Plain Strain Fracture Toughness, K_{IC}, of Al-Li Alloys

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ABSTRACT Plain strain fracture toughness, K_{IC} tests were carried out, in accordance with ASTM E399, on 19mm thick and 25mm thick compact tension specimens of 8090-T8, 2090-T8 and 2091-T8, to be compared with the property of 7475-T7351 and 7050-T7451. Only K_Q value was obtained for all tested materials except for 7050 in the case of using 19mm thick chevron notched specimens. In some cases, depending on the fatigue pre-cracking conditions, the shape of the fatigue pre-crack front edge of Al-Li alloys was different from that of the conventional 7xxx alloys. For the 25mm thick specimens, tests were conducted for 2090, 2091 and 7475. Valid K_{IC} was obtained for 2090 and neither for 2091 nor 7475. In the comparison of the fractured crack surfaces between two Al-Li alloys, the interval of lamination observed on the crack surface of 2090 was much shorter than that of 2091. This should be one of the reasons why the valid K_{IC} was obtained only for 2090-T8.

1. INTRODUCTION

Al-Li alloys with high specific strength and high specific elastic modulus were developed to be used for aerospace structures replacing the conventional high strength 7xxx alloys. For the aerospace application, the toughness of the material is one of the most important properties affecting the performance of the components. Especially, plain strain fracture toughness, K_{IC}, based on the linear elastic fracture mechanics, is a parameter used for the design of the structural parts.

In the present study, the plain strain fracture toughness tests were carried out on Al-Li alloys 8090, 2091 and 2090 according to the standard test method ASTM E399 [1] in order to characterize the fracture of Al-Li alloys.

2. EXPERIMENTAL PROCEDURE

2.1 Specimens

The Al-Li alloys used in the present study were supplied from Alithium Co., Ltd. In the first experiment, 22mm thick plates of 8090-T8 and 2091-T8 were used, where the chevron notched 19mm thick compact tension specimens were made and employed. The 50mm thick plate of 7475 – T7351 and 7050-T7451, conventional high strength Al-Zn-Cu-Mg alloys, were also tested for comparison under the same test conditions. Specimens were taken from each plate in order that the crack plane orientation should be L-T direction. The crack starter notch was machined and fatigue pre-crack was introduced into each CT specimen using an Electro-servo hydraulic machine according to ASTM-E399. Referring to the reports [2,3], a chevron form of notch was chosen.

In the second experiment, 25mm thick CT specimens were taken from 30mm thick plate of 2090-T8 and 2091-T8 and a straight form of crack starter notch was adopted. Other specimen configurations were the same to that of 19mm thick specimens.

2.2 Tensile Test

Tensile tests on the materials were carried out with the specimens of 9.9mm in diameter. The specimens were taken in order that the tensile direction coincided with the rolling direction of the plates.

2.3 Fracture toughness test

Plane-strain fracture toughness tests were carried out at three different research facilities on the specimens taken from the same material. Though such test conditions as load and cycles for introducing a fatigue pre-crack, test speed to tearing the pre-cracked specimens etc. satisfied the requirements in ASTM-E399, they might be different to some extent among different research facilities located in different places. The validity of the fracture toughness and the effect of condition for introducing fatigue pre-crack on the crack morphology and the test results were examined. The effect of thickness on the test results was also examined comparing the results from 19mm and 25mm thick specimens.

3. RESULTS AND DISCUSSION

3.1 Tensile properties

The results of tensile tests were shown in Table 1 where two parameters, Young's modulus (E) and 0.2% proof stress ($\sigma_{0.2}$) will be used for introducing the fatigue crack and the judgement of validity of the obtained results K.

Table 1 Tensile Properties of specimens

Alloy	Thickness mm	UTS MPa	0.2%PS MPa	Elongation %	Young's Modulus GPa
8090-T8	22	479	386	7.8	79.1
2091-T8	22	530	446	9.5	76.5
2091-T8	30	510	424	12.9	76.5
2090-T8	30	574	543	8.9	76.0
7475-T7351	50	482	405	18.3	69.7
7050-T7451	50	531	466	15.3	68.4

3.2 Introduction of fatigue pre-crack

The fatigue cracking will be induced in accordance with the procedures outlined in ASTM E 399. Referring to the record of experimental data of each research facility, the load employed for introducing the fatigue pre-crack is different to some extent from each other. Although the requirement in ASTM E 399, that is, the ratio of maximum stress intensity of the fatigue cycle to the Young's Modulus of the material, K_{max}/E shall not exceed the $0.0032m^{1/2}$, was satisfied at each facility, there was a difference in the shape of the front edge of the fatigue crack of among the facilities. The length of the fatigue crack of each specimen of 2091 measured at 5 different points between the side surfaces is shown in Fig.1 together with the results of 7475 for comparison. The examples of morphology of the cracked surface of specimens are shown in Fig.2. Usually, as shown as a data of 7475 in Fig.1, the length of the fatigue crack at the points close to the surface is shorter compared to that at the middle of the specimen. But some of the data of 2091 indicate an opposite tendency that the length of the crack is the longest at the surfaces. On the other hand, some data show the same trend as conventional alloy 7475. The difference could be attributed to the difference in K_{max} among the facilities. At higher K_{max}, the shape of front edge of fatigue crack differs from that of the conventional alloys. This shows the possibility that the front edge shape of fatigue crack of Al-Li alloy is more sensitive to the fatigue cracking condition than the conventional alloys. 8090 did not show this feature under the test conditions of the present study.

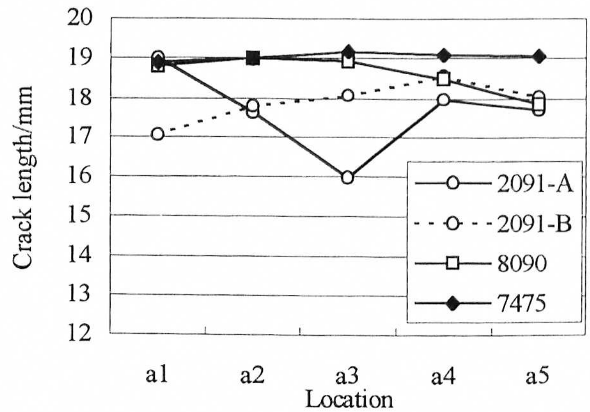

Fig.1 Crack length of the specimens measured at 5 different points between the side surfaces of 19mm thick specimens with the chevron notch.

According to the requirement in ASTM E 399, the crack length a (crack starter notch plus fatigue crack) should be between 0.45 to 0.55 times the width of specimen. Comparing at the same value of K_{max}/E, number of cycles leading to the required fatigue crack length of Al-Li alloys was

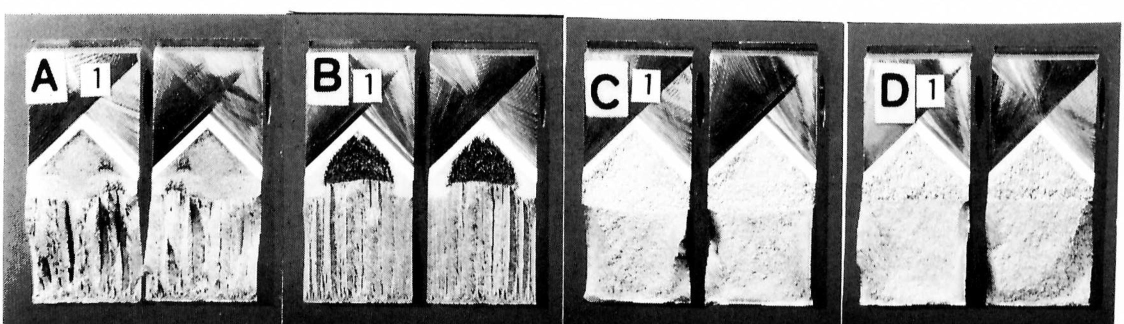

Fig.2 The crack surfaces of 19mm thick chevron notched specimens after the test.
A) 8090-T8, B) 2091-T8, C) 7475-T7351 and D) 7050-T7451.

larger than that for 7xxx alloys. This could be attributed to the laminated structure of Al-Li alloys.

Referring to the above results, in the second experiment with 25mm thick specimens, the straight form of crack starter notch was adopted. In this case, neither 2091 nor 2090 showed the tendency mentioned above. So the configuration of the crack starter notch should also affect the fatigue crack shape.

3.3 Fracture toughness test

The results of the plane strain fracture toughness test are shown in Table 2. All the results listed in Table 2 are the average of 13 data obtained at three different research facilities. An example of load-displacement curve of the 19mm thick specimens of each alloy is shown in Fig.3. The characteristics of load-displacement curves of Al-Li alloys were different form those of conventional alloys, that is, the ratio P_{max}/P_Q, one of the parameters required for validity judgement, of 2091 and 8090, was larger than that of 7475 and 7050 as shown in Table 2 and the validity requirement, $P_{max}/P_Q < 1.10$ was not satisfied in both Al-Li alloys. It is assumed that this feature could be related to laminated cracks that characterize Al-Li alloys. While another requirement for validity judgement,

$$2.5(K_Q/\sigma_{0.2})^2 < B, a, \qquad (1)$$

was satisfied in 2091 and 7050, it was not satisfied in 8090 and 7475. Here B and a are the thickness and crack length of the specimens respectively. Finally, valid K_{IC} value was obtained only for 7050.

One more feature of the Al-Li alloy in this test is the cleavage on the crack surface. It should be attributed to the delamination at the grain boundary and affected by the grain structure of the material. The pitch of the cleavage surface is different among Al-Li alloys.

For the 25mm thick specimens taken from 33mm thick plate, tests were conducted for 2090-T8 and 2091-T8. 7475 taken from the same material tested with 19mm thick specimens were also tested again with 25mm thick specimens. The characteristics of the crack surface of 2090 are different to those of 2091 and 8090 as shown in Fig.4.

Though the valid K_{IC} was not obtained for 7475, the value $2.5(K_Q/\sigma_{0.2})^2$ decreased by about 25% 0with the increase of specimen thickness. So K_{IC} should be obtained by adopting more thick specimens. On the other hand, the value P_{max}/P_Q of 2091 did not change to a great degree compared to that of 19mm thick specimens. So there are little possibility of getting valid K_{IC} value for 2091 even with more thick specimens. Valid K_{IC} was obtained only for 2090. In the comparison of the fractured crack surfaces between two Al-Li alloys, the interval of lamination observed on the crack surface of 2090 was much shorter than that of 2091. This should be one of the reasons why the valid K_{IC} was obtained only for 2090-T8.

The scatter of the fracture toughness data of Al-Li alloys among samples and the research facilities is much larger compared to that of the conventional Al-Zn-Mg-Cu alloys as shown in Table 2. This could be attributed to the difference in fatigue crack configuration and/or the fluctuation of the pitch of delamination that appeared on the crack surface.

Table 2 Test results of the plane strain fracture toughness test

Alloys	Thickness (mm)	P_{max}/P_Q	K_Q (MPa·$m^{1/2}$)		Validity
			Ave.	Std. Dev.	
8090	19	1.31	35.9	3.7	Invalid
2091	19	1.27	36.8	5.1	Invalid
7475	19	1.10	47.7	2.0	Invalid
7050	19	1.04	34.9	1.1	Valid
2091	25	1.32	33.5	3.2	Invalid
2090	25	1.02	16.8	0.4	Valid
7475	25	1.02	41.1	2.6	Invalid

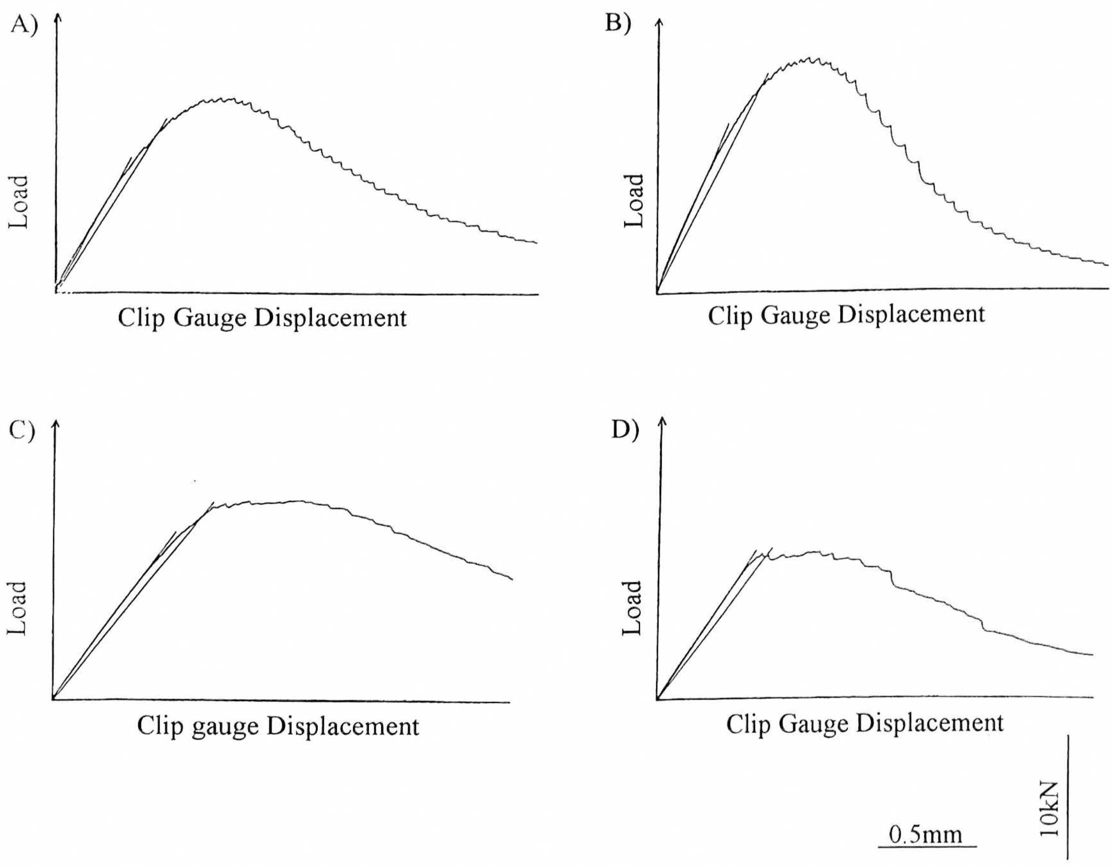

Fig.3 The examples of load –displacement curve of A)8090-T8, B)2091-T8, C)7475-T7351 and D)7050-T7451.

4.CONCLUSIONS

Plane strain fracture toughness K_{IC} tests were carried out for Al-Li alloys 2090, 2091 and 8090 together with conventional high strength Al-Zn-Mg-Cu alloys 7475 and 7050.

1) The valid K_{IC} value was obtained only for 2090-T8 and the reference alloy 7050-T7451.
2) The shape of front edge of fatigue crack introduced in 2091-T8 was affected more severely by the condition of fatigue cracking, that is K_{max}/E, compared to other alloys. Therefore much attention should be given to the introduction of fatigue pre-crack.
3) The characteristics of crack surface of Al-Li alloys, that is, interval of cleavage appeared on the crack surface of Al-Li alloys are different to each other. This should affect the appearance of load-deflection curve of the alloys.

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