ELASTIC-PLASTIC FRACTURE TOUGHNESS, J_{IC}, OF Al-Li SERIES ALLOYS

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ABSTRACT The elastic-plastic fracture toughness values, J_{IC} values, of 8090-T8 and 2090-T8 Al-Li and 7475-T7351 Al-Zn-Mg-Cu alloys are measured adopting single specimen methods, that is, AC electrical potential methods according to JSME S 001 and ASTM E 1737, respectively. Multiple specimen method according to ASTM E 813 is also adopted to measure J_{IC} values of those alloys. The valid J_{IC} values can be obtained by these methods in each alloy. The crack tortuosity and delamination cracking trend decrease by adding side grooves on the specimen. The effect of side grooves on the fracture toughness is also investigated in each alloy.

Keywords : Al-Li alloy, Al-Zn-Mg-Cu alloy, J_{IC} value, AC electrical potential method, multiple specimen method, side groove

1. INTRODUCTION

Al-Li alloys are in general fractured associated with laminated cracks. This type of fracture is somewhat different from that of ordinary high strength aluminum alloys. Some special care will be needed to measure the intrinsic fracture toughness of Al-Li alloys. On the other hand, the valid plane strain fracture toughness, K_{IC}, based on the linear elastic fracture mechanics is difficult to be obtained in aluminum alloys. The elastic-plastic fracture toughness, J_{IC}, test is expected to offer valid J_{IC} in aluminum alloys. The fracture toughness testing method proper to Al-Li alloys should be therefore established.

The plastic-elastic fracture toughness tests were carried out on Al-Li alloys like 8090 and 2090 according to the standardized methods for measuring fracture toughness, J_{IC}, in order to extract the problems on evaluating the intrinsic fracture toughness of the alloys. The elastic-plastic fracture toughness tests using single specimen and multiple specimens, that is, alternative current, AC, electrical potential method and multiple specimen method, respectively were adopted in the present study.

2. EXPERIMENTAL PROCEDURES

2.1 Materials and specimens

The materials used in the present study were rolled plates of 8090-T8 and 2090-T8 Al-Li alloys, and 7475 -T7351 Al-Zn-Mg-Cu alloy which was a reference alloy.

Compact tension specimens, that is, CT specimens with various thickness and round tensile specimens with a diameter of 9.9 mm and a gage length of 35 mm were machined from the rolled plates of the alloys mentioned above. The straight notch was machined into the each CT specimen. The notch direction of the CT specimen and the tensile direction of the tensile specimen were perpendicular and parallel to the rolling direction of the plates, respectively. Fatigue crack was introduced into the each CT specimen using the electro-serve hydraulic machine according to ASTM E 813 [1]. Side grooves were machined into some CT specimens after introducing fatigue crack.

2.2 Tensile tests

Tensile tests were carried out on the tensile specimens using an Instron type machine at a cross head speed of 2.5×10^{-2} mm/s up to proof stress followed by a cross head speed of 3.3×10^{-1} mm/s up to break.

2.3 Fracture toughness tests

Elastic-plastic fracture toughness tests were carried out on the CT specimens using an Instron type machine at a cross head speed of 8.33×10^{-3} mm/sec. Single specimen methods, AC electrical potential methods according to JSME S 001 [2], and ASTM E 813 [1] and ASTM E 1737 [3], respectively , and multiple specimen method according to ASTM E 813 [1] were adopted for fracture toughness tests in the present study. The validity of fracture toughness and the effects of specimen thickness and side grooves on the fracture toughness were examined.

2.4 Observation of crack morphology and fracture surface

Crack path observation was carried out on the specimen surface using an light microscope. Fracture surface observation was carried out using a scanning electron microscope, SEM.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Specimen thickness and validity of fracture toughness

J integral value at the crack initiation point detected by the sudden change of AC electrical potential according to JSME S 001 [2], J_{in} values, obtained in the CT specimens of 8090-T8 Al-Li alloy without side grooves are shown in Fig.1 as a function of specimen thickness. J_{in} values are somewhat scattered. Each J_{in} value is however judged to be valid.

The crack path in this case is very tortuous as shown in Fig.2 where the crack morphology has been observed on the surface of 19 mm thick CT specimen without side grooves in 8090-T8 Al-Li alloy. The side grooves will be effective to reduce the crack tortuosity

3.2 Effect of side groove on the crack path and fracture toughness

The crack morphology observed on the 15 mm thick CT specimen of 8090-T8 Al-Li alloy with side grooves is shown in Fig.3. The crack propagates straightly by adding sidegrooves.

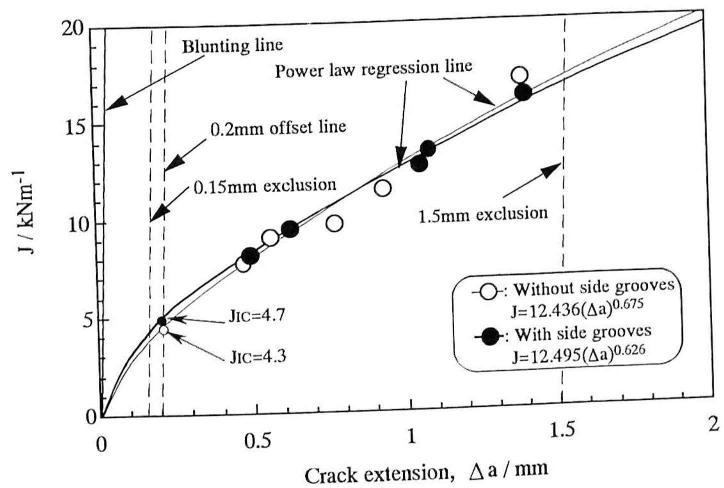

Fig.1 J value at crack initiation point detected by single specimen method, AC electrical potential method, in CT specimen of 8090-T8 Al-Li alloy as a function of specimen thickness.

Fracture toughens values, J_{IC} values, obtained in 15 mm thick CT specimens of 8090-T8 Al-Li alloy with and without side grooves using AC electrical potential method according to JSME S 001 [1] where the crack initiation point has been determined by the sudden change of the AC electrical potential are shown in Fig.4. All the fracture toughness values are judged to be valid. J_{IC} value decreases by adding side grooves in 8090-T8 Al-Li alloy.

On the other hand, J_{IC} values obtained in 25 mm thick CT specimens of 2090-T8 Al-Li and 7475-T7351 Al-Zn-Mg-Cu alloys with side grooves are greater than those without side grooves as shown in Fig.5.

The crack path in the specimen of 8090-T8 Al-Li alloy without side grooves were very tortuous while that in the specimens of 2090-T8 Al-Li and 7475-T7351 Al-Zn-Mg-Cu alloys without side grooves was little tortuous. The delamination cracking trend was also much greater in 8090-T8 Al-Li alloy than in 2090-T8 Al-Li and 7475-T7351 alloys. Crack tortuosity and delamination cracking

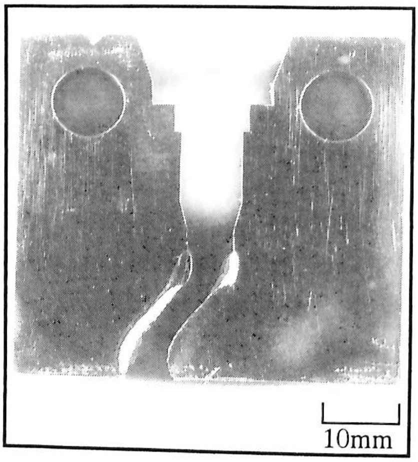

Fig.2 Crack morphology observed on the surface of 19 mm thick CT specimen without side grooves in 8090-T8 Al-Li alloy.

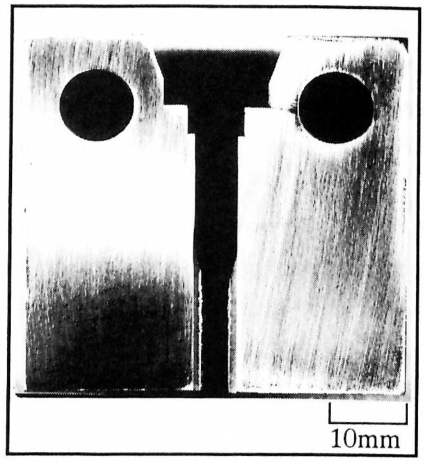

Fig.3 Crack morphology observed on the surface of 15 mm thick CT specimen with side grooves in 8090-T8 Al-Li alloy.

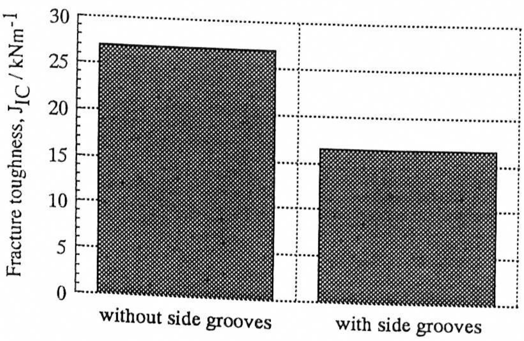

Fig.4 Fracture toughness values, J_{IC} values, obtained in 15 mm thick CT specimens without and with side grooves using single specimen method, AC electrical potential method, in 8090-T8 Al-Li alloy.

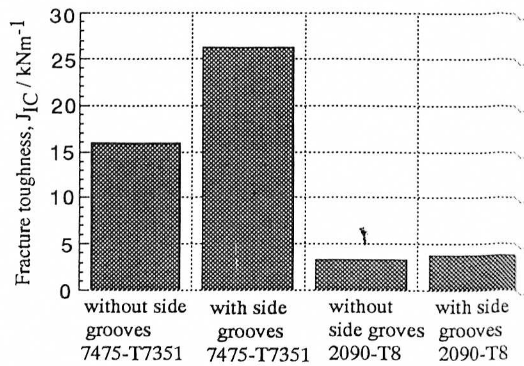

Fig.5 Fracture toughness values, J_{IC} values, obtained in 25 mm thick CT specimens without and with side grooves using single specimen method, AC electrical potential method, in 2090-T8 Al-Li and 7475-T7351 Al-Zn-Mg-Cu alloys.

increase fracture toughness. The fracture toughness will therefore decrease in the specimen of 8090-T8 Al-Li alloy with side grooves because the degree of tortuosity and delamination cracking trend are decreased by side grooves. The side grooves simultaneously increase the stress triaxiality of the crack front near the specimen surface. The increase in stress triaxiality leads to the increase in the load for calculating the fracture toughness while that certainly decreases the crack tortuosity and delamination cracking trend as mentioned above. In 2090-T8 Al-Li and 7475-T7351 Al-Zn-Mg-Cu alloys, the effect of the side grooves on increasing the load for calculating the fracture toughness is greater than that on decreasing the crack tortuosity and delamination cracking trend, and then J_{IC} value increases by adding side grooves.

The J-R curves and J_{IC} values obtained in 25 mm thick CT specimens of 2090-T8 Al-Li alloy with and without side grooves using multiple specimen method according to ASTM E 813 [2] are shown in Fig.6. The J_{IC} value determined by the multiple specimen method also satisfies the valid conditions of ASTM E 813 [2] and decreases by adding side grooves.

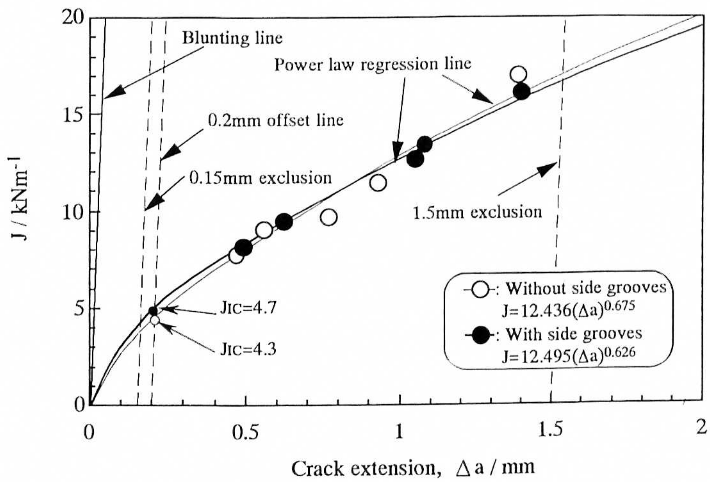

Fig.6 J-R curves and fracture toughness values, J_{IC} values, obtained in 25 mm thick CT specimens without and with side grooves using multiple specimen method in 2090-T8 Al-Li alloy.

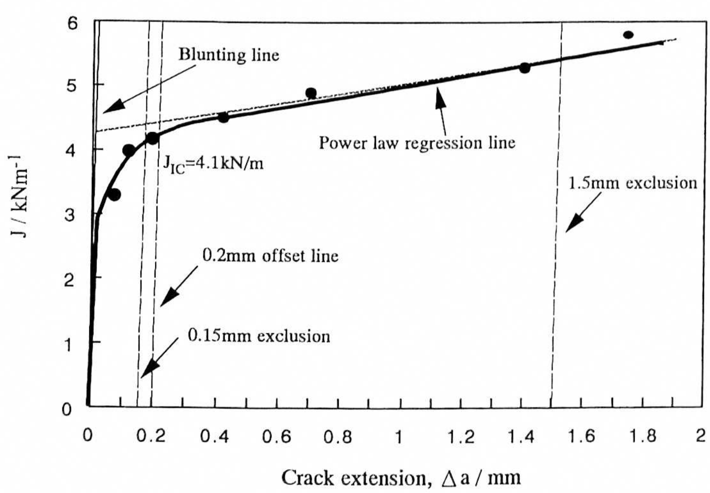

Fig.7 J-R curve and fracture toughness value, J_{IC} value, obtained in 25 mm thick CT specimen with side grooves using single specimen method, AC electrical potential method, in 2090-T8 Al-Li alloy.

3.3 Fracture toughness determined using AC electrical potential method according to the ASTM method

The J-R curve and J_{IC} value in the 25 mm thick CT specimen of 2090-T8 Al-Li alloy with side grooves determined using AC electrical potential method according to ASTM E 1737 [3] is shown in Fig.7. The fracture toughness value satisfies the valid conditions of ASTM E 813. The J_{IC} value is determined to be 4.1 kN/m.

4. CONCLUSIONS

(1) The crack path in Al-Li alloys is straight when the side grooves are added on the specimen.

(2) The valid elastic-plastic fracture toughness value, J_{IC} value, can be obtained in Al-Li alloys using AC electrical potential method and multiple specimen method according to ASTM E 813 and E 1737.

(3) The J_{IC} value decreases by adding side grooves on the specimen when the crack path is considerably tortuous like in the case of 8090-T8 Al-Li alloy. On the other hand, the J_{IC} value increases by adding side grooves on the specimen when the crack path is straight like in the cases of 2090-T8 Al-Li and 7475-T7351 Al-Zn-Mg-Cu alloys.

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