AN ALUMINIUM-LITHIUM ALLOY WITH IMPROVED IN-PLANE ISOTROPY

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Abstract

Al-Li alloys designated as 1441 with lower Li and higher Cu contents compared to the 8090 composition were produced in the form of sheets of 1.2 to 8 mm thickness in clad and unclad conditions. Alloy ingots were processed so as to obtain high degree of recrystallisation in the semifinished products. The semifinished products were heat treated to obtain the required yield strength (> 360 MPa) while minimising the presence of grain boundary weakening features. Tensile properties in L, LT and 45° directions were found to be well balanced in all the cases. Fracture toughness was found to be satisfactory. Fatigue Crack Growth Rates (FCGR) were found to be intermediate between those of 2014 and 8090C alloys, and were similar in L-T and T-L orientations.

Introduction

Anisotropy of mechanical properties has been identified as one of the critical problems in the development of Al-Li alloy mill forms. It manifests itself as: (i) low ductility in the ST direction and low toughness in L-S or T-S orientations in thick products [1, 2], and (ii) low ductility in LT direction, low toughness and fatigue resistance in T-L orientation, and low yield strength in the off-axis directions [1, 3] in thick as well as thin products.

Each type of anisotropy may result from different factors, acting independently or in a synergistic manner. For example, low ductility, fracture toughness and FCG resistance in the through-thickness direction of plates and in the transverse direction of sheets is due to the combined effect of (a) elongated grain structure, (b)coplanar slip causing strain localisation at the grain boundaries and (c) weak grain boundaries due to δ'-precipitate free zones (PFZ's), elemental segregation and coarse precipitates [1-3]. On the other hand the low yield strength in the off-axis directions in the rolling plane is caused by the presence of strong texture [1-6], and aided by preferred precipitation of semicoherent phases along selected crystallographic planes [7]. Efforts in the past have concentrated on minimising one or more of these factors and have resulted, to varying degrees, in reducing the anisotropy of properties [1,2,5].

In the present work, an effort has been made to minimise the anisotropy in sheet products through modifications in the chemical composition, and by applying the existing knowledge base on the effects of processing parameters on recrystallisation, texture and the matrix and grain boundary precipitate structure [8].

Experimental Details

Aluminium-lithium alloys, designated as 1441, with nominal composition Al-1.9 %Li-1.8 %Cu-0.8 %Mg-0.09 %Zr (with 0.08 %Fe, 0.04 %Si and < 10 ppm Na) were produced by DC casting and processed by a combination of hot and cold rolling to 8 (hot rolled only), 2 and 1.2 mm thicknesses. The sheets were solutionised (ensuring fast heating rates), cold stretched 2-3% and aged at 170 °C for 20-32 hours so as to develop proof strength of about 360 MPa.

Tensile tests were carried out along L, LT and 45° angle with respect to the rolling directions on specimens conforming to ASTM E8M (25 mm G.L.) specifications. Plane stress fracture toughness was evaluated for all sheets using 200 x 620 mm panels with centre crack configuration. Fatigue crack propagation rates were measured with stress ratio R=0.1 in L-T and T-L orientations on compact tension specimens with 50.8 mm width and half-height to width ratio of 0.6. Optical, transmission electron and scanning electron microscopy techniques were used (following standard specimen preparation techniques) for examining the grain structure, precipitate structure and fracture surfaces, respectively.

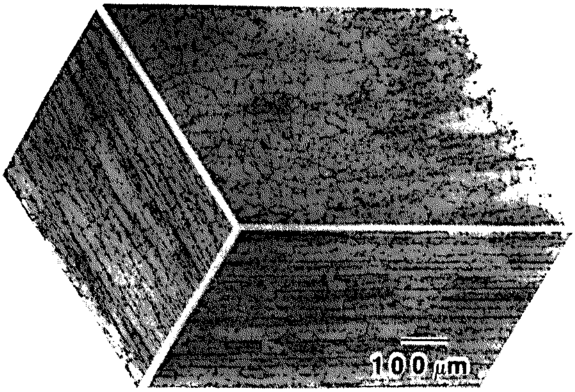
Results and Discussion

Figures 1 to 3 show the optical microstructures of 8, 2 and 1.2 mm thick sheets. In all the three sheet products, the microstructure was found to be recrystallised. In the 8 mm thick sheet, the microstructure is found to be lamellar recrystallised while the thinner sheets (2.0 and 1.2 mm) displayed equiaxed recrystallised grain structures. This is the result of low finish rolling temperature and (for the thin sheets) cold work both of which increase the stored strain energy thus increasing the driving force for recrystallisation during subsequent solution treatment. In all cases the grain size in the core was somewhat coarser than the overall grain size, (see Fig 3 b), which indicates the importance of heating rate on the recrystallised grain size. The different etching response of the surface layers, as seen in Figures 2 b and 3 b is attributd to the presence of Al-cladding.

Coarse intermetallic particles, mostly containing Fe and Cu, are observed at random locations, while the high angle grain boundaries are seen to be decorated with etch pits, as seen in Figures 2 c and 3 c. The metastable δ' (Al_3Li) and S' (Al_2CuMg) precipitates and the δ'-PFZ near a high angle grain boundary are shown in Figure 4. Both δ' and S' are fine and distributed uniformly throughout the matrix. The width of the δ'-PFZ is about 30-40 nm and considered to be small compared to the typical values corresponding to peak ageing (190°C /24h) treatments (≈ 0.2 μm). Grain boundary precipitates were very fine and sparsely distributed under these ageing condition.

The tensile and fracture properties of the sheets are presented in Table I. The balance of properties for the thin sheets in the three directions is found to be excellent. The property isotropy is seen to be better than other Al-Li alloys, as seen in Table I. The plane stress fracture toughness for the sheets was evaluated in the L-T orientation, and was in the range 75-79 MPa$\sqrt{m}$

The tensile fracture surfaces (Figure 5) revealed predominantly grain boundary fracture, with remaining areas showing microvoid coalescence and transgranular shear components. The slip bands caused by the coplanar slip within the grains led to step formation on the grain boundaries, as seen in Figure 5. The predominantly grain boundary tensile failure and the presence of slip steps on the grain boundaries suggest that S' precipitation was not adequate to prevent coplanar slip. The nature of fracture remained similar in all test directions.



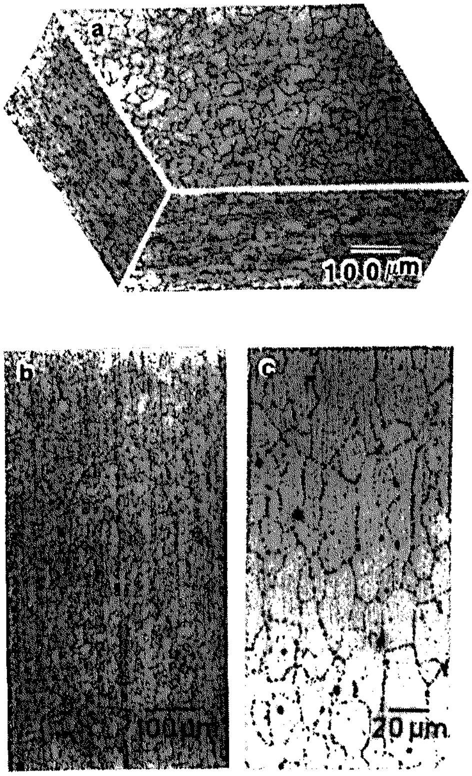


Figure 2. Microstructure of 1441 Al-Li alloy 2 mm thick (clad).

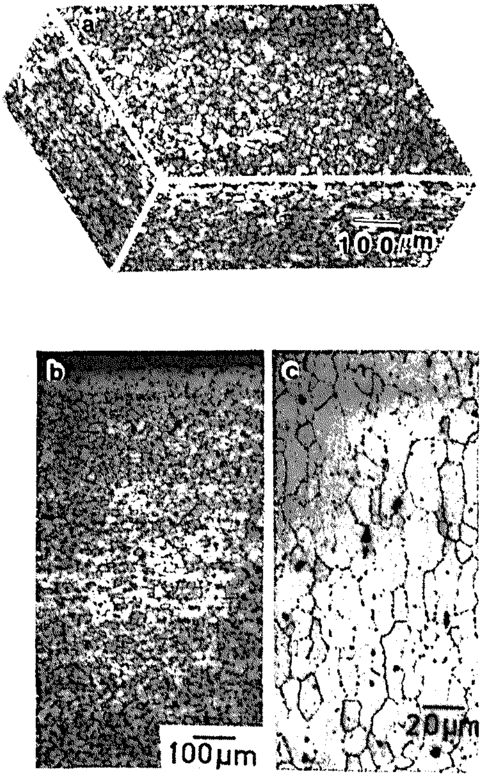


Figure 3. Microstructure of 1441 Al-Li alloy 1.2 mm thick (clad).

Table I. Tensile Properties of 1441 and Other Al(-Li) Alloys

Alloy (mm)	Test dir	0.2%PS (MPa)	UTS (MPa)	El (%)	Fracture Toughness K_c (MPa$\sqrt{m}$)
1420	L	280	458	14	LT: 74
(4)	45°	252	448	20	
	T	276	441	9.5	TL: 57
1440	L	390	478	8.5	LT: 47
(20)	45°	338	467	12.5	
	T	385	484	9.4	TL: 49
1440	L	365	458	6.5	LT: 123
(6)	45°	321	444	18	
	T	350	479	10.8	TL: 91
1460	L	457	500	5.8	LT: 72
(4)	45°	421	496	10.2	
	T	462	522	4.5	TL: 46
1441	L	380	447	8.5	LT: 75
(8)	45°	355	460	8.0	
	T	373	455	8.5	
1441	L	399	456	9.3	LT: 76.5
(2c)	45°	392	461	10.3	
	T	425	482	8.8	
1441	L	411	465	8.7	LT: 79
(2u)	45°	396	472	9.2	
	T	389	471	9.7	
1441	L	394	441	9.1	LT: 75
(1.2c)	45°	379	430	10	
	T	404	452	8.3	
1441	L	401	455	9.7	LT: 77
(1.2u)	45°	375	445	12.2	
	T	365	445	12.5	
2014	-	360	420	8.0	LT/TL:82/60

Alloy designations and nominal compositions:
1420: Al-5Mg-2.2Li-0.1Zr 1440: Al-2.2Li-1.2Cu-0.9Mg-0.1Zr
1460: Al-3Cu-2.2Li-0.1Zr c: clad, u: unclad condition
Properties of alloys other than 1441 are from ref [9].

The FCG rate Vs. stress intensity factor range ΔK data are presented in Figures 6 and 7. The FCGR's for the 1441 alloys are 3 to 5 times lower than those for 2014 alloy of comparable yield strength (Figure 6). It may be noted here that the 8090C alloy for which the fatigue date is presented in Figure 6 had yield strength of about 320 MPa which is lower than that of the 1441 alloys. The FCG behaviour is found to be almost identical in both

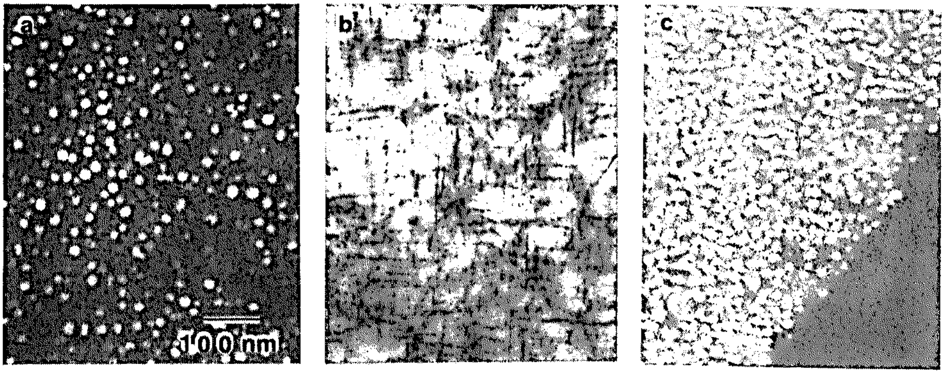


Figure 4. Precipitate structure in 1441 Al-Li alloy (2 mm) (a) Al_3Li (δ') (b) Al_2CuMg (S') and (c) δ'-PFZ near a high angle grain boundary

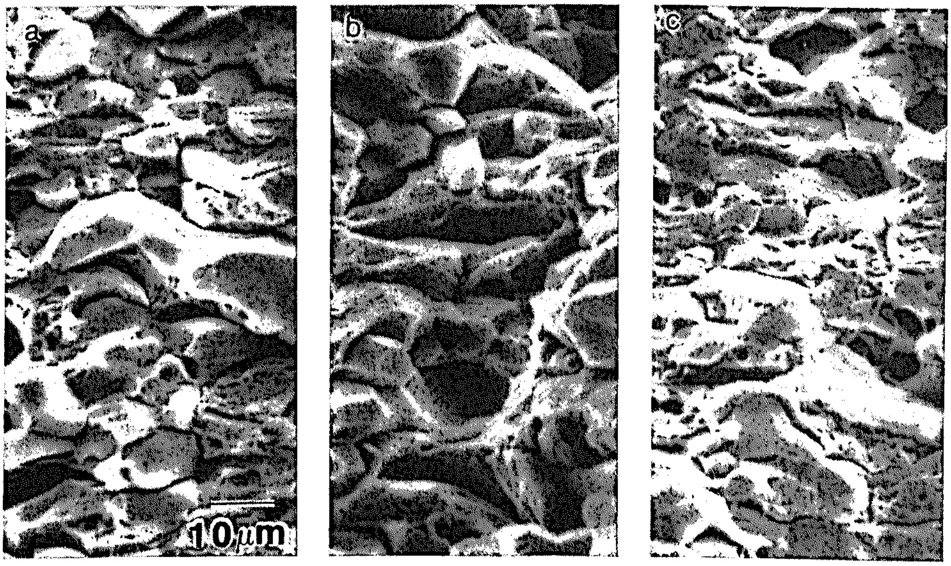


Figure 5. Tensile fracture surfaces of 1441 Al-Li alloys tested in (a) L, (b) 45° and (c) LT directions with respect to the rolling direction.

L-T and T-L orientations for all the three sheet thicknesses (Figure 7). The fatigue failure near threshold ΔK regions was found to be of mixed mode, i.e. comprising of quasicleavage and transgranular shear components (see Figure 8).

The isotropy of yield strength can be related to the high degree of recrystallisation (and the absence of strong texture) in all the sheet products. Good ductility in the LT direction and good FCG resistance in the T-L orientation can be attributed to a) the presence of recrystallised grain structure and b) virtual absence of grain boundary weakening features (see Fig. 4 c). The observation of a large grain boundary component in the tensile fracture surface is clearly due to the strain concentration at the grain boundaries due to planar slip.

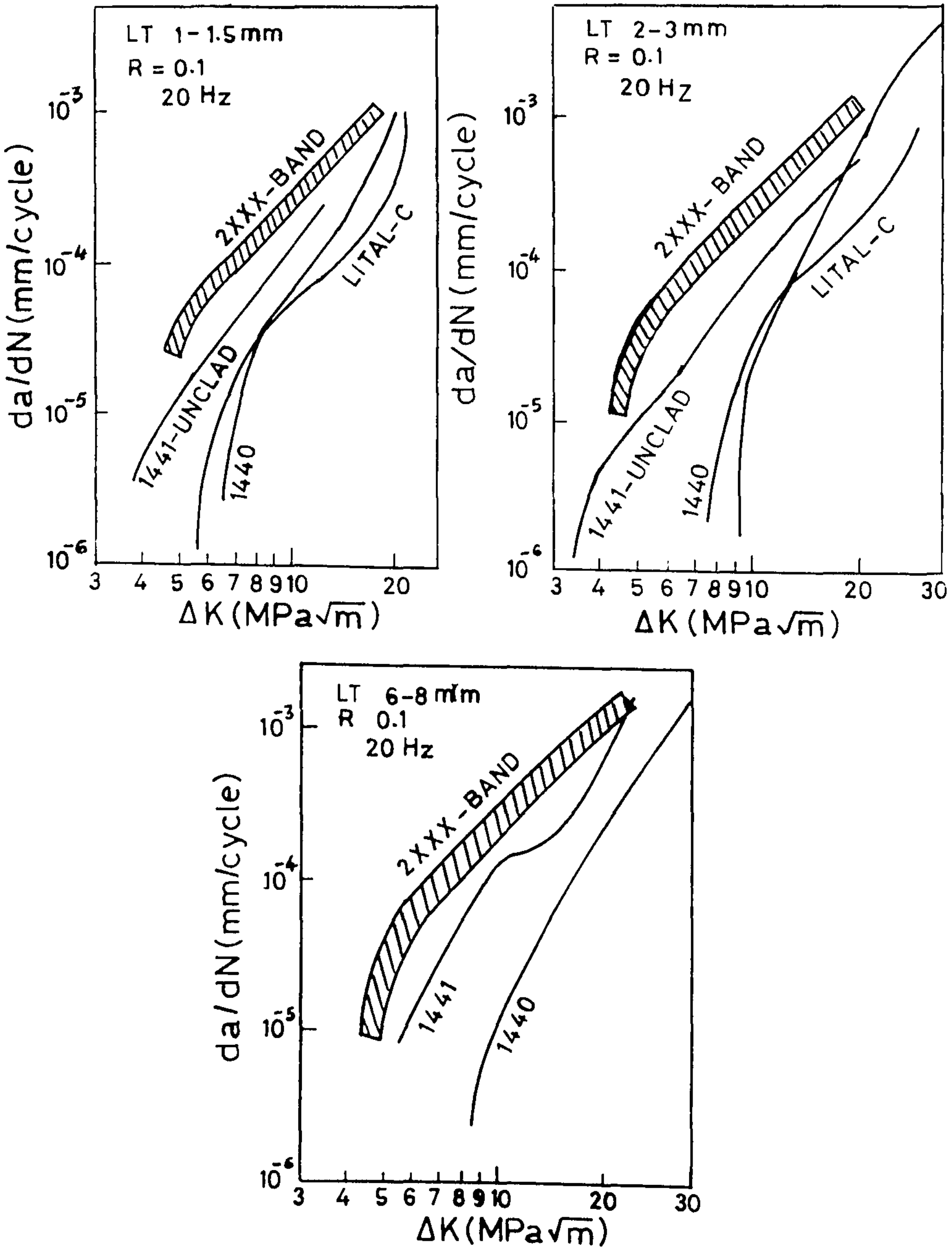


Figure 6. Fatigue crack propagation behaviour of unclad 1441 and other Al(-Li) alloys, R=0.1. FCG data for 2xxx, 1440 and 8090 (LITAL-C) alloys is taken from ref [9].

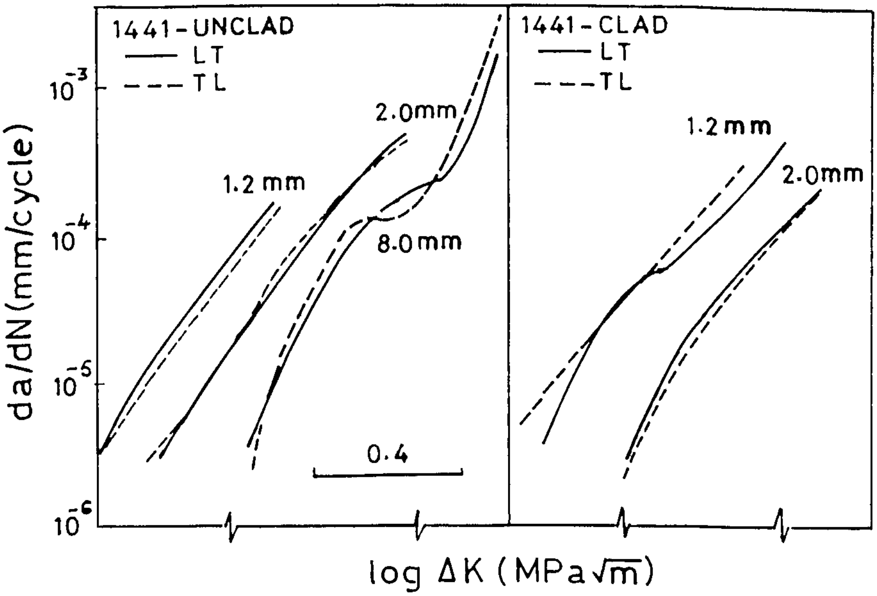


Figure 7. Orientation dependence of FCG rates for 1441 alloys, R=0.1

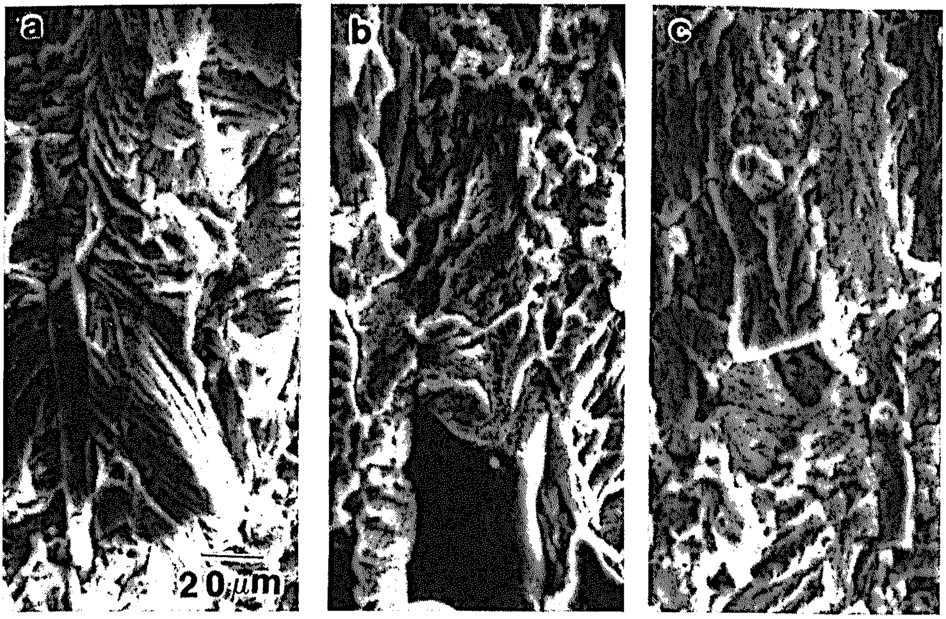


Figure 8. Fracture surfaces of fatigue crack propagation specimens near threshold Δ K regions (a) 1.2 mm (b) 2 mm and (c) 8 mm unclad sheets.

It is felt that, in addition to the selection of optimum Zr content and optimum process parameters, the low Li content of the present alloys compared to that of 8090 alloy ($\approx$2.2-2.5 %) is also responsible for the improved response to recrystallisation, an observation which was also confirmed in a separate study [8].

Conclusions

1. Al-Li alloys with high degree of recrystallisation and low presence of grain boundary weakening microstructural features were produced in 8, 2 and 1.2 mm thick sheet forms.
2. The tensile properties were, in general, isotropic in the rolling plane. Plane stress fracture toughness was evaluated in L-T orientation and was satisfactory.
3. The fatigue crack propagation rates were lower than 2014 alloy, and werre very similar in the L-T and T-L orientations.

Acknowledgments

The authors wish to thank their respective organisations for the support received and for the permission to publish this work.

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