APPENDIX B

EFFECT OF Li LEVEL, ARTIFICIAL AGING, AND TiB_2 REINFORCEMENT ON THE FRACTURE TOUGHNESS OF WELDALITE™ 049-TYPE ALLOYS

Plane-strain fracture toughness (K_{IC}) was evaluated for Weldalite™ 049 with and without TiB_2 reinforcement. For the non-reinforced variant, changes in toughness were measured for various aging conditions and lithium levels.

Toughness testing was carried out on fatigue precracked compact tension (CT) specimens at 24°C (75°F), as per ASTM standard E-399, by Westmoreland Mechanical Testing and Research, Inc., Youngstown, PA. Specimens were machined in both the L-T and the T-L orientations, with the standard 1.27-cm (0.500-in) geometry, 0.927-cm (0.365-in.) thick.

Toughness was measured as a function of aging time at 160°C (320°F) for the two Weldalite™ 049(1.3) heats, 049(1.3) [heat 116] and 049(1.3) [heat 072] (Table B-1). The composition of these heats differed only in that 0.03 wt% Ti was added to 049(1.3) [heat 116] as an additional grain refiner. Both heats showed a decrease in toughness with increasing aging time, although toughness values for heat 116 were significantly higher than those for heat 072. This greater toughness may be due to a subtle change in the grain size resulting from the presence of Ti or, alternatively, to differences in texture or substructure formed during extrusion. K_{IC} and K_q values are quite promising: 22.5 MPa$\sqrt{m}$ (20.5 ksi$\sqrt{in}$) at a yield strength of 700 MPa (101.5 ksi), and 35.7 MPa$\sqrt{m}$ (32.5 ksi$\sqrt{in}$) at a yield strength of 565 MPa (82.0 ksi), respectively.

An extensive temper development program is currently under way at both Martin Marietta Laboratories and Reynolds Metals Co. to optimize temper and microstructure for the best combinations of toughness and strength. In fact, a reduction in the Cu content of Weldalite™ 049 to 4.75 wt% has already been shown to improve K_{IC} on both extrusions and rolled plate. For example,

Table B-1

Effect of Aging Time on the Fracture Toughness* of Weldalite™ 049

Alloy**	Aging Time at 160°C (320°F) (h)	Orientation	K_{IC} ksi√in	K_{IC} (MPa√m)	K_q ksi√in	K_q (MPa√m)	YS ksi	YS (MPa)
049(1.3) [heat 072]	6	L-T	24.8	(27.3)	--		86.0	(593)
	20	L-T	14.8	(16.3)	--		93.8	(647)
	24 (T8)	L-T	13.2, 12.0	(14.5, 13.2)	--		98.0	(676)
		T-L	11.4, 11.1	(12.5, 12.2)	--		--	--
049(1.3) [heat 116]	6	L-T	--		32.5†	(35.7)	82.0	(565)
	20 (T8)	L-T	20.5	(22.5)	--		101.5	(700)

* 1.27-cm (0.500-in) (CT) compact fracture toughness specimens, 0.927-cm (0.365-in) thick, tested at 24°C (75°F)

** 0.953-cm x 10.2-cm (0.375-in x 4-in) extruded bar, WQ, stretched

† Invalid test as per ASTM E-399

Heubaum and Pickens,[1] using specimens in the L-T orientation from extruded Weldalite™ 049 bar containing about 5.0% Cu, obtained K_{IC} values of 24.2, 34.6, and 50.6 MPa$\sqrt{m}$ (22, 31.5, and 46 ksi$\sqrt{in}$) at yield strength levels of 717, 621, and 414 MPa (104, 90 and 60 ksi), respectively.

The effect of Li level on the K_{IC} of Weldalite™ 049-type alloys was determined for three variants at nominally the same strength level (Table B-2). As shown in Section I of this report, increasing the lithium content of Weldalite™ 049 decreases the maximum strength obtained in the peak-aged temper. Therefore, to compare toughness at similar strengths, we aged both of the 049(1.3) heats to an underaged temper (6 h at 160°C (320°F)) and alloys 049(1.6) and 049(1.9) to their peak-aged (comparable strength) tempers 34 h at 160°C (320°F)) (Table B-2). Under these conditions, the K_{IC} values for 049(1.6) and 049(1.9) were about 30% lower than the lowest K_{IC} value for 049(1.3). However, since grain boundary microstructure may play an important role in the fracture of aluminum-lithium alloys -- and is more a function of artificial aging history than alloy strength per se -- we also compared toughness values for the three lithium levels in the peak-aged temper. The low toughness for heat 049 (heat 072) is unfortunate and these studies should be repeated with more representative material that also includes alloys with lower Cu content.

Reinforcement of Weldalite™ 049(1.3) with TiB_2 particles produced a similar toughness (Table B-3) comparable to that of alloy 049(1.3) [heat 072], but lower than that for 049 [heat 116] in the peak-aged temper.

(1) F.H. Heubaum and J.R. Pickens, Presentation by J.R. Pickens at Al-Li V, Williamsburg, VA, Mar. 29, 1989.

Table B-2

Effect of Lithium Level on the Fracture Toughness* of Weldalite™ 049

Alloy	Weight % Li	Aging Time at 160°C (320°F) (h)	K_{IC} ksi√in	K_{IC} (MPa√m)	K_q ksi√in	K_q (MPa√m)	YS ksi	YS (MPa)
049 (1.9)	1.9	34 (T8)	16.8†	(18.5)	--		78.0	(538)
049 (1.6)	1.6	34 (T8)	17.4†	(19.1)	--		84.2	(579)
049 (1.3) [heat 072]	1.3	24 (T8)	12.6†	(13.8)	--		98.0	(676)
		6	24.4	(26.8)	--		86.0	(593)
049 (1.3) [heat 116]	1.3	20 (T8)	20.5	(22.5)	--		101.2	(698)
		6			32.5	(35.7)††	82.0	(565)

* 1.27-cm (0.500-in) compact fracture toughness specimens, 0.927-cm (0.365-in) thick, tested at 24°C (75°F)

** 0.953-cm x 10.2-cm (0.375-in x 4-in) extruded bar, WQ, stretched

† Mean of two tests

†† Invalid test as per ASTM E-399

Table B-3

Fracture Toughness* for TiB_2-Reinforced
vs Non-Reinforced Weldalite™ Alloys in the T8 Temper

Alloy**	Orientation	K_{IC} ksi√in	K_{IC} (MPa√m)	YS ksi	YS (MPa)
049(1.3) [heat 116]	L-T	20.5	(22.5)	101.2	(698)
049(1.3) [heat 072]	L-T	12.6†	(13.8)	98.0	(676)
	T-L	11.2†	(12.3)		
049(1.3)-TiB_2	L-T	12.4†	(13.6)	94.2	(650)
	T-L	10.8†	(11.9)		

* 1.27-cm (0.500-in) compact fracture toughness specimens, 0.375-in thick, tested at 24°C (75°F)

** From 0.953 cm x 10.2 cm (0.375-in x 4-in) extruded bar

† Mean of two tests