Ageing & Fracture Behaviour of an Al-Li-Cu-Mg Alloy with Refined Microstructures produced by Severe Plastic Deformation

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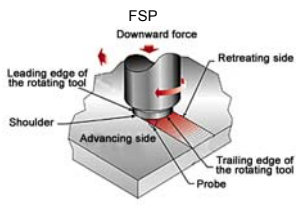
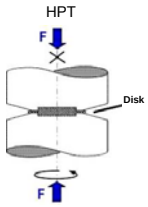
Introduction

The prospect of using Severe Plastic Deformation (SPD) techniques to refine microstructure, especially grain size, in order to improve mechanical properties of materials has attracted considerable attention recently. However, little work has been carried out on fine-grained precipitation age-hardening materials. The present work is aimed at investigating the age-hardening response and fracture behaviour of Al-Li alloys after microstructural refinement using High Pressure Torsion (HPT) and Friction Stir Processing (FSP).

Experimental Details



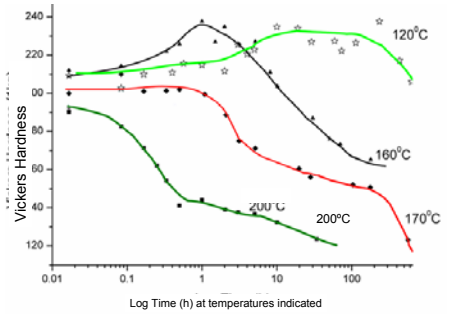


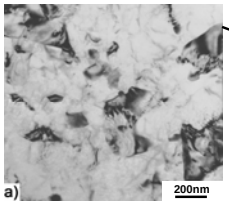
Al2.2Li 1.0Cu 0.7Mg 0.1Zr 0.07Fe 0.01Si (wt%) 8090 plate with elongated grains (30µm x 400µm x 300µm) was used.

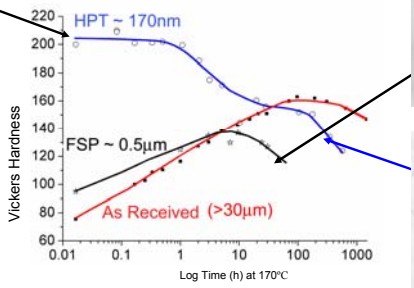
FSP was carried out using two different conditions: A – 400rpm tool rotation, 76mm/min traverse speed, pin depth ~11mm, multiple passes, cooling behind tool using water spray, producing a grain size ~10µm. B – 225rpm tool rotation, 76mm/min traverse speed, pin depth ~ 3.2mm, a single pass, cooling with a dry ice and antifreeze bath prior to and after processing, producing a grain size ~ 0.5 µm.

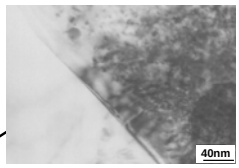
HPT was carried out on solution treated disks at 20ºC using a pressure of , rotations (to 'saturation'), producing a grain size of ~ 170nm.

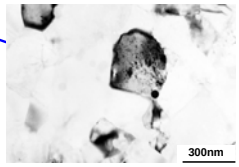
Effect of HPT and FSP on Grain Size and Age-hardening Response







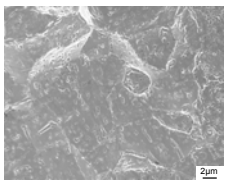




- HPT reduced the grain size from >30µm to ~170nm, resulting in a high hardness (~200HV) prior to ageing, as a result of grain-size strengthening (Hall-Petch relation) and work hardening.
- The ageing response of HPT specimens depended on the ageing temperature: At ≥ 170°C, softening due to grain growth outweighed hardening due to precipitation. At ≤ 160°C, hardening due to precipitation occurred initially before softening due to grain growth.
- The peak hardness of FSP material (0.5 µm) was less than that for the coarse-grained material (despite some grain-size strengthening), probably because the volume fraction of precipitate-free zone adjacent to grain boundaries was ~28% for the fine-grained material, compared with essentially 0 (for the coarse-grained material).

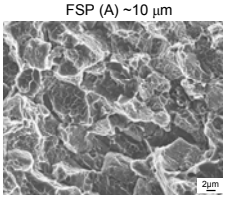
Effect of Grain Size on Fracture Behaviour of Aged Material (VH ~140) tested at 20ºC

8090 T8771 >30(µm)



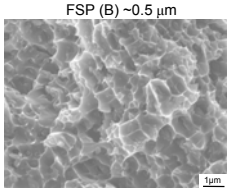
Brittle Intergranular Fracture

FSP (A) ~10 µm



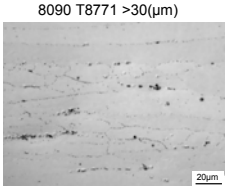
Dimpled Intergranular Fracture

FSP (B) ~0.5 µm

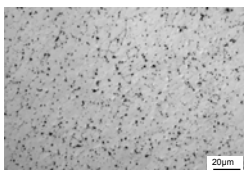


Dimpled ransgranular Fracture

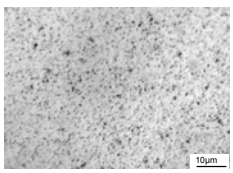
8090 T8771 >30(µm)



FSP (A) ~10 µm

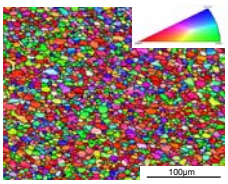


FSP (B) ~0.5 µm

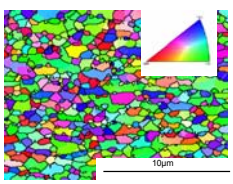


Optical micrographs of electropolished surfaces show that FSP not only refines the grain size but also fragments constituent particles, producing more uniform distribution, especially for the finer grain size.

FSP (A) ~10 µm

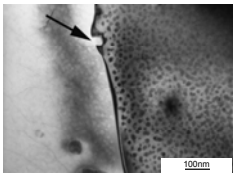


FSP (B) ~0.5 µm

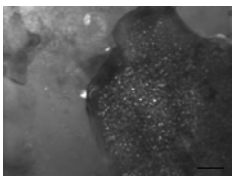


EBSD shows that FSP produces refined grains with predominantly high angle grain boundaries for both processing routes. (note not all the grain boundaries are detected for the finer grain size)

TEM (A) ~10 µm

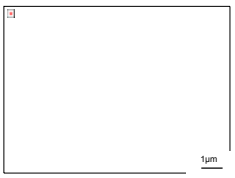


TEM (B) ~0.5 µm



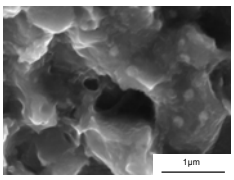
TEM microscopy shows that grain boundary precipitates are present in the 10µm FSP material, but are sparse if present in the 0.5mm FSP material. Precipitate free zones were found to be present in both 0.5µm and 10µm FSP material.

SEM (A) ~10 µm



SEM of fracture surfaces of FSP materials (from specimens pre-exposed to gallium) reveals the distribution of particles on the grain boundaries

SEM (B) ~0.5 µm



Conclusions

- The present study (and others in the literature) suggest that the stability of ultra-fine or nanocrystalline grains produced by SPD, i.e. grain growth at quite low temperatures, could limit the extent to which grain refinement is practically useful.
- FSP, which involves dynamic recrystallization at high temperatures, does not produce grains as small as other SPD techniques, but grains are not as unstable. However, FSP fine-grained Al Alloys may have lower strengths than coarse-grained alloys due to greater volume fraction of grain boundary precipitate –free zones.
- The change in fracture mode resulting from FSP in the 8090 Al-Li-Cu-Mg alloy probably arises partly from finer dispersions of particles. Less strain localisation at grain boundaries due to finer grain sizes may also be involved.