FRACTURE TOUGHNESS CHARACTERIZATION OF EXTRUDED AlMgSi1.

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This paper contains a study of fracture mechanics properties of extruded AlMgSi1 alloy. A number of variables have been investigated using different elastic-plastic fracture toughness parameters as CTOD, J_{Ic} and J_R-curves. Both Compact Tension and 4-point bend specimens of 15.5 and 25mm thichness were used. Test variables included chemical composition, specimen orientation and various types of heat treatment. Results have shown that the fracture toughness are to a large extent affected by these variables. A new method for crack depth measurements have been developed based on a pulsed DC potential drop technique. Comparison of single specimen results using pulsed DCPD with multi-specimen results gave a very good agreement.

INTRODUCTION.

AlMgSi1 (AA6082-T6) is the most used aluminium alloy for offshore application. This alloy has a fairly high strength, a good corrosion resistance, a good weldability and is easily extruded into desired size and shapes. Use of aluminium offshore is beneficial because of a possible weight saving of up to 60% compared to steel. This requires optimum design with respect to stresses, shape and section thickness. The safety margins against failure may therefore be important. Relatively little is known about elastic-plastic fracture toughness parameters for extrusions of this alloy, and parameters affecting the toughness.

The present investigation was performed to establish the fracture toughness properties of the material in order to evaluate the significance of possible defects in aluminium structures. Fracture mechanics has a long tradition in the aerospace industry and special high strength/ high toughness alloys of the 2XXX or 7XXX series alloys have been developed to improve the damage tolerances (1). An

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extensive work have also been carried out to establish the safety againts catastrophic failure of the aluminium vessels of LNG-tankers (2) made of AlMg4.5Mn (AA5083-0). No tradition for application of fracture mechanics in the design phase or in evaluation of defects exist for extruded AlMgSi1.

EXPERIMENTAL.

Two alloys of the same type were investigated in the experimental program. The two alloys differed both in section shape and chemical composition. Both alloys were extruded sections. Alloy A was an extruded plate of 15.5 by 280 mm, while alloy B had a rectangular shape of 31.7 by 76.2 mm. The chemical composition of the two alloys is shown in Table 1. The microstructure of alloy A consisted of an elongated grain structure in the extrusion direction, while alloy B had a fibrous grain structure with grains several mm long. The mechanical properties for the longitudinal direction are shown in Table 2.

Table 1. Chemical composition of the two alloys.

Alloy	Mg	Si	Mn	Fe	Cu	Zn	Cr	Zr	Ti
A	0.79	1.1	0.69	0.43	0.068	0.16	0.014	0.002	0.022
B	0.68	0.98	0.52	0.20	0.0037	0.0039	0.0017	0.003	0.01

Table 2. Mechanical properties in the longitudinal direction.

Alloy	Yield strength (MPa)	Tensile strength (MPa)	Elongation A_5 (%)
A	281	328	10
B	318	338	16

CT specimens of 25mm thickness made of alloy B were tested both with and without 2.5 mm side grooves. 4-point bend specimens of 15.5 for alloy A and 25mm thickness for alloy B were also tested. In addition to testing in the as-extruded condition (T-6) the test programme also included testing of heat cycled specimens of alloy B. During the heat cycle process the specimens were heated to peak temperatures in the range 250-400°C in an air circulation furnace in order to study the effect of the heat cycle experienced during welding. All testing was according to ASTM E813-87.

The crack length was measured by using the DC potential drop method and hence, it was possible to measure the crack growth during testing without any partial unloading. A microprocessor based DCPD instrument developed at SINTEF which was controlled by a personal computer was used for this purpose (3). The electrical conductivity of aluminium is about 5 times better than for steel. Then, to obtain the same accuracy for aluminium than for steel, about 5 times higher current density is required. Figure 1 shows a very good agreement between the J_R-curve derived by the DCPD method and the multispecimen results.

Table 3 Fracture toughness results.

Alloy	Orientation	Type	J_{Ic} [kN/m]	K_{JIc} [MPa√m]	δ_m [mm]
A	L-T	4-p	12.75	31.6	0.045
B	L-T	4-p(sg)	41.3	56.7	0.18
B	L-T	CT(sg)	38.0	54.6	0.17
B	L-T	CT	42.1	57.4	0.17
B	T-L	CT(sg)	13.75	32.9	0.050

RESULTS AND DISCUSSION.

Results from the fracture toughness testing are summarized in Table 3.
Alloy B had a considerably better fracture toughness than alloy A. The J_R curves of the two alloys, Figure 2, also revealed considerable difference in tearing resistance. The most probable reason for this was that alloy A had a higher volume fraction of AlFeSi inclusions, and the size of the inclusions were also larger.

The orientation of the crack compared to the extrusion direction had a large influence on the fracture toughness. As it appears from Figure 2, the initiation toughness and the J_R curve are 3-4 times higher for the L-T orientation. The reason for this was that the AlFeSi inclusions were inhomogeneously distributed in the metal, and the effective distance between the particles was less in the T-L than the L-T direction. Figure 3 illustrates the difference in load capacity for the two different orientations of alloy B.

As can be seen from Table 3 the 4-point bend specimen gave slightly higher tougness values than CT specimens, however, the difference is not drastic. Specimens without side grooves also gave slighly higher values than with side grooves. This was expected, but the difference was not great up to a crack growth of about 2mm.

The effect of overaging was to decrease the mechanical strength and increase the fracture toughness. The trend was more and more pronounced with increasing peak temperature. This is consistent with the wellknown fact that fracture toughness usually decreases with increasing strength. The J_R-curves for overaged specimens are shown in Figure 4 compared with the as-extruded condition. The general trend here was that the tearing resistance increased with increasing peak temperature. At 350 and 400°C it was very difficult to distinguish crack growth from crack tip blunting by the DCPD measurements.

Overaging will result in coarsening of the strengthening precipitates. Some of the larger precipitates grow at the expense of the smaller ones. The strengthening effect of the Mg_2Si precipitates will be effectively reduced and completely lost if the overaging temperature is high enough or the time sufficiently long. The overaging has no effect on the size and distribution of the larger inclusions.

CONCLUSIONS.

The results showed that large variations in fracture toughness can be expected for extruded AlMgSi1 alloys. This is attributed to variations in the volume fraction, size and distribution of larger inclusions, mainly of AlFeSi type. Especially crack orientation is an important parameter for extruded aluminium.

4-point bend specimens gave slightly higher fracture toughness values than for CT specimens. Ungrooved specimens also gave slightly higher values then with side grooves, but the difference was not great.

Heat cycled specimens in the range 250°-400°C increased the fracture toughness with a marked reduction in the strength.

ACKNOWLEDGEMENT.

The present work is part of a dr. engineer research work at the Norwegian Institute of Technology sponsored by Skanaluminium.

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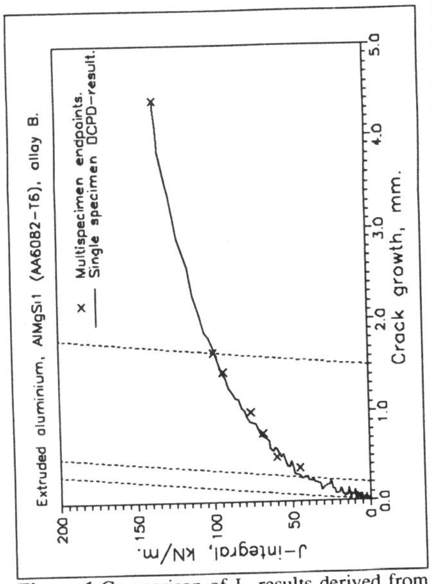

Figure 1 Comparison of J_R results derived from DCPD compared to multispecimen results.

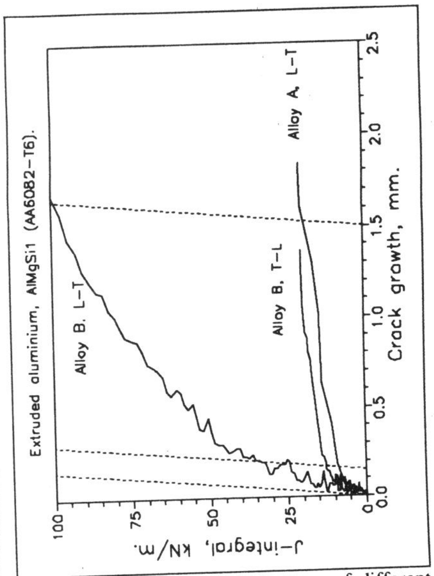

Figure 2 Comparison of J_R-curves of different alloys and orientation.

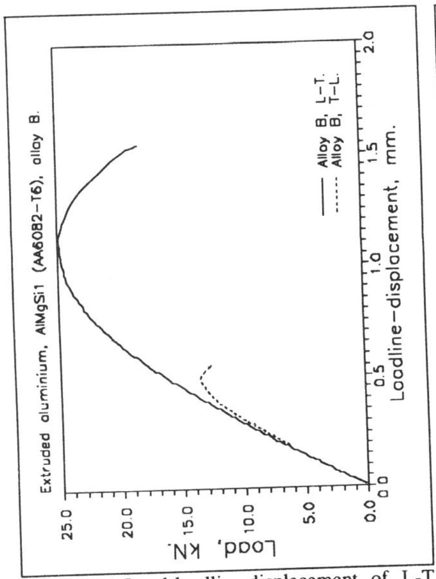

Figure 3 Load-loadline-displacement of L-T and T-L orientation of alloy B.

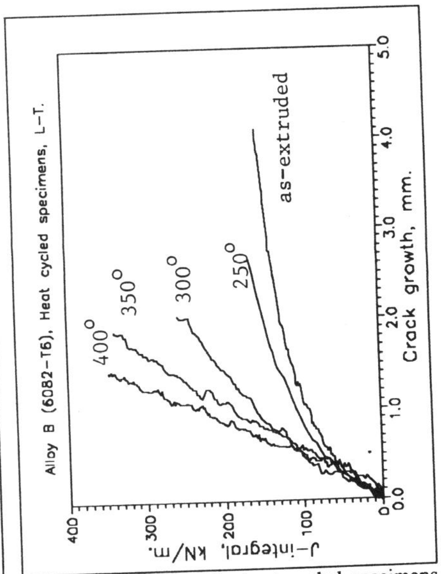

Figure 4 J_R curves for heat cycled specimens of alloy B.