11. STRUCTURE AND MECHANICAL PROPERTIES OF NANOSTRUCTURED METALS PREPARED BY SEVERE PLASTIC DEFORMATION

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Ultrafine-grained (UFG) nanostructured materials having grain sizes of tens and hundreds of nanometers recently have aroused interest among researchers in the materials science field. With respect to their mechanical properties, one would hope to be able to obtain the extremely strong states that can be expected in the case of strong grain refinement according to the Hall-Petch relationship (Gleiter 1989, Weertman 1993). UFG materials can also acquire superplasticity at relatively low temperatures and/or high strain rates by reducing the grain size of the materials to the nanometer range (Valiev 1997a). All this explains the interest in the mechanical properties processed in bulk samples having ultrafine-grain sizes.

It has been demonstrated that bulk nanocrystalline materials may be prepared using a gas condensation method with subsequent consolidation in an inert gas environment. They may also be prepared using mechanical alloying followed by compaction. Nevertheless, problems associated with these techniques still exist, including the retention of some residual porosity and the difficulty of fabricating large samples with UFG structure for subsequent mechanical testing.

These problems can be overcome by producing an ultrafine grain size in coarse-grained materials through the procedure of severe plastic deformation, i.e., a very high plastic strain performed at relatively low temperatures (usually less than 0.3-0.4 T_m) under high imposed pressure (Fig. 11.1) (Valiev 1993, Valiev 1996). This procedure has been successfully used to refine the structure until it reaches a mean grain size of 29 nm as well for consolidation of nanocrystalline powders in different metals and intermetallics (Valiev 1996).

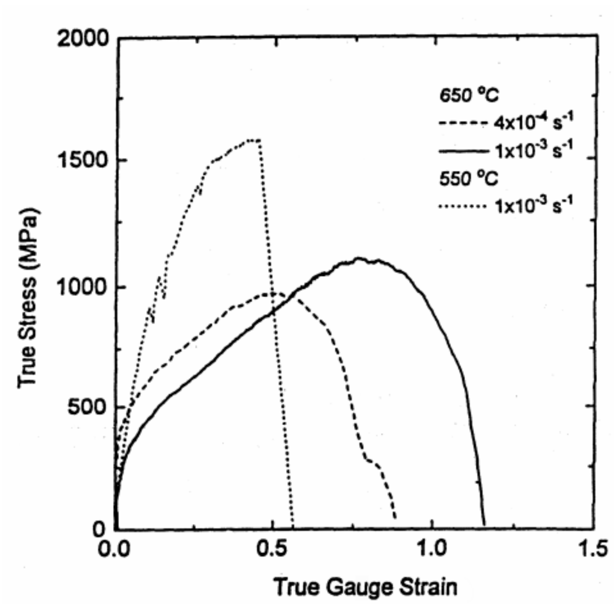

Fig. 11.1. True stress-strain curves of tensile tests for nanocrystalline Ni_3Al, Cr doped B (d = 70 nm).

This talk focuses on the fabrication of several pure metals and alloys with nano- and submicrometer grain sizes by severe plastic deformation techniques, the results of their structural characterization, and the data on their enhanced mechanical properties at ambient temperature and superplastic conditions. Special attention is paid to the relationship between the defect structures of grain boundaries and the mechanical behavior of the ultrafine-grained materials produced.

Several examples of such promising properties as high strength, elevated fatigue life, superplasticity at low temperatures, and high strain rates revealed in processed nanostructured materials are considered and discussed (see Figures 11.2 and 11.3).

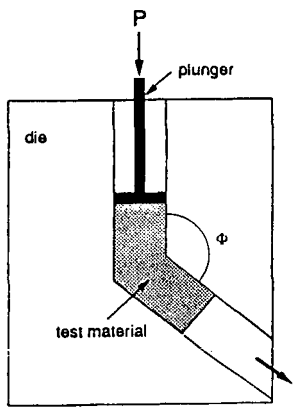

Fig. 11.2a. Principle of equal-channel angular pressing.

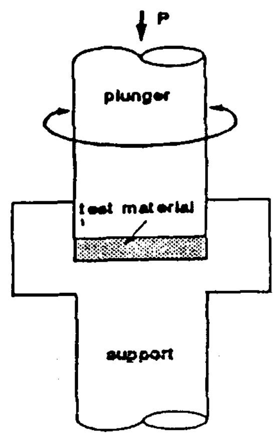

Fig. 11.2b. Principle of torsion straining.

Analysis of True Strains:

a) Equal-channel angular pressing

$$\varepsilon = \frac{N \cdot 2}{\sqrt{3} \cdot ctg\phi}$$

N = number of cycles

b) Torsion straining

$$\varepsilon = \frac{2\pi \cdot n \cdot r}{d}$$

n = number of turns

r = radius of specimen

d = thickness of specimen

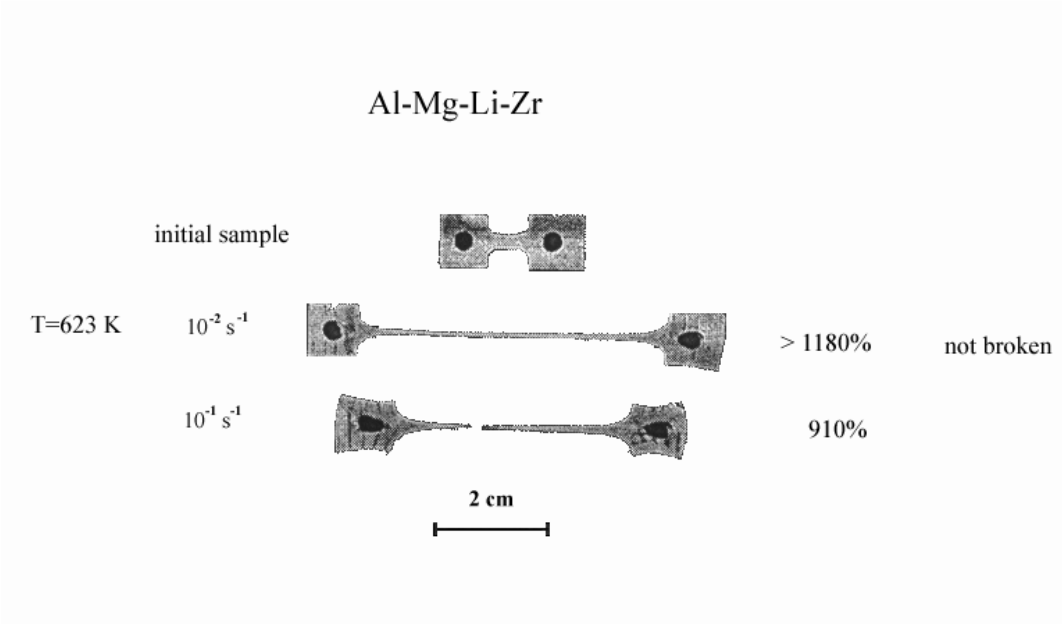

Fig. 11.3a. High strain rate superplasticity in Al alloys, subjected to equal-channel angular pressing—Al-Mg-Li-Zr.

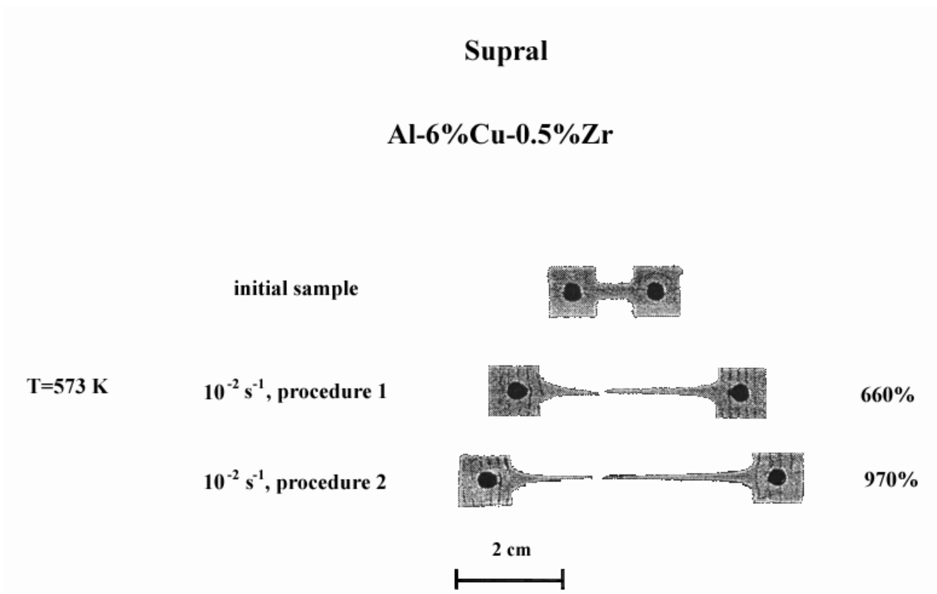

Fig. 11.3b. High strain rate superplasticity in Al alloys subjected to equal-channel angular pressing—Al-6%Cu—0.5%Zr.

References

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