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The effect of grain size on workhardening and superplasticity in Zn/0.4% Al Alloy

- by -

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Superplasticity* requires, amongst other things, a metal with a grain-size in the range 0.5-5μ. Theories of SP invoking dynamic recovery require that the cell-size of the substructure for the alloy in question is larger than the SP grain-size, so that gliding dislocations are always annihilated in the grain boundaries and workhardening cannot occur (1,2). Thus the grain-size is critical, and for a given set of conditions, there must be a grain-size greater than which SP cannot be achieved.

In this investigation a Zn/0.4 Al alloy was rolled into sheet with a grain-size of < 1μ. It is believed that this small grain-size is possibly due to the stabilizing effect of the β phase, precipitating in the grain boundaries. Samples of this material were now annealed at various temperatures, producing the grain-sizes shown in Table 1 and Fig. 1.

Table 1

Annealing for 5 minutes at different temperatures to give a range of grain sizes.

Temperature (°C)	Grain-size (d)(μ)
150	3.0
200	10.0
250	20.0
300	87.0
350	120.0

Load-extension (LE) curves, and the maximum engineering stress and total elongation values are shown in Figure 2. A plot of the 0.2% flow stress vs. $d^{-\frac{1}{2}}$ is shown in Figure 3.

The differences in the LE curves are most marked. The < 1μ and 3μ grain-sizes give typical SP curves; the similarity between these curves and those obtained by hot-working (3) must be noted. Referring now to Figure 2a, during stage A, workhardening, that is, dislocation entanglement and grain-boundary pile-up occur. At the peak of the curve, workhardening ceases and dislocation climb begins. Stage B is a transition region between A and C, the steady-state region, where dislocation generation is balanced by climb and annihilation.

The 10μ grain-size shows quite a different behaviour. Here, slip and workhardening are occurring, and though twinning is seen in the microstructure, it is not the predominant deformation mechanism and is not evident on the LE

* Subsequently, SP will be used for superplastic(s) and superplasticity.

curve. With a further increase in grain-size (20μ) twinning is recorded on the LE curve ductility decreases. With 87μ and 120μ grains, twinning is predominant and ductility decreases still further.

It will be noted that the 0.2% flow stress rises with increasing grain-size in the SP range and falls with increasing grain size in the workhardening range; the latter observation according with the Hall-Petch relationship. A similar grain-size effect has been observed for Zn/ZnO alloys by Tromans and Lund (4).

These results show that, when a certain critical grain size is reached, dislocation interactions (workhardening) occur and SP (dislocation climb and annihilation) ceases and emphasize again the role played by dislocations in SP.

References

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4. D. Tromans and J.A. Lund, Trans. Quart. A.S.M., 59, 673, 1966.

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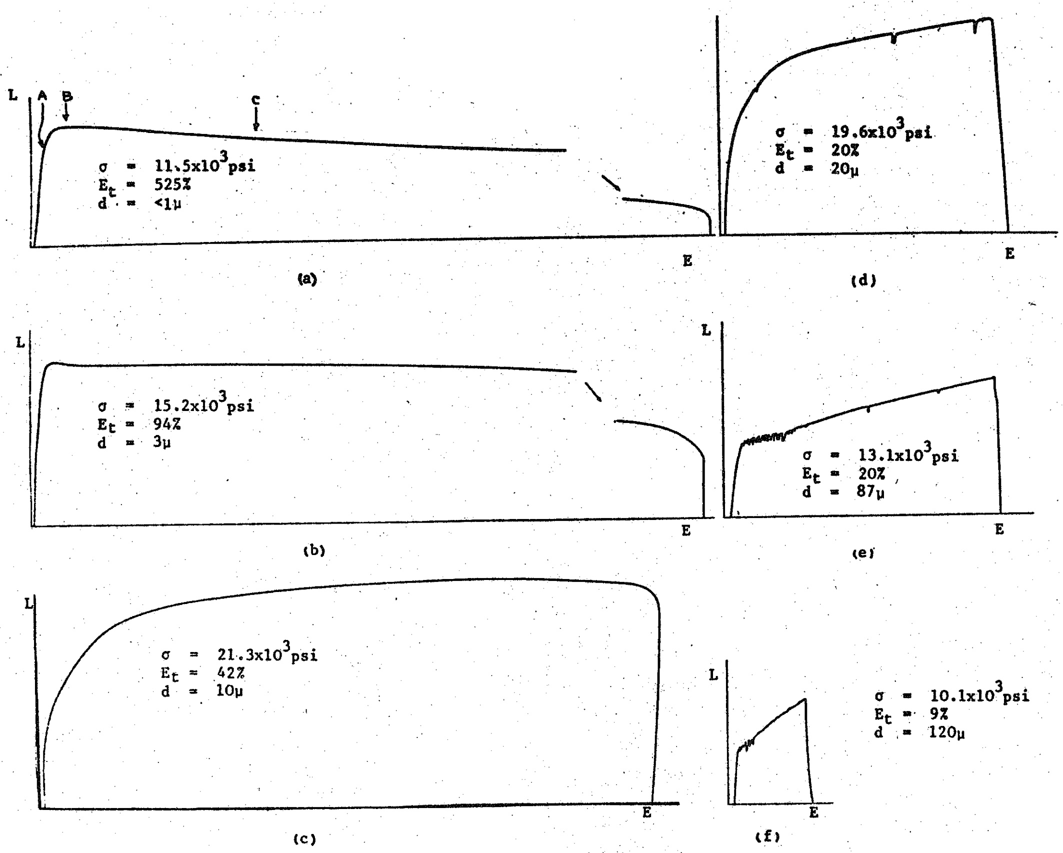

FIG. 2 LE CURVES FOR INCREASING GRAIN-SIZES

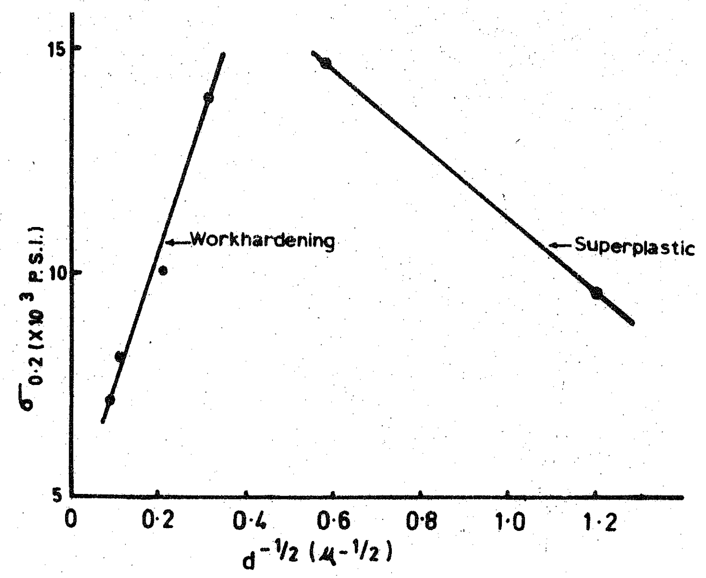

FIG. 3 THE RELATIONSHIP BETWEEN 0.2% FLOW STRESS (σ) AND GRAIN-SIZE ($d^{-\frac{1}{2}}$)

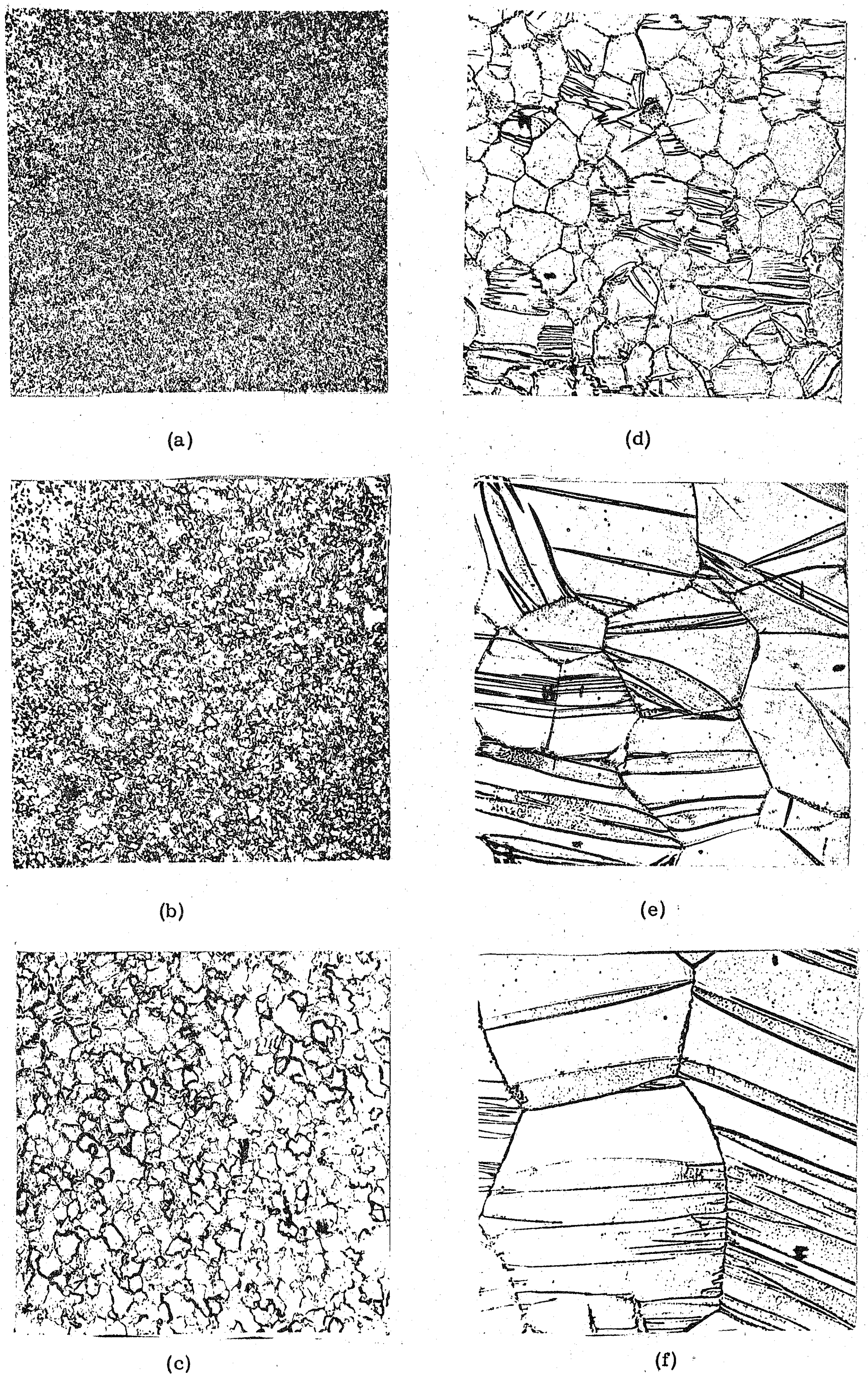

FIG. 1 AS ROLLED (a) AND ANNEALED AT 150^{o}C(b), 200^{o}C(c), 250^{o}C(d), 300^{o}C(e), 350^{o}C(f)