

# Brittle-Intergranular Fracture (BIF) in Al-Li and other Aluminium Alloys



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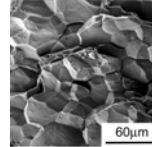


## Background

Al-Li alloys are especially prone to brittle intergranular fracture (BIF) e.g. fracture surface of airframe panel from crashed helicopter shown. Use of Al-Li alloys in aerospace has been limited largely due to their susceptibility to BIF. Part of the problem is that during service further ageing leads to a decrease in toughness below acceptable levels.



Brittle Intergranular Fracture Surface

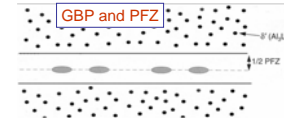


## Proposed Causes for BIF

Localised Planar Slip

Grain Boundary

Continuous shearing of precipitates on a slip plane resulting in "localised" planar slip and dislocation pile-ups at grain boundaries.



Grain Boundary Precipitates (GBP) and Precipitate Free Zones (PFZ) that localise strains at grain boundaries.

Solute Segregation



The segregation of Li, Mg and Zn solute at the grain boundary [1]. Solute weakens inter-atomic bonds at grain boundary.

## Experimental Procedures and Materials

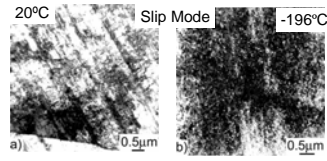
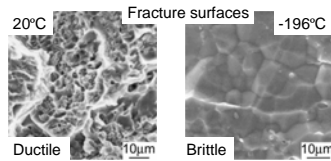
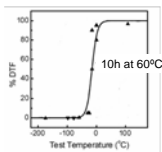
Composition wt%

Alloy	Li	Mg	Cu	Fe	Si	C	O	other
AA8090 plate	2.2	0.7	1	0.07	0.01	-	-	
AA5091 extrusion	1.29	4.11	-	-	-	1.17	0.41	
Al-Mg casting		10.6	0.25	0.3	0.25			0.15Mn, 0.15Zn, 0.25Ti

Experimental techniques include: cantilever bend tests to examine fracture behaviour, atomic force microscopy (AFM) to observe slip behaviour, electron microscopy (TEM and SEM) to examine the precipitation kinetics, atom probe for grain boundary analysis, and severe plastic deformation techniques including friction stir processing and high pressure torsion (HPT) to refine the grain size.

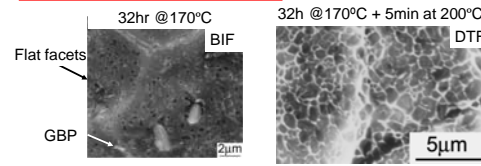
## Fracture Behaviour vs Slip Mode (& temperature)

8090 Al-Li Very Under-Aged

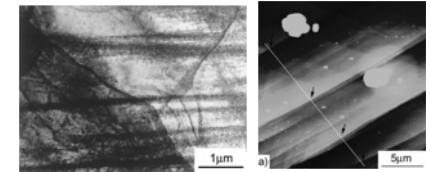


A sharp transition with temperature from ductile to brittle is present in very under-aged (VUA) Al-Li 8090 where no GBP or PFZ are present [2]. Hence PFZ and GBP cannot be the main cause of BIF. TEM micrographs show that slip planarity decreases with temperature, suggesting that slip is not important for BIF [3,4]. Observations support a grain boundary phase transition dependant on the extent of lithium segregation.

8090 Al-Li Near Peak Aged (T8771)



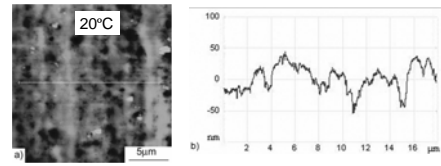
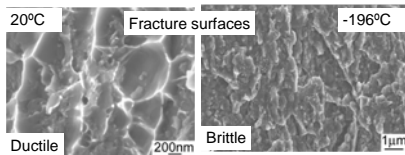
Planar Slip – TEM and AFM Observations



BIF is present in 8090 Al-Li T8771 with flat facets and precipitates and is exacerbated by GBP which localise strains at the grain boundary [5]. Polished deformed surfaces show that slip is planar and localised. Re-ageing T8771 for 5mins at 200°C leads to a twofold increase in toughness and a dimpled fracture surface appearance, with only a slight reversion of  $\delta$ , but no change in slip mode [5]. Slip mode again does not seem to be important for BIF.

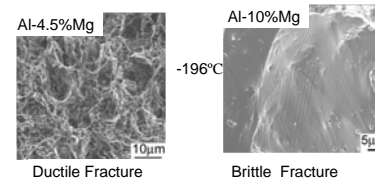
Mechanically Alloyed 5091 (grain size ~ 500nm)

Slip observations on polished deformed surfaces at 20°C



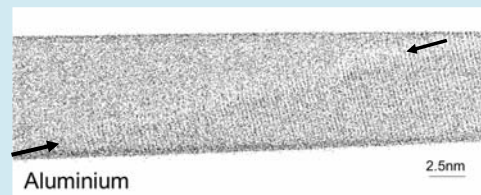
The ductile to brittle transition is also present in MA 5091. Slip observations show that slip is homogeneous at 20°C and should be homogeneous at -196°C. Again it seems that slip mode does not seem to have an influence on the fracture behaviour.

Al-Mg



Ductile to Brittle transitions with temperature are also present in Al-Mg alloys with high amounts of magnesium (>7wt%). The reason for BIF at higher concentrations of magnesium is probably due to magnesium segregation [7,1]. Fairly homogeneous slip is expected for these alloys since they are solid solution strengthened (no precipitates to be sheared). Again it seems that the slip mode does not have any correlation with fracture observations.

## Atom Probe Analysis at Grain Boundaries



Grain boundaries in high pressure torsion (HPT) AA5091 (heat treated 30hr at 150°C, 110nm grain size) show magnesium segregation but lithium depletion. Further testing is underway to understand the depletion in lithium. The depletion in lithium may be related to i) unreliable lithium detection in the atom probe, ii) lithium diffusion to grain boundary triple points and/or iii) a change in grain boundary characteristics of ultra-fine grained alloys. Future work will also involve fracture testing of HPT materials at different temperatures to determine the effect of grain refinement on fracture behaviour.

## Conclusions

- Slip mode does not seem to be important for brittle intergranular fracture.
- Brittle intergranular fracture is more likely due to grain boundary solute segregation in Al-Li and Al-Mg alloys.
- Magnesium segregates to the grain boundary in HPT AA5091.
- A depletion of lithium was observed at the grain boundary - further work is required to understand this.

## References

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- [2] S. P. Lynch, B. C. Muddle, Philosophical Magazine A, **82** (2002) 3361-3373.
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- [7] S.L. Cundy, P.N.T. Unwin, R. B. Nicholson et al., Proc. Roy. Soc. A, **v307 1490** (1968) 267-281.