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Effect of prestrain on the superplastic behaviour of a fine grained 7475 Al alloy

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The effect of prestraining at a fast strain rate (region III) on the subsequent superplastic behaviour (region II) of a 7475 Al alloy has been studied. The results show that prestraining causes a decrease in the elongation to failure as compared to the non-prestrained (as-received) samples. This decrease in elongation is postulated to be associated with the growth of cavities formed during prestraining as well as grain growth during deformation in region II. Prestraining in region III did not lead to any observable inhomogeneities in strain distribution during subsequent deformation.

1. Introduction

It has been established in several creep investigations that prestraining at room temperature, usually up to a maximum strain of ~25%, leads to a significant decrease in the measured elongation to failure when the material is subsequently creep tested at elevated temperatures [1–3]. This drop in ductility has been related to an increase in the density of grain boundary cavities as a result of the prestraining treatment [4, 5].

But for a few investigations listed above, the effect of prestraining on the subsequent superplastic behaviour of materials remains unexplored. Ahmed and Langdon [6] have shown that prestraining of a superplastic and fine grained Pb-62 wt % Sn alloy at a fast strain rate in region III (or high stress regime) leads to a decrease in the elongation to failure on subsequent testing at a slower rate in region II (or superplastic regime). This decrease was attributed to the development of strain inhomogeneities during the prestrain.

In this paper, the effect of prestraining at a high strain rate ($\dot{\varepsilon} = 1 \times 10^{-2}\ \mathrm{s}^{-1}$) on subsequent deformation in the superplastic regime has been studied in a fine grained 7475 Al alloy, which has a potential for application in the aerospace industry.

2. Experimental procedure

The experiments were performed on a 7475 Al alloy heat treated to condition "E". A patented process [7] had been used to yield a fine grain size in the alloy. The material was supplied by the Rockwell International Science Cènter. Specimens were tested in both the as-received condition as well as after prestraining.

In this material, the grain morphology was dissimilar along three mutually perpendicular directions. All grain sizes quoted in this paper are reported as the cube root of the grain sizes measured along three mutually perpendicular directions. Tensile specimens were cut parallel to the rolling direction from 1.5 mm thick sheet, with an initial gauge length of 7 mm. All tests were conducted using an automated MTS machine programmed to run in constant true strain rate mode. The test temperature was controlled at $517 \pm 1\,^{\circ}\mathrm{C}$. In order to measure the homogeneity of strain distribution along the gauge length of the deformed specimens, the initial gauge length of the specimens was marked by lines spaced 1 mm apart. The exact separation between these lines was measured before and after the test using vernier callipers. These measurements were used to calculate the percentage strain in each section. This value is henceforth referred to $\Delta l/l_0$. The total percentage strain over the entire gauge section was also calculated and is henceforth referred to as $\Delta L/L_0$. Using this procedure, it is possible to plot variations of strain along the gauge length, $\Delta l/l_0$, as a function of total specimen strain, $\Delta L/L_0$. The same procedure was adopted for measuring the strain homogeneity along the gauge length of the prestrained specimens by dividing the gauge length before superplastic deformation at a strain rate of $2 \times 10^{-4}\ \mathrm{s}^{-1}$ into 12 equal parts.

Metallography involved both optical and transmission electron microscopy. Thin foils for transmission electron microscopy were prepared by electropolishing 3 mm discs in 75 parts of methanol and 25 parts of nitric acids at ~50 °C under an applied current of 100 mA. For optical microscopy, conventional metallographic polishing was followed by etching in Keller's reagent.

3. Results

3.1. Prestraining

In order to determine what level of prestrain would be imposed on specimens for subsequent evaluation of superplastic properties, a series of specimens was strained at 517 °C at a strain rate of 1×10^{-2} s^{-1} to different levels of true strain. Fig. 1 shows a photograph of four such specimens with the total true strain level of each noted alongside. Fig. 2 shows the variation of local strain, $\Delta l/l_0$, for these specimens as a function of location of particular segments along the gauge length. It is clearly evident from this figure that the strain distribution remains homogeneous along the gauge length up to a total true strain of 0.69. Beyond this level of true strain, the data indicates formation of a diffuse neck leading to increased levels of local strain near the mid section of the gauge length.

The cavitation characteristics as a function of total strain are seen in Fig. 3a, b. These are montages of optical micrographs obtained from three mutually perpendicular directions from samples strained to total strains of 0.5 and 1.11, respectively. While the level of cavitation is in general low, it is evident that it increases with the level of total strain. Based on this phase of the work, it was decided that specimens prestrained to a total true strain of 0.5 would be used in evaluating the effect of prestraining on subsequent superplastic behaviour.

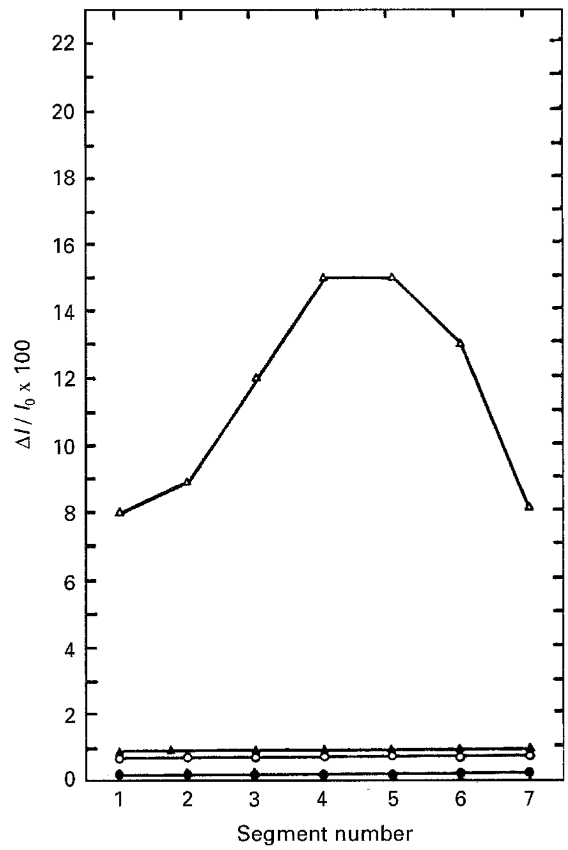

Figure 2 Plot of local strain, $\Delta l/l_0$, at each segment of initial length, l_0 along the gauge length of the specimens deformed to various strain levels of (a) (●) 0.20, (b) (○) 50, (c) (▲) 0.69 and (d) (△) 1.11 at a test temperature of 517 °C and strain rate of 1×10^{-2} s^{-1}, initial area of crossection of the gauge length $A_0 = 10.24$ mm^2, $L_0 = 7$ mm, each segment = 1 mm.

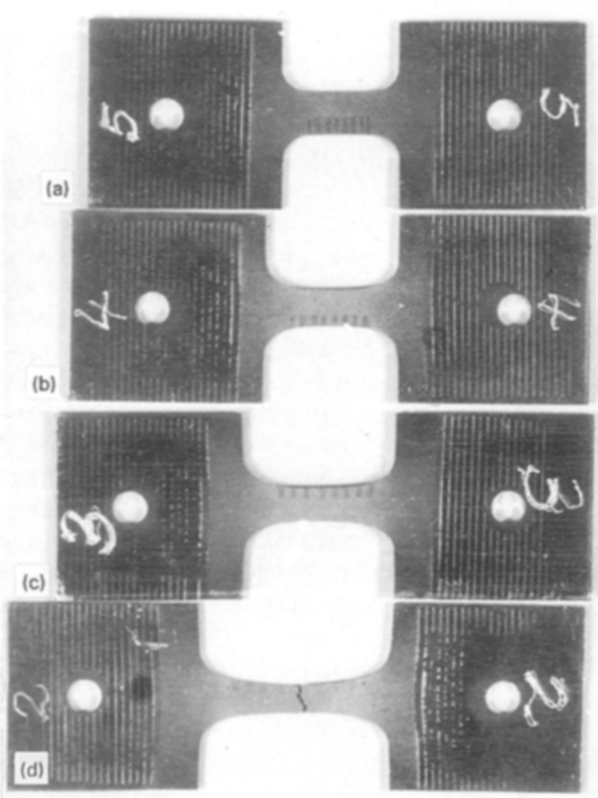

Figure 1 Optical micrographs of the 7475 Al alloy deformed to (a) $\varepsilon = 0.20$, (b) $\varepsilon = 0.50$, (c) $\varepsilon = 0.69$ and (d) $\varepsilon_{FRACTURE} = 1.11$ at a temperature of 517 °C and strain rate of 1×10^{-2} s^{-1}.

3.2. Effect of prestrain

As mentioned above, specimens prestrained to a true strain level of 0.5 were used in this phase of the work. The recrystallized grain size of these specimens was about 8.2 µm. The superplastic deformation characteristics of as-received and prestrained specimens were compared for deformation carried out at 517 °C at a strain rate of 2×10^{-4} s^{-1} (region II) [8, 9]. The detrimental effect of prestrain on the superplasticity of this alloy is immediately obvious upon comparing the true strain at failure. While the as-received material failed at a true strain of 2.31, the prestrained specimen failed at ~1.75 at a strain rate of 2×10^{-4} s^{-1}.

Fig. 4 shows the grain size as a function of imposed total true strain for the prestrained specimens. It is immediately seen that in the prestrained sample, grain growth occurs in the course of superplastic deformation. Fig. 5 is a plot of local strain as a function of segment number for the prestrained samples deformed at various strain rates within the range 1×10^{-5} to 5×10^{-3} s^{-1} at 517 °C.

The level of cavitation at failure for the as-received and prestrained specimens are compared in Fig. 6a, b, respectively. These montages of optical metallographs clearly demonstrate the enhanced level of cavitation caused by prestraining. It is to be noted that at a prestrain level of 0.5, the level of cavitation was quite low (Fig. 3a). This suggests that even this low a level of

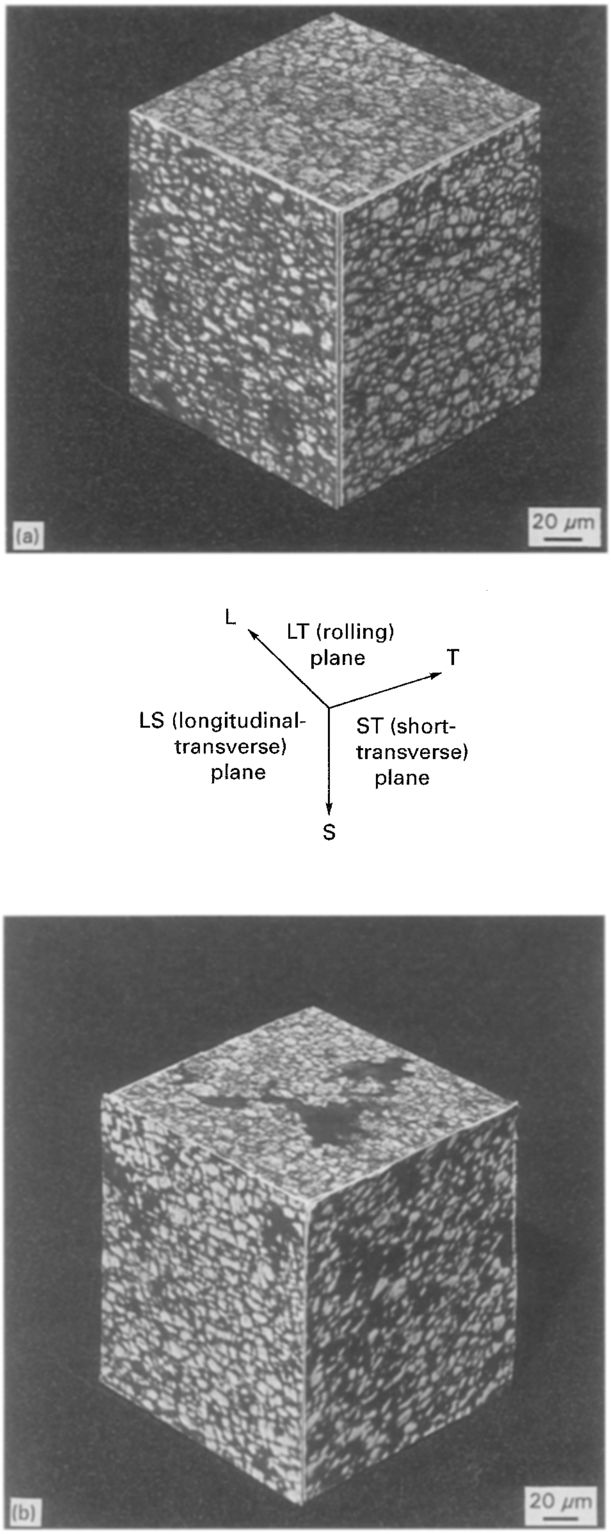

Figure 3 Optical micrographs of specimens deformed at a strain rate of $1 \times 10^{-2}\,s^{-1}$ and at temperature of 517 °C to a strain level of (a) 0.5 and (b) 1.11.

cavitation can be quite detrimental to superplastic behaviour and that cavity nuclei formed at prestraining may grow during superplastic deformation. The increased level of dislocation activity due to the prestraining is evident from comparing the TEM micrographs of as-received and prestrained samples (Fig. 7a, b, respectively) which have been deformed to a total true strain of 1.4.

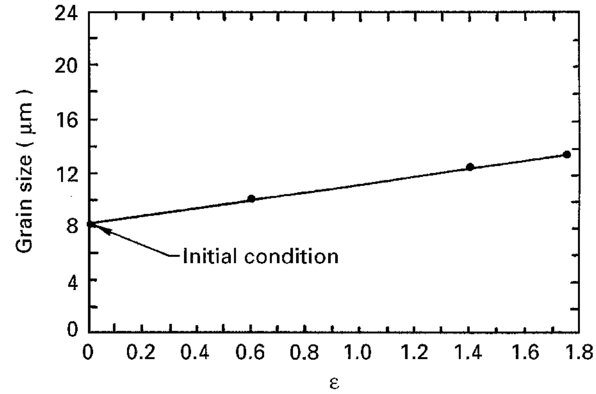

Figure 4 Plot of grain size versus true strain of prestrained specimen (at $10^{-2}\,s^{-1} = 0.5$) deformed at a temperature of 517 °C strain rate of $2 \times 10^{-4}\,s^{-1}$.

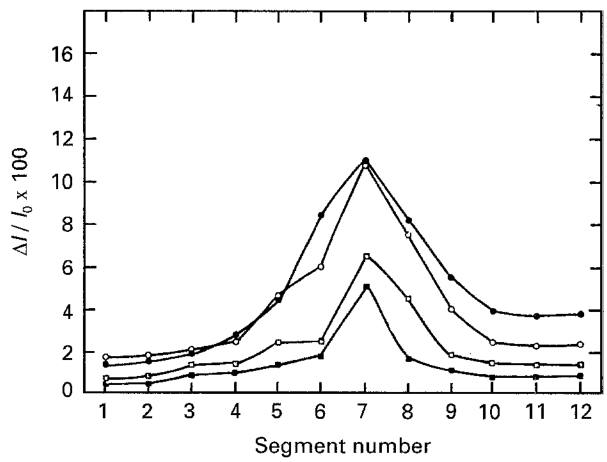

Figure 5 Plot of local strain, $\Delta l/l_0$, in a segment of initial length, l_0, long the gauge length of the prestrained specimens (at $10^{-2}\,s^{-1}$) deformed to failure at various strain rates at a temperature of 517 °C and at various strain rates. $A_0 = 6.94\ mm^2$, $L_0 = 12$ mm, each segment = 1 mm. $\%\Delta L/L_0$: (●) 444, (○) 475, (□) 228, (■) 154. $\dot{\varepsilon}$, s^{-1}: (●) 5×10^{-5}, (○) 2×10^{-4}, (□) 1×10^{-3}, (■) 5×10^{-3}.

4. Discussion

The main characteristic of true superplasticity is that it corresponds to Newtonian viscous flow with, m, the strain rate sensitivity, equal to one and consequently, infinite elongation to failure should occur. In practice, however, this condition is not attainable in real metals, and there is instead an optimal superplastic condition when $m \geqslant 0.5$ and failure occurs by quasistable plastic flow [10]. Under these conditions, when m is significantly < 1, it is important to consider various factors which play a role in determining the attainable superplastic ductility. There have been numerous investigations on the study of these various factors [9] (such as strain rate, temperature and grain-size), and the present results supplement this earlier work by providing information on the influence of prestraining treatment.

The present investigation provides evidence that prestraining at a faster strain rate (region III) tends to decrease the elongation to failure obtained upon subsequent superplastic deformation at a slower strain rate (region II). This is in accord with the results of earlier work [1–3, 6] on this phenomenon.

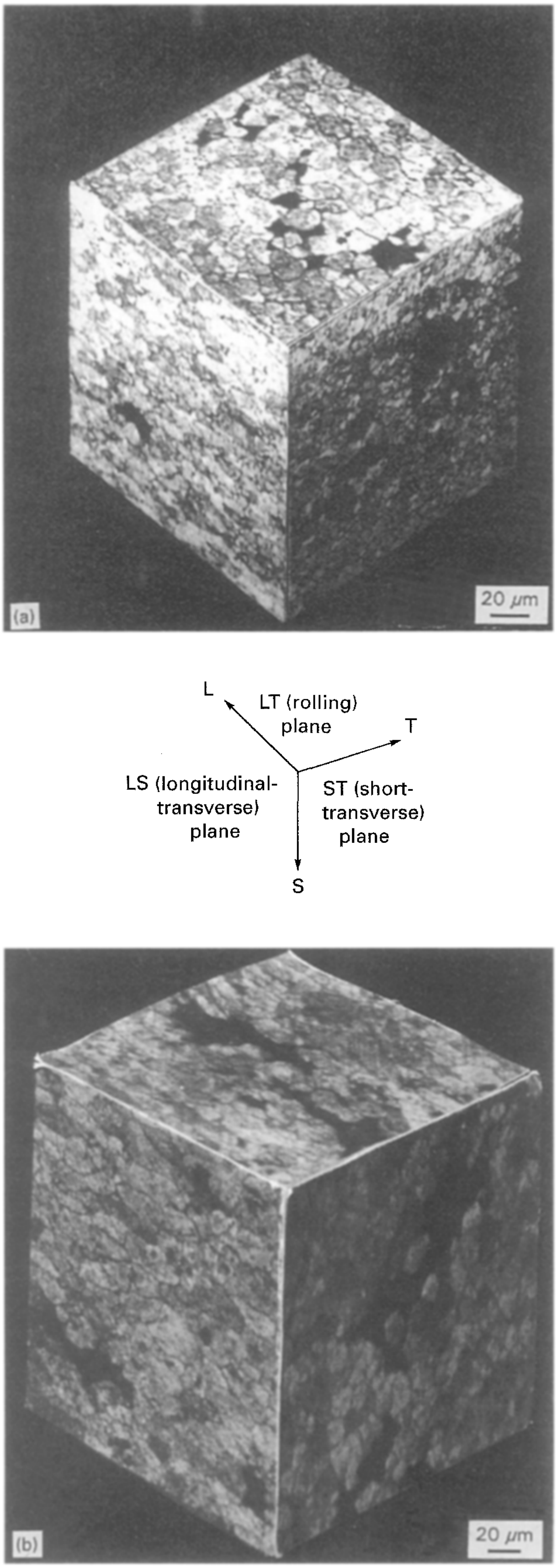

Figure 6 Optical micrographs of the (a) as-received ($\varepsilon_{FRACTURE}$ = 2.31) and (b) prestrained ($\varepsilon_{FRACTURE}$ = 1.75) specimens deformed to failure at a strain rate of 2×10^{-4} s^{-1} and at temperature of 517 °C.

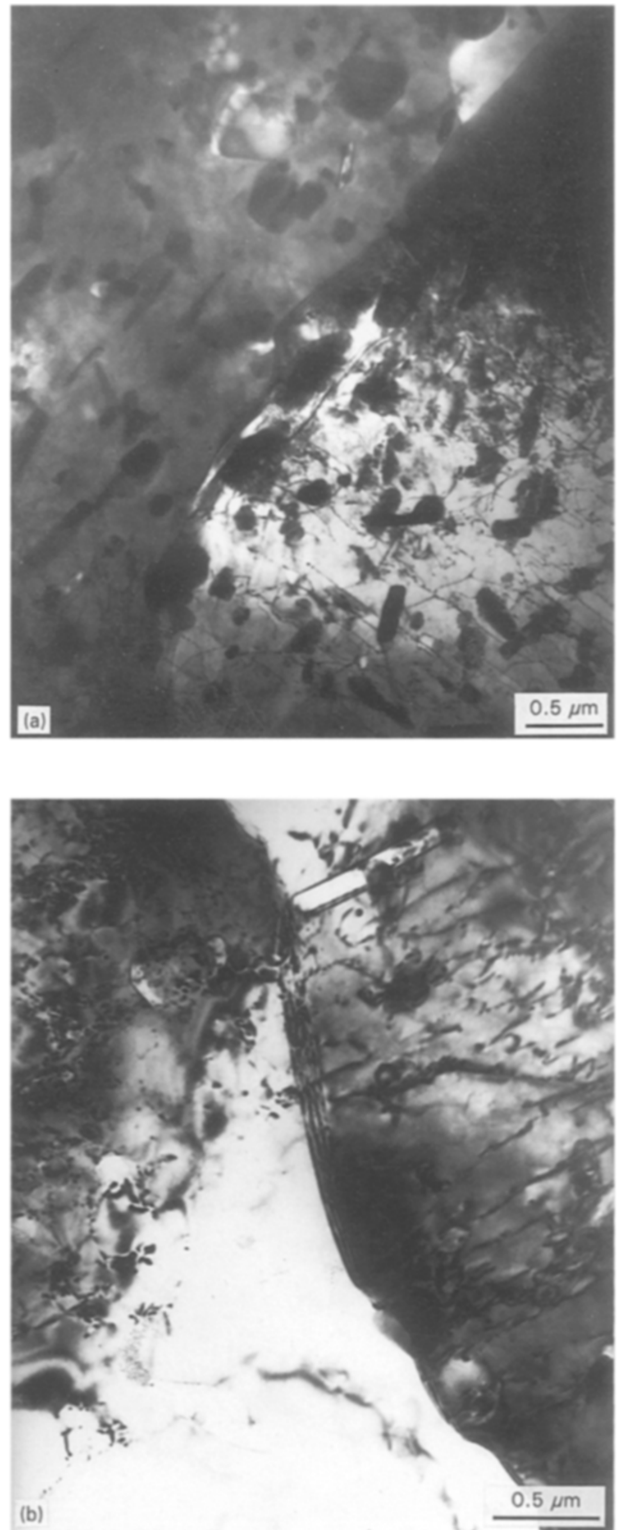

Figure 7 Transmission electron micrographs of the (a) as-received and (b) pre-strained specimens, deformed at temperature of 517 °C and strain rate of 2×10^{-4} s^{-1} to a true strain of 1.4 (elongation = 305%).

Since there is evidence for both grain growth and increased dislocation activity during prestraining, an increase in flow stress may be expected during prestraining. Since the flow stress is inversely related to the stable cavity radius [11], this progressive increase in flow stress would render ever smaller cavities stable [12]. It is thus felt that dynamic nucleation of cavities occurs during the prestraining. It is well established that cavity growth occurs during superplastic deformation. Since no strain inhomogeneities were evident as a result of prestraining, one concludes that the decrease in superplastic ductility upon prestraining is a result of grain growth and growth of cavities (formed during prestraining) in the course of superplastic deformation.

5. Conclusions

1. Prestraining at a fast strain rate in region III leads to a decrease in the elongation to failure when tested subsequently at a slower rate in region II.

2. This decrease is associated with growth of cavities which form during prestraining as well as grain growth during subsequent superplastic flow.

3. There was no evidence for strain inhomogeneities i n the prestrained specimens.

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