A METALLOGRAPHIC STUDY OF TORSIONAL SUPERPLASTIC FRACTURE IN Zn-22% Al EUTECTOID ALLOY

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ABSTRACT

Metallographic evidence is presented which supports cavitation as the dominant mechanism in the fracture process of Zn-22% Al alloy during superplastic deformation. It is shown, qualitatively, that cracks (void-sheets) form primarily along regions where superplastic creep is replaced by another deformation mechanism, probably intragranular slip.

KEYWORDS

Cavity; initiation and growth; void sheets; grain boundary sliding; intragranular slip.

INTRODUCTION

The failure of superplastic materials has been extensively investigated over the last decade and the results of these investigations have been recently reviewed (Langdon, 1977; Taplin, 1979). It is now firmly established that most superplastic materials tested in tension fail by an intergranular cavitation mechanism. Cavities nucleate early during superplastic deformation at the grain and interphase boundaries, then grow and interlink leading to the final failure.

The purpose of this paper is to present new metallographic evidence of the cavitation process in the superplastic Zn-22% Al alloy tested in torsion.

EXPERIMENTAL

Solid round specimens machined from high purity Zn-22% Al eutectoid alloy were tested in torsion at constant shear strain rates between $5 \times 10^{-4} s^{-1}$ and $1 \times 10^{-1} s^{-1}$ over the temperature range of 413°K and 533°K with grain sizes between 0.8×10^{-4} cm and 3.5×10^{-4} cm. All the tests reported in this paper are for specimens tested in the superplastic regime. A more detailed description of the test procedures and mechanical test results is given elsewhere (Arieli, 1979).

Since the strain rate, strain and stress, all vary along the specimen's radius in a torsion test, the applied strain rate, the measured stress and the calculated strain are valid only for a thin layer at the specimen's surface, thus making quantitative analysis of the fracture process somewhat cumbersome. Therefore, the results of this study are presented only in a qualitative sense.

RESULTS

When final fracture occurred, the specimens were not completely separated along the fracture surface. In the superplastic regime, regardless of the applied strain rate, the central portion of the specimen remained unfractured, Fig. 1a. By contrast, in specimens tested outside the superplastic regime (dislocation climb region) complete separation occurred, the fracture surfaces appearing bright and smooth. The area of the unfractured central region of the specimen varied with the applied strain rate, increasing as the applied strain rate decreased, Figs. 1b, c. The fractured surface of the specimens show extensive mechanical damage, suggesting that the specimens continued to deform even in the presence of the fracture with the two surfaces rubbing together.

When the unseparated central regions of the specimens are fractured at room temperature, individual cavities formed during prior deformation within superplastic regime can be seen, Fig. 2. The size of these cavities seems to increase as the applied strain rate increases. Some of the cavities grew and eventually coalesced forming much larger cavities. Eventually, most of the cavities became interlinked forming almost concentric void sheets along the specimen's axis, Figs. 1 b, c. Such a longitudinal crack, starting from the fracture surface, Fig. 3a, was examined in detail. The main observation is that grains along the crack remained fine, Fig. 3b, although extensive deformation induced grain growth was observed in this material (Arieli, 1979). Also, the small grains are elongated whereas the grains far from the crack maintain an essentially equiaxed structure, Fig. 4. Fig. 4 shows the end of the crack and it is evident that new cavities are in the process of becoming linked to the main crack.

DISCUSSION

In this particular alloy, the absence of second-phase hard particles which can act as stress concentrators during deformation, suggests that cavity initiation is related to the dominant deformation mechanism within the superplastic regime, i.e. grain boundary sliding. Anything which will hinder the sliding accommodation will lead to cavity formation (Arieli and Mukherjee, 1980a). Once cavities are formed and reach the critical size they grow either by diffusion or power-law growth (Taplin, 1979). Moreover, the presence of cavities themselves will affect the flow behavior of the grains surrounding these either by acting as internal stress raisers or due to the lack of a sliding interface (the size of the cavities is larger than the size of the grains) or both. Consequently, the grains surrounding the cavities will deform by a mechanism different from that for superplastic creep (Arieli and Mukherjee, 1980a). Most probably this mechanism is intragranular slip, as evidenced by the elongated grains which did not grow during deformation, Figs. 3b and 4, the deformation enhanced grain growth being a characteristic of superplastic creep (Arieli and Mukherjee, 1980b). The linked cavities form void sheets concentric to the specimen's axis. Since the strain rate (hence the stress) varies along the specimen's radius, this shows that the void-sheet formation mechanism is independent of strain-rate (stress) although its growth rate is probably dependent on strain rate. Finally, when the density of the longitudinal void-sheets is high, the material between the sheets cannot support the stress and collapses leading to the final fracture.

SUMMARY AND CONCLUSIONS

This study presents new evidence that the fracture process in the superplastic Zn-22% Al alloy is controlled by the initiation, growth and interlinkage of cavities during deformation. Cavities initiate and grow as a result of irregularities in the accommodation process for grain boundary sliding (Arieli and Mukherjee, 1980a), become interlinked when either cavities touch each other physically or when the ligaments between the cavities fails plastically. The linked cavities form void-sheets and the final fracture occurs when the density of the void-sheets is high and the material between them collapses under the stress.

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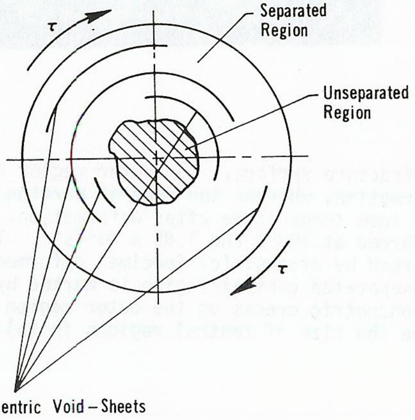

Figure 1(a)

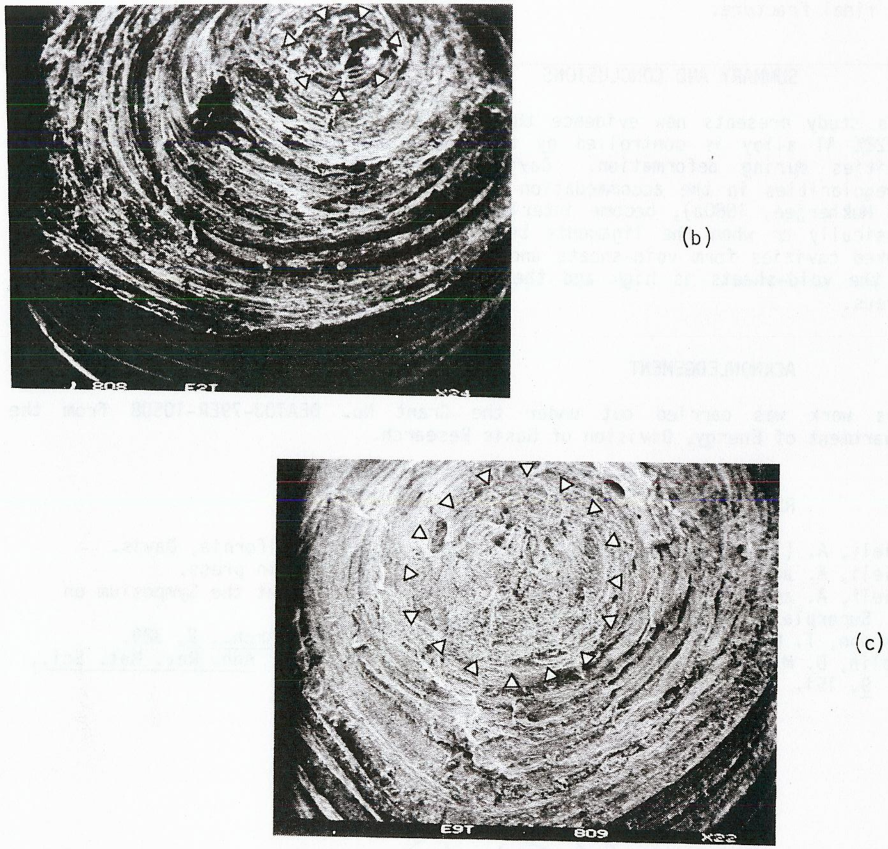

Fig. 1 - View of the fracture surface. The outer region fractured during superplastic deformation, whereas the central portion of the specimen was separated at room temperature after deformation, (a) Schematic; (b) Specimen deformed at 503^{o}K and $1.88 \times 10^{-2}s^{-1}$. The unseparated central region is marked by arrows; (c) Specimen deformed at 503^{o}K and 9.4×10^{-4} s^{-1}. The unseparated central region is marked by arrows. Notice the concentric cracks on the outer region in both (b) and (c). Also, compare the size of central regions in (b) and (c).

Fig. 2 - Fractograph of the unseparated, central region in Fig. 1(b).

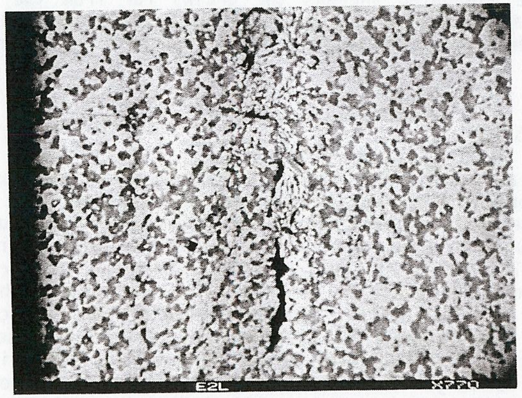

Fig. 4 - The region at the end of the crack shown in Fig. 3a. Notice elongated grains and isolated cavities in the process of becoming interlinked to the main crack.

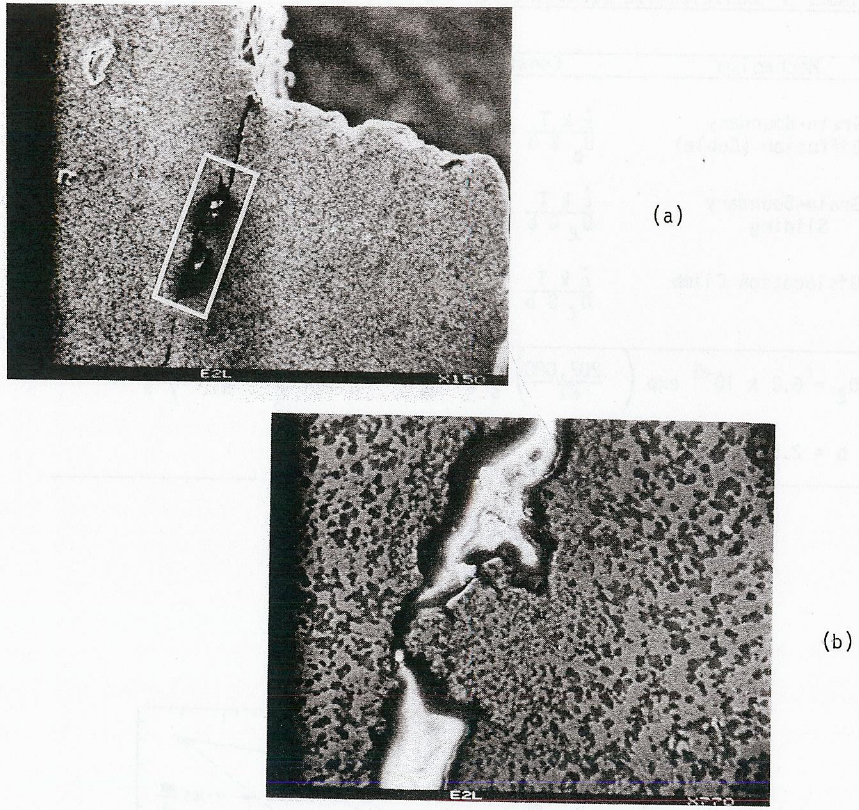

Fig. 3 - (a) Longitudinal section through the torsion specimen. Notice one of the concentric cracks shown in Fig. 1(b) which extends down the specimen axis from the fracture surface; (b) Enlarged view of the square marked area in (a). The grains adjacent to the crack remained fine and are slightly elongated. The grains away from the crack remained essentially equiaxed and deformation-enhanced grain growth is evident.