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LETTER

Effect of grain size on the activation energy for plastic deformation near room temperature in a Zn–28.7 pct Al–1.9 pct Cu alloy

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Introduction

The Zn–22 wt pct Al eutectoid alloy is a superplastic material which has been used in a number of experimental investigations of superplasticity. Considerable attention has been devoted to this alloy, because this material has numerous potential applications [1]. Zinc-rich aluminum alloys with: Fe [2, 3] or with Copper additions [2–5], has been of engineering interest over recent years, because the addition of some alloying elements enhances the wear resistance, elastic modulus, yield strength and corrosion resistance under the service conditions of stress and temperature without having a major effect on the superplastic behavior during production of components.

The main goal of this investigation is to study the effect of grain size on the activation energy for plastic deformation, near room temperature, in a Zn–Al–Cu Alloy. The chemical analysis of the alloy used in this work was Zn–28.7 wt pct Al–1.9 wt pct Cu. The superplastic material was obtained by extrusion resulting in a grain size 2.7 µm. A number of flat tensile specimens were prepared from this material. A set of specimens were heat treated at 548 K for 3 h, followed by rapid quenching in water at room tempeature. This treatment produce a grain size of 0.6 µm, measured by the line intercept method [6].

The experiments were conducted using two grain size specimens. Flat tensile specimens, having 1.6 cm gage length and 0.2 × 0.32 cm cross-section, were used to study creep behavior. Creep tests were carried out using a constant load machine (SATEC), which was modified to provide constant applied stress, with a variation of no more than 0.7% in the chosen stress. Stresses between 1.6 MPa and 20.5 MPa were applied to the samples producing steady state strain rates between $6.4*10^{-9}$ s^{-1} to $1.6*10^{-2}$ s^{-1}. The strain during the creep tests was measured with a Schaevitz linear variable differential transformer (LVDT) accurate to $\pm1.3*10^{-4}$ cm, and this information was monitored using a data acquisition system. The test temperatures ranging from 294 K to 398 K were achieved by using tungsten lamps around the specimen holder. This heating device was capable to rise to the selected temperature of the specimen within 20 s. The test temperatures were constant at the level of ±0.5 K.

The plots of true strain, ε, against time, t, which were obtained for specimens with grain sizes of 2.7 µm and 0.6 µm are, respectively illustrated in Figs. 1 and 2. Examination of Fig. 1 corresponding to samples with 2.7 µm has shown that the creep curves exhibit a very short decelerating primary stage followed by a steady state stage; and also exhibit that primary transient strain increases with increasing the applied stress. Unlike our experimental

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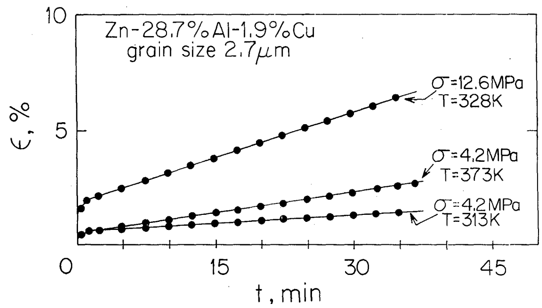

Fig. 1 Creep curves (true tension strain versus time) for Zn–28.7 pct Al–1.9 pct Cu alloy, having grain size of 2.7 μm at different temperatures and stresses

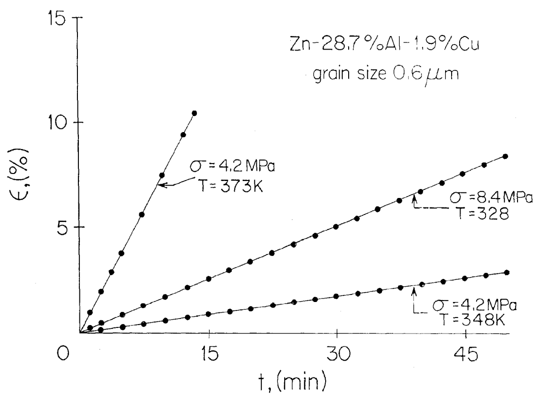

Fig. 2 Creep curves (true tension strain versus time) for Zn–28.7 pct Al–1.9 pct Cu alloy, with grain size of 0.6 μm, at different temperatures and stresses

results, long decelerating primary stage has been observed in other Zn–22 pct Al specimens containing high Fe content [7]. However, transient primary strain, which increases with increasing stress has been reported before [8]. From Fig. 2 which corresponds to samples with grain size of 0.6 μm, it is clear that creep curves do not exhibits any primary stage at different temperature and stresses.

The logarithmic plot of tension strain rate, $\dot{\varepsilon}$, versus the applied stress, σ, under steady state conditions for grain size d of 2.7 μm and 0.6 μm are, respectively shown in Figs. 3 and 4. The individual datum points were obtained from creep steady state curves on different specimens. As shown by Fig. 3, specimen with $d = 2.7$ μm exhibits a stress exponent n, [9], of 4.9 ± 0.5 as an average of the values at different temperatures, and applied stresses between 4.2 MPa and 16.5 MPa. In Fig. 4, the experimental σ vs. $\dot{\varepsilon}$ data for $d = 0.6$ μm are shown at several temperatures. This figure indicates evidence for a continuous increase in slope with increasing stress. However, each curve for it self depends on the applied stress. For the case of 296 K and applied stress between 1.6 MPa and 4.2 MPa the tension samples exhibits a value for $n = 2.3$ together with equiaxied grains which have no appreciable

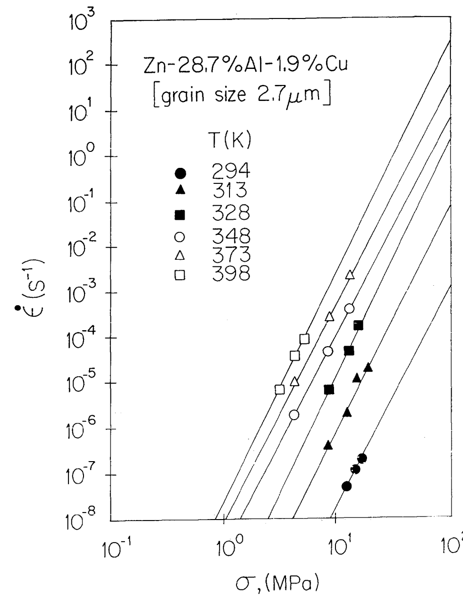

Fig. 3 A logarithmic plot of tension strain rate, $\dot{\varepsilon}$, vs. the applied stress, σ, under steady state conditions for Zn–28.7 pct Al–1.9 pct Cu alloy with $d = 2.7$ μm

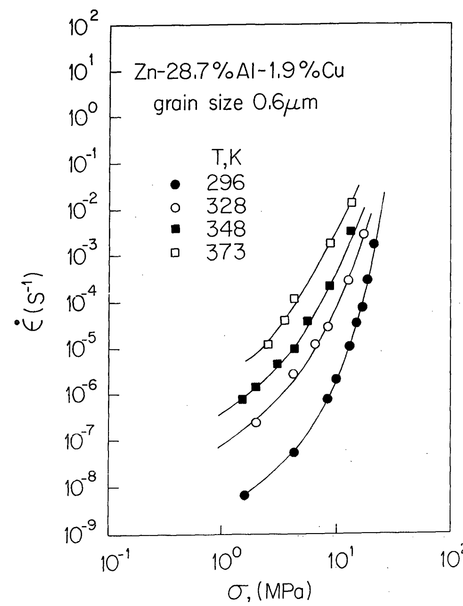

Fig. 4 A logarithmic plot of tension strain rate, $\dot{\varepsilon}$, vs. the applied stress, σ, under steady state conditions for Zn–28.7 pct Al–1.9 pct Cu alloy with grain size of 0.6 μm

change in size during deformation. To examine the possibility of the existence of a threshold stress, τ_o, during the plastic flow of Zn–28.7 pct Al–1.9 pct Cu (for $d = 2.7$ μm) the steady state strain rate were measured at different temperatures and applied stresses. In Fig. 5 a plot for $(\dot{\varepsilon})^{1/n}$ vs. σ (where $n = 4.9$) on a double linear scale for $d = 2.7$ μm, is presented. In this figure the linear portion of

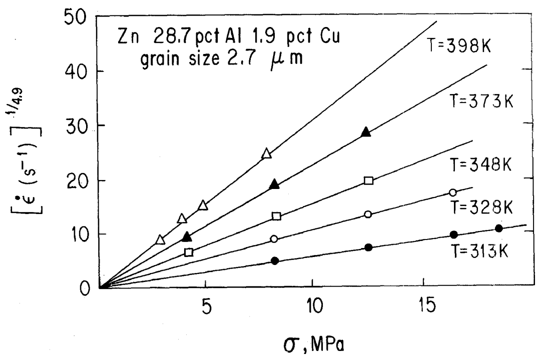

Fig. 5 A plot for $(\dot{\varepsilon})^{1/n}$ vs. the applied stress σ, where n = 4.9 on a double linear scale for Zn–28.7 pct Al–1.9 pct Cu alloy, with d = 2.7 μm

the creep rate versus applied stress pass through the origin when extrapolated to zero strain rate, indicating the absence of a threshold stress. Also, the absence of a threshold stress has been previously reported for creep tests on the alloy of Zn contained 20.9 wt% Al and other elements as follows (ppm) 4000 Cu, 280 Fe, 100 Pb, 26 Mg, 20 Ni, 20 Cd and 10 Mn [8].

The apparent activation energy for samples with grain size of 2.7 μm was determined as follow: From Fig. 3, values of $\dot{\varepsilon}$ were chosen at constant applied stress for several temperatures; by using this data Fig. 6 was build up. The activation energy values were obtained from the slopes of the curves appearing on Figs. 6 and 7. The values for the apparent activation energy for samples with grain

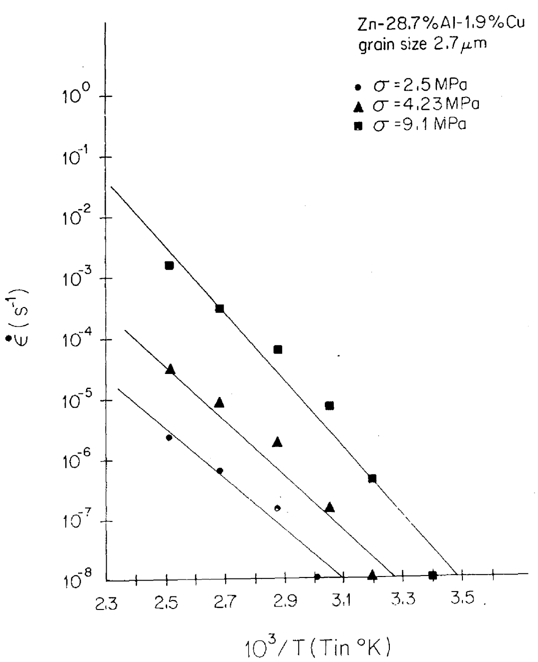

Fig. 6 A logarithmic plot of tension strain rate, $\dot{\varepsilon}$, vs. the inverse of temperature T for Zn–28.7 pct Al–1.9 pct Cu alloy, with d = 2.7 μm

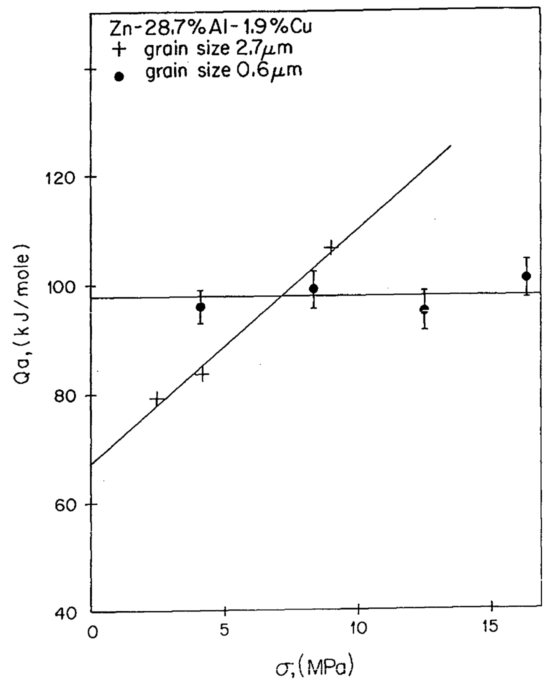

Fig. 7 Apparent activation energy versus applied stress for two grain sizes, 0.6 μm and 2.7 μm, respectively, in Zn–28.7 pct Al–1.9 pct Cu alloy

size of 0.6 μm, which were determined from Fig. 4 by following standard procedures [10], are also shown in Fig. 7. From Fig. 7 it is clear that the apparent activation energy exhibits a very different behavior with the applied stress depending on the grain size of the deformed samples.

Also the true activation energy for creep deformation on samples with d = 2.7 μm, was estimated from Creep rate versus stress data for different temperatures (Fig. 3) following standard procedures [10]. The stress dependence for the obtained values is shown in Fig. 8. It is clear that such experimental data obey the relationship Q ≈ A/σ, with A as a constant. The same dependence has been obtained by Montemayor-Aldrete et al. [11] from the analysis of the experimental data of Zn–22 pct Al due to Mohamed et al. [12]. Similar behavior has been previously reported for creep activation energy in some hexagonal close-packed metals such as Zn and Mg [13–15].

It is possible that the different creep behavior for Zn–28.7 pct Al–1.9 pct Cu alloy specimens with different grain sizes is related to changes in the diffusion mechanisms associated with the change in the grain size of the deformed samples. The main result of this paper is that the Zn–28.7 pct Al–1.9 pct Cu alloy with a very small grain size (0.6 μm) exhibits very different creep properties from the same alloy with a grain size of 2.7 μm, when samples of both grain sizes are tested under the same range of stresses and temperatures.

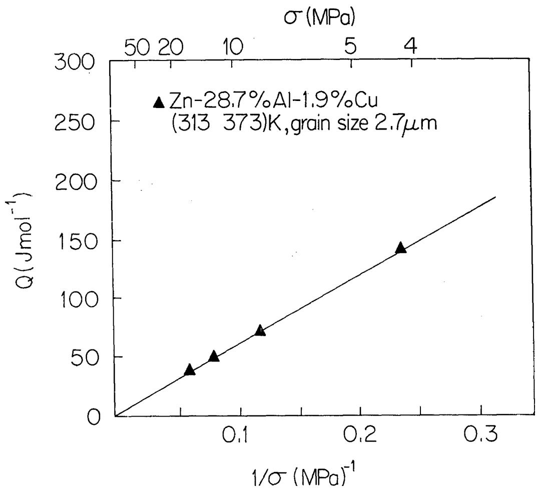

Fig. 8 The true activation energy for creep deformation versus inverse of the applied stress for Zn–28.7 pct Al–1.9 pct Cu alloy with d = 2.7 μm

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