_1Gb) > 4 \times 10^{-8}$, the exponential law creep takes place. At normalized strain rates, $\dot{\varepsilon}kT/(D_1Gb)$, ranging from 4×10^{-8} to 4×10^{-14}, the n value is ∼4 and the true activation energy, Q_c, is equal to 139 ± 12 kJ/mol, suggesting high temperature dislocation climb. At low normalized strain rate, a transition to Newtonian viscous flow occurs.

Keywords: Creep; Deformation mechanism; Al–Mg alloy; Threshold stress; Dispersoids

1. Introduction

It is known that aluminum alloys containing unshearable dispersoids normally exhibit a superior creep resistance at elevated temperatures due to the presence of a threshold stress, below which the strain rate is assumed to be negligible [1–12].

Threshold behavior of dispersion-strengthened aluminum alloys is originated from very fine particles impeding the motion of lattice dislocations [3–8]. In the aluminum alloys and discontinuous aluminum matrix composites produced by powder metallurgy (PM) these dispersoids can be oxides resulted from the technological route [4,5–7]. These oxides serve as effective barriers to dislocation motion and give rise to the threshold stress for creep [4–11]. As a result, the creep strain rate in these materials is essentially lower than that in solid solution aluminum alloys produced by ingot metallurgy (IM) at similar values of temperature and applied stress. At the same time, the IM aluminum alloys are attractive materials for high temperature applications due to good combination of creep resistance, strength, and fracture toughness [12].

Recently, it has been demonstrated that IM aluminum based composite [13,14] as well as aluminum alloys [15] can also exhibit threshold behavior. However, at present the origin of the threshold stress in these materials is under discussion. In a previous work [15] it was shown that an ingot metallurgy (IM) 2219 aluminum alloy exhibits threshold behavior. The values of threshold stress in this material and in two PM Al–Cu–Mg–Mn alloys [7,9] were found to be essentially the same. Therefore, it can be expected that fine second-phase particles of transition elements can play a similar role in IM aluminum alloys enhancing their creep resistance at high temperature deformation as nanoscale oxides in PM aluminum alloys.

The present work aims to provide detailed information on the deformation behavior of an 5083 aluminum alloy additionally alloyed by 0.2 wt.% Zr. This material produced by

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ingot metallurgy contains dispersoids of Al_3Cr and Al_3Zr [16] and, therefore, can exhibit threshold behavior.

2. Experimental material and procedures

An experimental version of the 5083 aluminum alloy, denoted as 5083 Al herein, with a chemical composition Al–4.7% Mg–1.6% Mn–0.2% Zr–0.18% Cr–0.1% Fe (in wt.%) was manufactured at Kaiser Aluminum and Chemical Corporation, Pleasanton, CA, USA. The alloy was fabricated by direct chill casting and homogenized at 520 °C for 10 h.

Full details of two types of mechanical tests used in the present study were given earlier [15,17]. In the present investigation, the compression tests were conducted in the temperature range 250–570 °C at strain rates ranging from 1.4×10^{-6} to $6 \times 10^{-2}\,s^{-1}$. A Schenk RMS-100 universal testing machine was used. In order to obtain additional experimental points at low strain rates in the temperature range 250–300 °C, creep tests were carried out at constant stress in tension using a creep machine with a contoured Andrade–Chalmers lever arm. In these experiments, the resultant steady-state creep rates ranged from 1.2×10^{-8} to $1.2 \times 10^{-4}\,s^{-1}$.

Specimens of 10 mm in diameter and 12 mm in height for the compression test and specimens of 20 mm in gauge length and 5 mm in diameter for the tension test were machined from the ingot. Both tests were conducted in air using a furnace in which the temperature was monitored and maintained constant within ±2 K. Each sample was held at a testing temperature for about 30 min in order to reach thermal equilibrium.

The microstructure of the material tested in the present study was examined by means of transmission electron microscopy (TEM) technique which was described in details in recent work [16]. Samples for TEM study were cut from the cross section of specimens, which were quenched in water in a furnace immediately after deformation.

3. Experimental results

3.1. Mechanical behavior

Typical true stress–true strain curves are shown in Fig. 1 for temperatures ranging from 250 to 570 °C. The σ–ε curves, which are representative for all testing conditions, exhibit a well-defined steady-state flow after a very short transient stage of plastic deformation ($\varepsilon < 0.1$).

Fig. 2 shows a plot of the steady state creep rate against strain obtained from the uninterrupted test (curve I) and the stress-change test (curve II). It is seen that the creep curve I also exhibits a very short stage of primary creep. Steady-state flow was attained at true strain values over 0.004. During the stress change tests a new steady-state was achieved after a very short transient stage (Fig. 2, curve II).

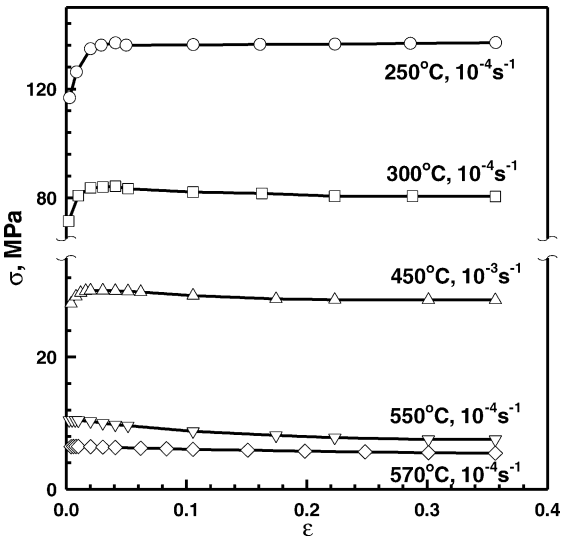

Fig. 1. True stress–true strain curves for the 5083 Al.

Note the data obtained from the uninterrupted tests show good agreement with those obtained from interrupted tests both in compression and in tension experiments as well.

3.2. Stress dependence of steady-state strain rates

Fig. 3 shows the variation of the imposed strain rate with the steady-state stress for Schenk test and the dependence of the steady-state creep rate on the applied stress for creep test on a double logarithmic scale, for temperatures ranging from 250 to 570 °C. One can see that the data obtained from the Schenk test show excellent agreement with those obtained from creep machine tests. Three temperature–strain regions

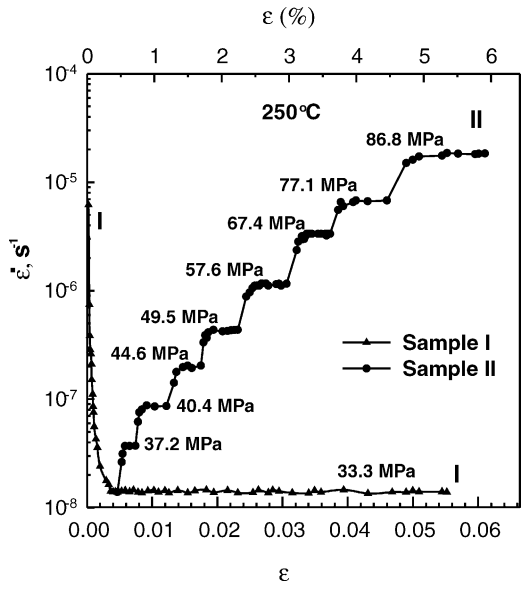

Fig. 2. Example of stress increase experiments and a creep curve for the 5083 Al.