Journal of the Korean Society of Marine Engineering, Vol.30, No.4, pp.474~482, 2006(ISSN 1226-9549)

Relationship between Pattern of Fatigue Crack Surface and Fatigue Crack Growth Behavior under K_{III} Mode-Four Point Shear in Al 5083-O

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(Manuscript : Received JAN 23, 2006 ; Revised MAR 9, 2006)

Abstract : Generally almost all fatigue crack growth is affected by mode I. For this reason a study on mode I has concentrated in the field of fracture mechanics. However the fatigue crack initiation and growth in machines and structures usually occur in mixed mode loading. If there is any relationship between the cause of fracture in mixed mode loading and fracture surface, fracture surface pattern will be the main mean explaining reasons of fatigue fracture and obtaining further information about fracture process. In this paper four point shear-fatigue test with Aluminum alloy Al 5083-O is carried out from this prospect and then the mixed mode distribution of fracture surface is examined from the result after identifying the generation of fatigue crack surface pattern. It was found from the experimental results that the fatigue crack surface pattern and the fatigue crack shear direction are remarkably consistent. Furthermore It is possible that the analysis of distribution of mixed mode through the fatigue crack surface pattern.

Key words : Fatigue crack growth behavior; Fatigue crack surface pattern; Mixed mode distribution

1. Introduction

Fracture accidents by fatigue crack growth account for more than 70 percent of all. Therefore, the studies on the fatigue crack growth have been treated carefully long time ago. The stress fields of crack front can be defined in fracture mechanics where mode I, II, III are classified in case that multi-axial stresses function on machines with crack and structure members. Even though these modes affect members with crack in many ways, the dominant factor is mode I. Therefore, studies on mode I have been focused on for many years in fracture mechanics.[1~3] However it is not always the case that fatigue crack initiation and growth of machines and structures occur only in pure mode I. They usually appear in the form of initial crack and then become a

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new crack geometry affected by mixed mode loading.[4]-[7] Therefore the study on mode Ⅱ,Ⅲ and mixed mode are necessary in this field. As a process of this study four point shear-fatigue test using Al 5083-O is carried out and characteristics of fatigue crack growth are analyzed by dividing the test methods compression-tension and compress- ion-compression.

2. Experimental Procedures

2.1 Specimens

The test material is Al 5083-O which is an alloy containing 4.45 percent of magnesium. This material has many features like low density-high strength, corrosion resistance, workability and weld-ability comparing with others.[8],[9] It is widely used as the materials of aerospace structure and LNG vessel. The chemical compositions and the mec-hanical properties of this material are shown in Table 1 and 2, respectively. The geometry and dimensions of the specimen are shown in Fig. 1. The 14㎜ of notch is inserted by wire slot cutting machine, wire diameter 0.25, and the 1㎜ of pre-crack is inserted on the center of the specimen by pure mode I Finally thorough straight

Table 1 Chemical Compositions (wt %)

Material	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Al 5083-O	0.40	0.40	0.10	0.70	4.45	0.15	0.25	0.15	REM

Table 2 Mechanical properties

Material	Y.S.(MPa)	T.S.(MPa)	El.(%)	Young's modulus(GPa)
Al 5083-O	147.1	289.3	22	70.6

Table 3 Test conditions

Test Method	Load(N)	Cycles(Hz)	Stress ratio(R)
Compression-Tension	7000	5	-1
Compression-Compression	12000	5	0

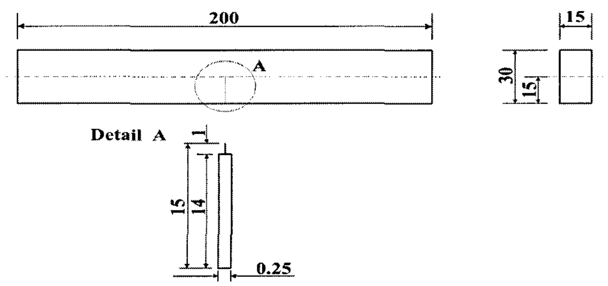


Fig. 1 Geometry of fatigue test specimen

edge crack, 15㎜, can be obtained.

2.2 Experimental methods.

The experimental device used for experiment is hydraulic servo type fatigue testing machine.

The loading modes are compression-tension and compression-compression. Fig. 2 shows illustration of four point shear-fatigue test and Fig. 3 is the jig shape at the test. As Fig. 3 shows specimen-① is put on steel plate-③and then load is subjected to compression-tension. K_I is used to prevent crack surface from contacting each other in jig push bolt-⑥ and the compre- ssion-compression test is shown in Fig. 3. While the test is carried out lubricating oil is provided to minimize the constraint force and frictional force on the contact section of specimen and jig. Test conditions are shown on Table 3.

3. Fatigue Crack Growth Behavior

As it is shown in Fig. 4 fatigue crack growth appears to be grown in a straight line up to 3 or 4㎜ since its occurrence. But above 4㎜ the crack grows in two-way direction which is about 45° or just one-way, wherefore slanted fracture surface comes out. This can be said it is a phenomenon occurred by the bending and torsion moment and jig constraints.

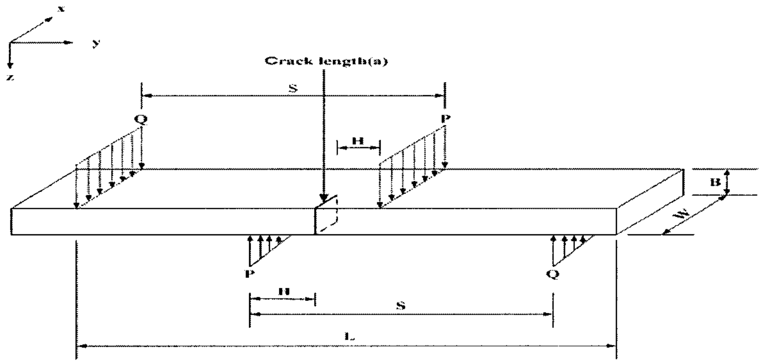
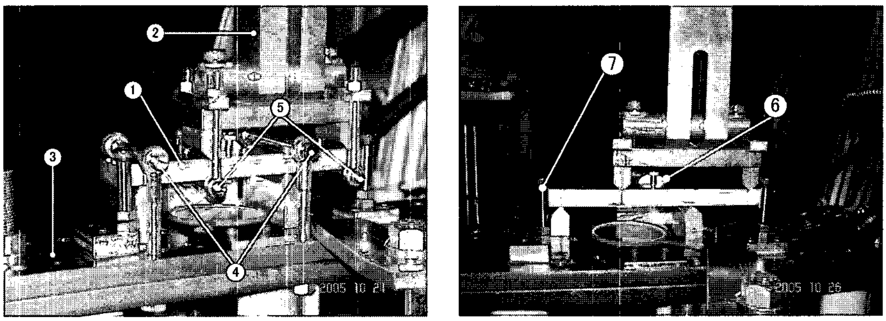


Fig. 2 Schematic illustration of specimen subjected four points shear loading



①Specimen; ②Head; ③Steel-plate; ④&⑤Tension jig; ⑥Push bot; ⑦Supporter

(a) Compression-Tension (b) Compression-Compression

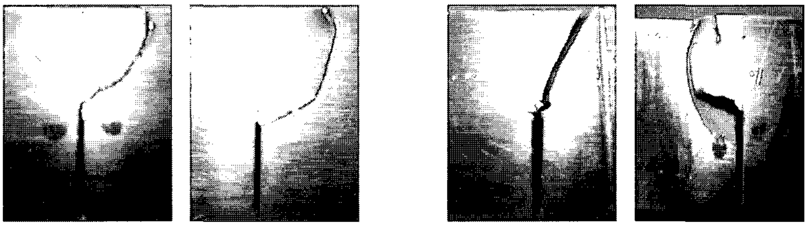
Fig. 3 Jig for four point shear-fatigue test

3.1 Fatigue crack growth in the compression- tension

Fig. 5 shows the relationship between fatigue crack growth length and fatigue life under compression-tension. As the graph shows initial crack on the upper and lower surface of specimen grows at the same time to the length of 3mm. And the growth stop for a long time above 3mm while lower surface crack of the specimen grows rapidly as Fig. 5 shows. On the other hand the growth of upper surface crack almost stops generating a branch point, which is 45°, because of torsion moment on crack front.

3.2 Fatigue crack growth in the compression-compression

Fig. 5 shows the relationship between fatigue crack growth length and fatigue life under compression-compression. As



Lower surface Upper surface
(a) Compression-Tension

Lower surface Upper surface
(b) Compression-Compression

Fig. 4 Fatigue crack growth in specimen surface

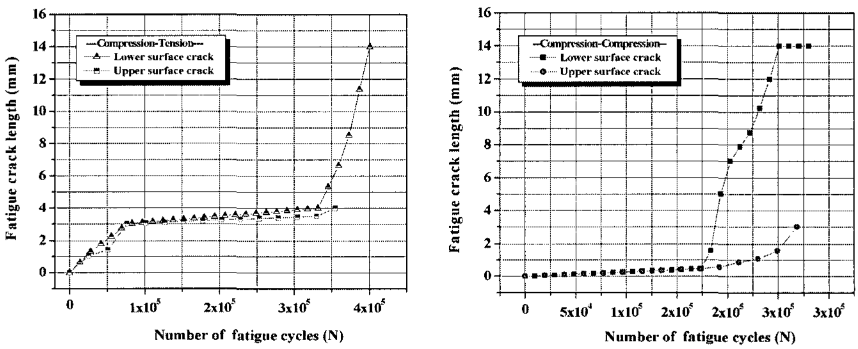
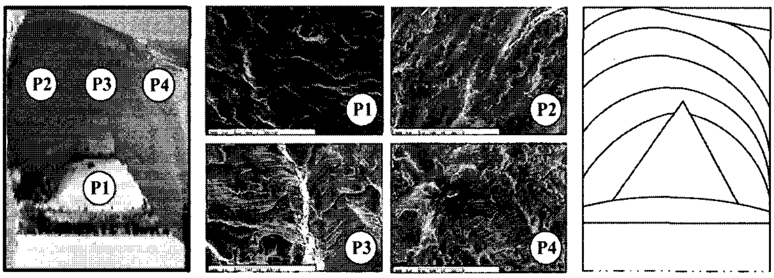


Fig. 5 Relationship between number of fatigue cycles and fatigue crack length



(a) Photograph (b) SEM-fractographs of $P_1 \sim P_4$ (c) Schema

Fig. 6 Photograph, SEM-fractographs and Schema of fatigue fracture surface in compression-tension

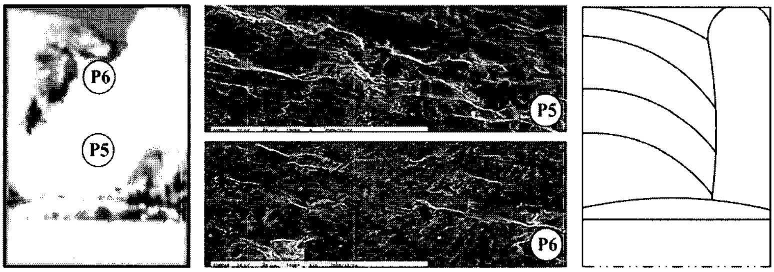
the graph shows initial crack of the upper and lower surface of the specimen grows at the same time to the length of 0.3mm under K_{III} mode. Other results are the same as the ones of compression-tension test.

4. Characteristics of Fatigue Crack Surface

The fatigue crack of Aluminum alloy is related to slip phenomenon of grain and grain boundary. Fatigue crack growth under mixed mode occurs on account of complex reason such as stress condition and disjunction resistance of slip surface.[1]-[3] This can be identified by SEM and fatigue crack surface pattern is observed in the fractographs. As Fig. 6(a) and Fig. 7(a) show, fatigue crack surface pattern are same as shell mark under compression-tension and beach mark under compression-compression. Fig. 6(b) and Fig. 7(b) show fatigue crack surface pattern are similar which are shell mark and beach mark depending on the fatigue crack direction.[4] Fig. 6(c) and Fig. 7(c) is the schema of fatigue crack surface pattern.

5. Distribution of Mixed Mode by Fatigue Crack Surface Pattern

The generation of fatigue crack surface caused by maximum shear stress direction is identified in chapter 4 and the schema



(a) Photograph (b) SEM-fractographs of $P_5 \sim P_6$ (c) Schema

Fig. 7 Photograph, SEM-fractographs and Schema of fatigue fracture surface in compression-compression

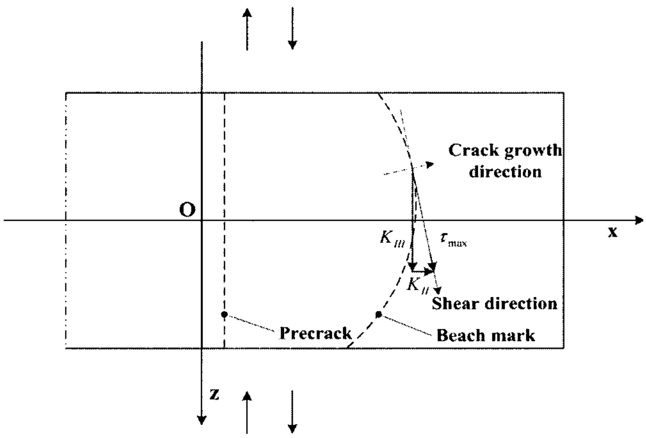


Fig. 8 Vector component of mixed mode

based on fatigue crack surface pattern makes the results clear. Based on this schema Fig. 8 shows the relationship between maximum shear stress and fatigue crack surface pattern. According to this figure, maxi mum shear stress operates in a tangent direction from the schema, wherefore if the size of maximum shear stress can be treated as unit vector, fatigue crack surface pattern can be expressed as vector component of K_{II} and K_{III}. Using this vector component, stress intensity factor distribution of mixed mode for compression-tension and compression-compression is examined. Since stress intensity factors are not the actual quantitative values they are expressed as F_{II} and F_{III}. The distribution of mixed mode is in accords with the other studies.[4][6]

5.1 Mixed mode distribution in the compression-tension

The distribution of mixed mode for thickness direction of specimen is analyzed by drawing schema as Fig. 6(c) from fatigue crack surface pattern in Fig. 6(a). When the ratios of surface crack growth length and total crack length of the specimen(a/W) are 0.6 and 0.8, the distribution of F_{II} and F_{III} is analyzed as Fig. 9. As Fig. 9 shows when the fatigue crack length ratio is 0.6, F_{III} on the center of specimen appears to be the maximum value and F_{II} appears to be the zero value. On the other hand, when the crack length ratio is 0.8, F_{II} appears to be the minimum value on the center of specimen and the maximum value on the both surfaces of

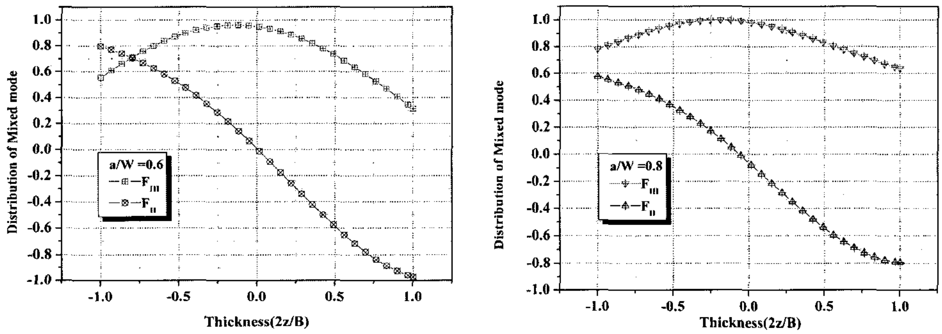


Fig. 9 Distribution of mixed mode(F_{II}, F_{III}) in compression-tension

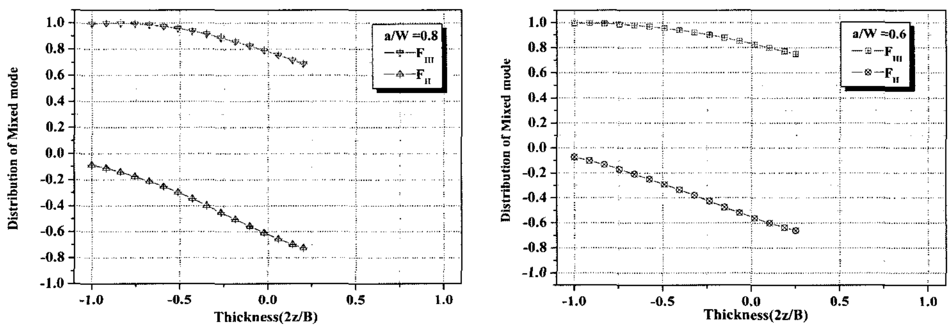


Fig. 10 Distribution of mixed mode(F_{II}, F_{III}) in compression-compression

specimen. And it is shown in Fig. 9 the distribution of F_{II} and F_{III} is similar with each other when fatigue crack growth length ratio(a/W) are 0.6 and 0.8. This is very similar to the studies analyzed using finite element method.[4]-[6]

5.2 Mixed mode distribution in the compression-compression

The distribution of mixed mode for thickness direction of specimen is analyzed by drawing schema as Fig. 7(c) from fatigue crack surface pattern in Fig. 7(a).

When the ratios of surface crack length and total crack length of the specimen (a/W) are 0.6 and 0.8, the distribution of F_{II} and F_{III} are analyzed as Fig. 10 shows. As it is shown in Fig. 10 the distribution of F_{II} and F_{III} is similar with each other when fatigue crack length ratio(a/W) are 0.6 and 0.8. In other hand, F_{III} is the maximum shear stress on the lower surface and the minimum on the upper surface.

6. Conclusions

If fracture surface is closely connected to fracture reasons, fracture surface pattern will be the important tool for analyzing the fatigue fracture as well as getting further information about fracture process. In this paper four point shear-fatigue test of K_{III} mode with aluminum alloy Al 5083-O is carried out from this prospect and then the mixed mode distribution of fracture surface is examined from the result after identifying the generation of fatigue crack surface pattern.

The results follow

(1) The fatigue crack of both compression-tension and compression-compression slowly grows at the initial stage and grows rapidly later stage and slanted fracture surface comes out.
(2) Fatigue crack surface patterns agree with direction of maximum shear and it is identified by fatigue crack surface
(3) Distribution of F_{II} and F_{III} of fatigue crack surface are analyzed by using crack surface pattern.

Acknowledgements

Prof. Kim`s Research Program was financially supported by the Kunsan National University`s Long-term Overseas Research Program for Faculty Member in the latter half of the year 2004.

The authors of this paper are grateful to Mr. Yamaguchi from Akaishi National College of Technology helping with specimen working and also to Dr. Kikuchi from Tokyo University of Science for giving a lot of advice.

All fatigue experiments were conducted in Materials Advanced Science and Technology laboratory of Structural Strength Simulation Engineering Laboratory, Faculty of maritime science, Kobe University. All experimental expenses were provided by the fond of Prof. Nishioka.

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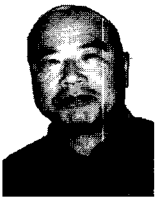

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