A new strategy to enhance ductility of ultra-fine grained materials

ARC Centre of Excellence Design in Light Metals

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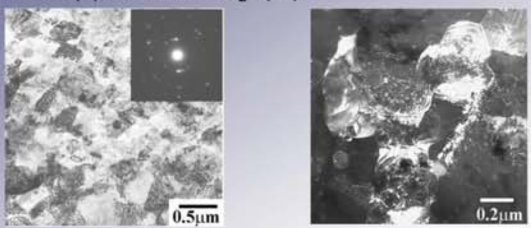
1. Introduction

Nanostructured and ultra-fine grained (UFG) metals have improved strength. However, the industrial application of nanostructured metals is restricted due to their low ductility. The value of uniform elongation is only about 1-2% and then the deformation is localized, resulting in necking. Different strategies have been proposed to increase the ductility of nanostructured metals. In this work, we have developed another strategy to enhance ductility of UFG materials. Our idea is based on activation of microshearing (localization of deformation at microscale) with stabilization against necking (localization of deformation at macroscale).

2. Material for investigation

Al6082 alloy is studied in solutionized condition. The billets 100x10x10 mm³ are subjected to equal channel angular pressing (ECAP) at 100ºC for 8 passes. The parameters of ECAP die: the angle of arc curvature (0º); the intersection angle (90º).

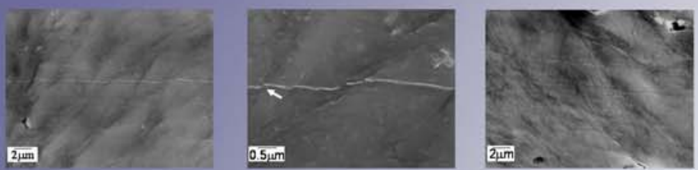


a) b)

Fig. 1. Microstructure of the Al6082 alloy after ECAP at 100ºC for 8 passes.

4. Deformation mechanisms

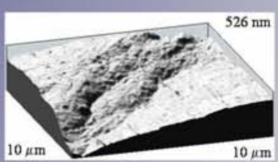
Deformation mechanisms in the UFG material were studied via SEM and AFM analysis



a) b) c)

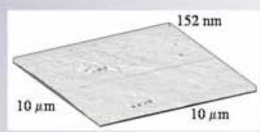
Fig. 4. SEM images of deformation relief of the UFG Al6082 alloy after tensile tests with strain rate: a), b) 1.1×10^{-5} s^{-1} (gauge length); c) 10^{-3} s^{-1} (necking area).

Profuse **micro shear banding (MSB)** is observed at 1.1×10^{-5} s^{-1} (Fig. 4a). Fig. 4b illustrates activity of **cooperative grain boundary sliding (CGBS)** (marked by white arrow). MSB activity decreases with increasing strain rate (Fig. 4). At strain rate of 10^{-2} s^{-1}, SB is observed only in necking area (Fig. 4c).



a)

b)



c)

Fig. 5. AFM 3D images of deformation relief of the UFG Al6082 alloy after tensile tests with strain rate: a) 1.1×10^{-5} s^{-1}, b) 10^{-3} s^{-1}.

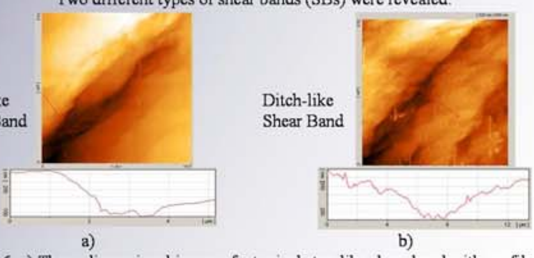
The interfacial developed area ratio R is an indirect measure of MSB activity.

Strain rate, s^{-1}	1.1×10^{-5}	10^{-4}	10^{-3}
R, %	2.44	1.09	0.43

Two different types of shear bands (SBs) were revealed:

Step-like Shear Band

Ditch-like Shear Band

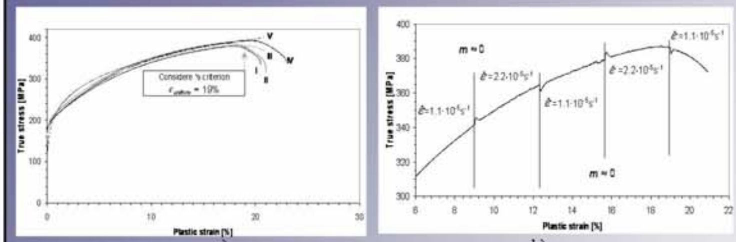


a) b)

Fig. 6. a) Three-dimensional image of a typical step-like shear band with profile; b) Three-dimensional image of a typical ditch-like shear band with profile.

3. Mechanical properties

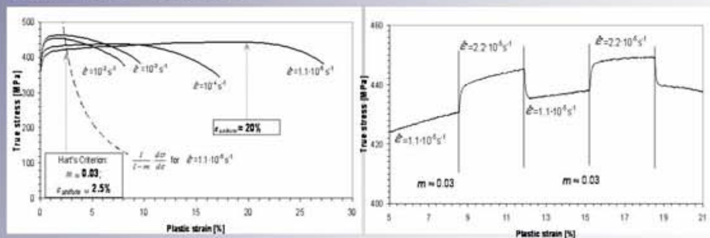
Room temperature tensile tests were carried out in an Instron 8801 machine with the strain rates of 10^{-2}, 10^{-3}, 10^{-4}, and 1.1x10-5 s^{-1} for both the coarse-grained reference material and the ECAP-processed UFG specimens.



a) b)

Fig. 2. True stress – strain curves for coarse-grained Al6082 alloy, a) at different strain rates: I – 10^{-2} s^{-1}, II – 10^{-4} s^{-1}, III – 10^{-5} s^{-1}, IV – 10^{-3} s^{-1}, V – power-law curve; b) strain rate jump test at the base strain rate of 1.1×10^{-5} s^{-1}.

There is no effect of the strain rate on the deformation behaviour of the coarse-grained material (Fig. 2a). The uniform tensile elongation e_u of the material is predicted by the **Considère** condition, $\varepsilon_u = n = 0.19$ (Fig. 2a).



a) b)

Fig. 3. True stress – strain curves for UFG Al6082 alloy, a) at different strain rates, b) strain rate jump test at the base strain rate of 1.1×10^{-5} s^{-1}.

Strong effect of the strain rate on uniform elongation in the UFG Al6082 alloy (Fig. 3a).

Strain rate, s^{-1}	1.1×10^{-5}	10^{-4}	10^{-3}	10^{-2}
ε_u, %	20	9.6	4.6	2.1

The measured ***m***-value determined from the stress jump magnitude is about 0.03. The Hart criterion fails to predict the uniform elongation: $\varepsilon_u^{HART} \approx 2.5\%$ vs. $\varepsilon_u^{experiment} \approx 20\%$ (Fig. 2b).

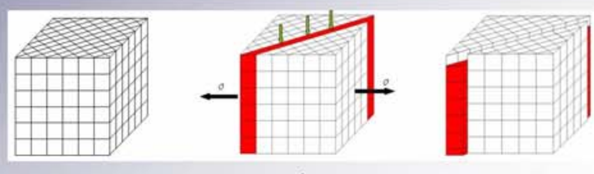
5. Nature of enhanced tensile ductility

Contribution of MSB and CGBS into ductility is estimated using simple models:

Shear banding provides 11.0% (of 20%) of uniform elongation
CGBS provides 2.6% (of 20%) of uniform elongation.

Significant contribution of MSB to the total uniform elongation is only possible due to CGBS activity, regardless of the smallness of its direct contribution.

1. CGBS stimulates MSB. A group of preferentially oriented grains forms a SB nucleus on the maximum shear stress plane inclined at 45º to the loading axis (Fig. 7a). Deformation is localised within it. The surface grains move down (Fig. 7b). As the minimal thickness of ditch-like SBs is of the order of magnitude of the grain size, 300 nm, this can occur only via CGBS of these grains involved in a ditch-like SB with respect to the 'matrix' (Fig. 7c).
2. CGBS suppresses transformation of the micro SBs into macro SBs, thus stabilising the sample against necking. Propagation of micro SBs and CGBS are controlled by dislocation activity within micro SBs. Deformation at low strain rates promotes CGBS which releases excessive energy within micro SBs and supresses their transformation into macro SBs.



a) b) c)

Fig. 7. An idealized model of a ditch-like micro SB formation via CGBS.

Acknowledgments

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