ORIENTATION DEPENDENCE OF FRACTURE TOUGHNESS IN 8090 ALUMINUM ALLOY PLATE USING CHEVRON NOTCHED SPECIMENS

J. Morrison* and K.J. KarisAllen*

The plane-strain fracture toughness of a 13 mm thick 8090-T8771 plate has been determined using chevron-notched short bar specimens. The specimens were notched both parallel (short-transverse) and perpendicular to the surface of the plate, and oriented at 30° intervals relative to the rolling direction. In-plane tensile properties were measured at the same orientations. Short-transverse toughness was about half that from specimens notched through the plate thickness. Minimum yield strength occured at 60° to the rolling direction, and maximum toughness at 90°.

INTRODUCTION

The chevron-notched short bar test for plane strain fracture toughness, K_{Iv}, has recently been standardized as ASTM E1304-89. It provides a simple, reproducible, and material efficient method of toughness determination. Differences between this procedure and standard through-cracked specimen tests for K_{Ic}, such as ASTM E399, include the elimination of the fatigue pre-crack, and a smaller minimum specimen size. Comparisons of K_{Ic} and K_{Iv} for aluminum alloys (Brown (1), Morrison et al. (2)) have shown good agreement, although at high toughness levels K_{Iv} data show a trend to higher values. It has been argued that this disparity might arise from an R-curve dependence of K_{Ic} (Eschweiler et al.(3), Barker (4)).

* Defence Research Establishment Pacific
Victoria, B.C., Canada

The new ASTM Standard requires a minimum specimen thickness B of $1.25(K_{IV}/\sigma_y)^2$, which is half that for pre-cracked compact and bend specimens. The square short bar specimen is as easy to test in the S-L and S-T orientations as in the L-T and T-L orientations. It can be used to study the variability of toughness in anisotropic materials even in relatively thin sections, and such phenomena as delamination fracture. A limited amount of short bar testing of aluminum-lithium has been published on cryogenic behaviour and heat treatment effects (Dorward (5), Ahmad (6)).

This paper describes an experimental study of the orientation dependence of tensile properties and fracture toughness in an aluminum-lithium alloy plate.

MATERIAL AND TEST PROCEDURES

The 13 mm thick medium strength commercial 8090-T8771 plate ("Lital A") had been solution treated, 6% stretched, and artificially aged. The manufacturer's chemical analysis and mechanical properties are shown in Table 1. Tests were conducted at room temperature on as-received material.

Tensile and fracture toughness tests were conducted on specimens cut from the plate at various orientations. Rectangular tensile specimens either 6 or 13 mm thick with a 13 mm wide by 25 mm gauge length were machined with their long axis at 30° intervals clockwise from 0° to 150° with respect to the rolling direction. In each orientation, duplicate 6 mm thick specimens were machined from one surface of the plate, and also from the mid-thickness, and 13 mm thick specimens were machined from the full plate thickness.

Rectangular 13 mm by 13 mm by 25 mm chevron-notch short bar specimens were machined with their long axis (crack extension direction) in each of the above six orientations. These specimens were notched both parallel to (at mid-thickness) and perpendicular to the plate surface in order to provide toughness values for the short-transverse as well as the in-plane loading

TABLE 1 - Chemical composition and mechanical properties.

Chemical Composition (wt. %)

Li	Cu	Mg	Fe	Si	Zr	Na	other
2.35	1.20	0.64	0.05	0.03	0.11	0.0005	0.07

Mechanical Properties

	σ_{YS} (MPa)	UTS (MPa)	Elong. (%)	Hardness (R_b)	K_Q MPa.√m
Long.	508	555	5	79	28 (T-L)
Trans.	479	548	8	82	31 (L-T)

directions respectively. Duplicate tests were conducted in accordance with ASTM Standard E1304. However, the narrow chevron slot could not be reproduced accurately within the 0.37 mm maximum width required by the standard, and was consequently relaxed to 0.48±0.025 mm. The reduced constraint may tend to increase the likelihood of a peak in load developing prior to the initiation of crack extension. All of the mechanical tests were conducted in a computer equipped servo-hydraulic machine using displacement control.

RESULTS

Table 2 shows the tensile test results, which are symmetrical with respect to plate orientation (30^o equivalent to 150^o, and 60^o equivalent to 120^o). The highest strength values were in the rolling direction, with a 20-25% lower yield strength and 10% lower UTS at the 60^o and 120^o orientations. The broken test specimens showed differing degrees of shear and in-plane splitting depending on the orientation (Figure 1). The strengths were comparable to those obtained by the manufacturer using larger specimens. The specimens from the

TABLE 2 - Tensile properties.

Orientation - degrees clockwise from rolling direction	0	30	60	90	120	150
a) Surface (6 mm)						
0.2%P.S. (MPa)	485	440	375	445	375	430
UTS (MPa)	530	510	485	525	490	515
elongation (%)	7	11	15	13	13	11
b) Centre (6 mm)						
0.2% P.S. (MPa)	530	460	385	495	380	455
UTS (MPa)	560	520	500	550	505	525
elongation (%)	6	9	14	9	13	9
c) Full thickness (13 mm)						
0.2% P.S. (MPa)	480	435	370	450	380	435
UTS (MPa)	540	515	490	525	495	515
elongation (%)	9	12	16	12	14	13

centre of the plate were slightly stronger than those from the outside, and tended more to shear fracture. Full thickness gave the same results as the surface (half thickness), indicating that the top and bottom halves of the plate were equivalent.

The results of the short bar tests are shown in Table 3. Figures 2 and 3 show typical fracture surfaces and load/load-line displacement curves respectively. Since the slot width violated the requirement of the ASTM standard, the short bar maximum load toughness is designated K_{QvM} rather than K_{IvM}. The maximum measurable toughness in a 13 mm thick short bar specimen notched through the thickness ranged between 38 and 48 MPa $\sqrt{m}$, based on the tensile data. The short-transverse specimens showed "crack jump" behaviour and serrated load-displacement curves, leading to a final sudden rupture (Fig 3(a)). In orientations with crack extension in close to the transverse direction, the serrations were more pronounced, but

TABLE 3 - Short bar fracture toughness K_{QvM}.

K_{QvM} (MPa.√m)	Orientation - degrees clockwise from rolling direction 0	30	60	90	120	150
notched						
- short transverse	14	15	17	19	19	14
- through thickness*	27	27	28	32	29	28

* prior to onset of out-of-plane tearing

otherwise these curves were all very similar. Specimens loaded in the plane of the plate showed an increasing tendency to out-of-plane tearing as the orientation rotated away from the rolling direction. The resulting "smooth" crack growth behaviour and load-displacement traces were characterized by an initial flat region of in-plane tearing followed by a gradual increase in load as the fracture plane deviated. At orientations more than 30^{o} from the rolling direction, the flat region was reduced to a "bump" on the curve, to the point at which, at 90^{o}, it virtually disappeared.

For the short-transverse specimens, the K values were calculated from maximum load, ignoring any prominent load peak occurring at the onset of tearing. This deviates from the ASTM standard, which demands a minimum amount of crack extension (defined by a minimum unloading slope) prior to determination of a peak load. Experience on aluminum suggests that the latter produces a similar but less reproducible result with the specimen type used here. For the through-notched specimens, K was taken from the initial part of the curve (if any) prior to the start of out-of-plane tearing, again ignoring any initiation peak.

DISCUSSION

Several differences are apparent between the 8090 plate and a conventional high strength aluminum alloy such as 7475.

Conventional alloys usually are weaker (and tougher) in the plate mid-thickness relative to the surface Brown (1), whereas the 8090 alloy was found to be stronger. In a chevron-notched specimen relative to a compact specimen, a larger proportion of the crack front is located in the centre of the plate, suggesting a lower measured K_{Iv} for 8090 aluminum. On the other hand the splits observed in tensile specimens are generally found between the centre and surface rather than at the plate centre, indicating higher toughness near the middle of the plate.

The values in Table 3 agree reasonably well with the manufacturer's values, and, irrespective of fracture plane, show a consistent trend to higher toughness with increasing divergence of the specimen axis from the rolling direction. The short-transverse toughness is of the order of 50-60% of that measured in the plane of the plate. The short bar specimen is very suitable for short transverse toughness measurement in alloys of this type. Work is under way to evaluate notch acuity effects, and the interpretation of load-displacement records.

REFERENCES

(1) Brown, K.R., in " Chevron-Notched Specimens: Testing and Stress Analysis", ASTM STP 855, American Society for Testing and Materials, Philadelphia, 1984, pp. 237-254.

(2) Morrison, J., Gough, J.P., and KarisAllen, K.J., J. Testing and Evaluation, Vol. 17, No. 1, 1989, pp. 14-19.

(3) Eschweiler, J., Marci, G., and Munz, D.G., in "Chevron-Notched Specimens: Testing and Stress Analysis", ASTM STP 855, American Society for Testing and Materials, Philadelphia, 1984, pp. 255-269.

(4) Barker, L.M., J. Testing and Evaluation, Vol17, No. 4, 1989 pp. 218-223.

(5) Dorward, R.C., Scripta Met., Vol. 20, 1986, pp. 1379-1383.

(6) Ahmad, M., Journal de Physique, Vol. 48, 1987, pp. 871-879.

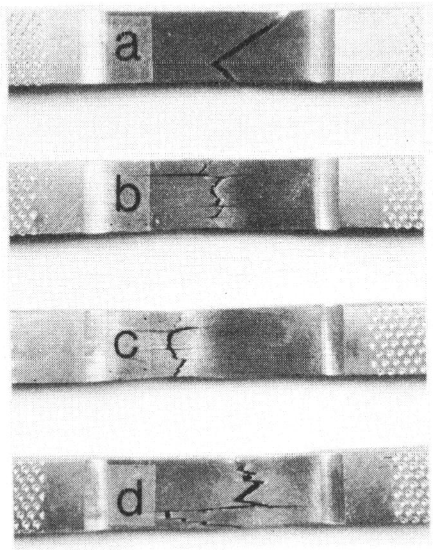

Figure 1 Tensile specimens: (a) 0^0,(b) 30^0, (c) 60^0, (d) 90^0

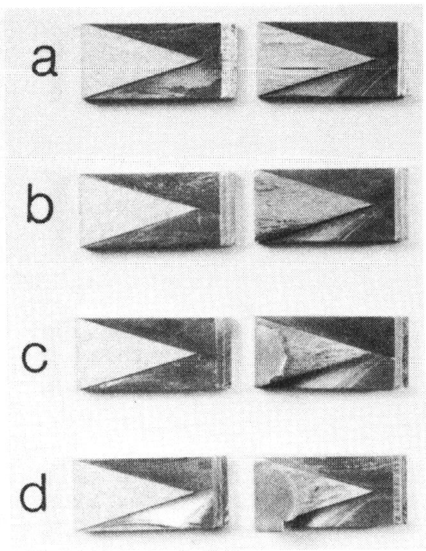

Figure 2 Short bar specimens: left-short trans., right-through thickness

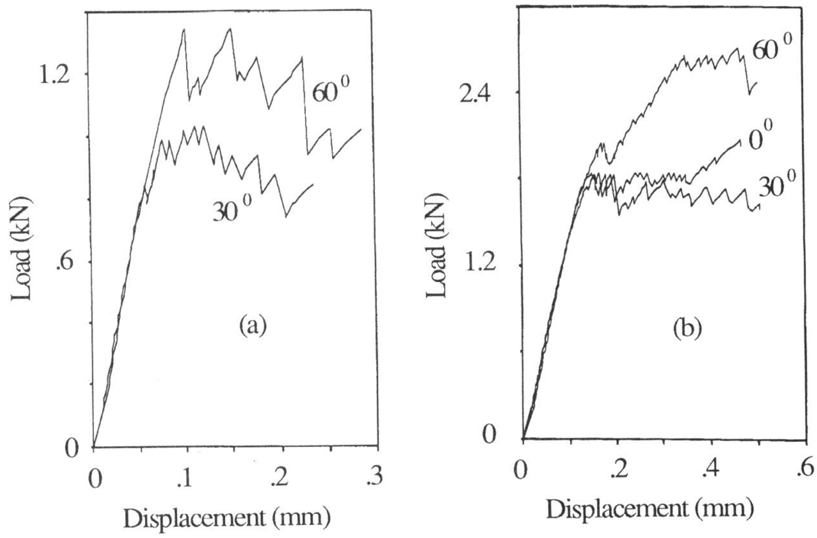

Figure 3 Load-displacement curves - a) short-transverse (b) through thickness chevron-notched specimens