Effects of Crack Tip Damage on K_{Iscc} with 4340 Steel

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1. Introduction

A development of a testing method with precracked specimen in dealing with stress corrosion cracking phenomena of ultra high strength steels made an epochmaking era for the analysis and assessment of the results.[1] Since then, many important factors such as microstructures, alloying elements, or other external variables on the stress corrosion cracking have been studied.[2,3,4,5,] However, most fundamentally, a preparation of precracked specimen or a way of fatigue cracking can be considered one of the crucial items when the material's essential property, K_{Iscc} is needed and very few papers seem to have contemplated this point up until now.[6,7] The purpose of this paper is to visualize effects of various crack preparations on K_{Iscc} of a ultra high strength steel.

2. Material and Experimental Procedure

Air melted AISI-SAE 4340 steel in the shape of 23 square bar is employed for the test and heat treatment is done to obtain two strength levels of 160 and 190 kg/mm^2 after rough machining of specimens. Its brief chemical composition is C:0.40, Si:0.30, Mn:0.70, Ni:1.80, Cr:0.80 Mo:0.25 and the mechanical properties are listed in Table 1. The specimens are 20 mm square x 100mm rectalgular type for K_{Ic} bend test and 20 mm square x 200 mm for K_{Iscc} cantilever type bend test. These specimens are prepared to have notch depth to specimen height ratio, a/w, of 0.3 in all cases. K_{Ic} test is performed by way of ASTM E399-70 using the 3 point test method. The K_{Iscc} testing apparatus is so-called cantilever type testing machine whose capacity is 150 kgxm and the arm length is 750 mm. Two environments were chosen- synthetic sea water and distilled water. The K_{Iscc} values were determined with 500 hours of endurance limit time at K_{Ii} applied level. During sustained loading, deflection of the cantilever arms is automatically recorded to monitor slow crack initiation and propagation. Fatigue cracking condition, which is the most important point in this paper, is chosen to be three levels of loading to give different notch tip conditions after several preliminary experiments. More precisely, the estimated initial skin stress at the root of machined notching of 4 mm is varied into three levels; 15%, 20%, and 30% of 0.2% yield strength of each material. A 10 ton capacity of Vibrophore type fatigue testing machine is used. Fatigue cracks are extended 2 mm for each specimen and the total length of cracks is controlled to be 6 mm , making a/w being 0.3. Further fatigue cracking conditions are indicated in Table 2. Both K_{Ic} and K_{Iscc} tests were done with these specimens. Incidentally, machined notched specimens of slit width with 0.15 mm, notch tip radius r being 0.07 mm were also tested in both cases for comparison.

3.Experimental Results

The K_{Ic} values obtained from various fatigue conditions are almost the same within the experimental errors and are shown in Table 1. These values well agree with results reported in various papers inthe past. The difference in K_{Ic} values between fatigue specimen and machined specimen can be understood in terms of notch tip acuity.

On the other hand, the K_{Iscc} values from those three fatigue loading conditions indicated a clear difference in both synthetic sea water and distilled water as can be seen in Fig.1 and 2, for example. In other words, the K_{Iscc} value of low fatigue loading condition in syn. sea water is about 2/3 of high fatigue loading condition. The same thing can be said for the case of distilled water. In case of 190 kg/mm^2 level steel the overall tendency is observed to be the same, only being less sensitive. Fig.3 is a summarization of the whole test results of K_{Iscc} values of two strength levels with various crack tip conditions in both environments. These data

clearly elucidate that if fatigue cracking is made with a relatively higher loading level of about 30% of yield strength, the result of K_{Iscc} would overestimate the actual value. Low fatigue loading specimen is severe for the test. This is particularly important or very careful attention should be paid if the material is stress corrosion cracking sensitive. The difference in fatigue loading also effects failure time at a rather earlier time of 1-20 Hr in Fig.3, for example. That is to say that for a certain K_{Ii}, higher fatigue loading specimen require longer time to failure than lower one. Deflection difference among the specimens does not have too significant meaning, only showing rather longer incubation period, which means an initiation of deflection or an initiation of sub crack growth occurs just before fracture in any case.

4.Discussion

The difference in K_{Iscc} with different fatigue condition could be rationalized by analyzing 1)formation of a plastic zone at the tip which causes a tendency of getting corrosive more easily, 2)compressive residual stress or any kind of damage at the tip. Electrochemical potential difference in base metal and crack tip is measured with capillary probe method to study the former situation. However, current method does not seem to give any meaningful data. To investigate the latter case, X-ray microbeam technique[8] is applied with 0.1 mm collimator and Cr target. Mid-section crack tips are submitted for this test. From the result, a difference in broadening of Debye rings which are formed by the reflection from (211) plane is observed. This evidence would indicate the cause in difference of the K_{Iscc} values. Further analysis is being undertaken as to the possibility of measuring residual stress which would have direct correlation with K_{Iscc} values or formation of sub-boundaries and increase of dislocation density which would give sites for trapping hygrogen, causing less sensitive against stress corrosion cracking.[9]

5.Conclusion

The following conclusions could be derived from the results:

1) Fatigue cracking condition is an important factor in measuring K_{Iscc} values of a material. Specimens made by high fatigue cracking loading would result in getting overestimated values. Fatigue loading of as low as possible should be applied.

2) Difference in K_{Iscc} values due to different fatigue loading could be attributed to either compressive residual stress at the crack tip or damages such as increase in dislocation density and sub-boundaries.

6.References

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Table.1 Mechanical Properties of Air Melted 4340 Steel.

Strength Level.	σ_B	$\sigma_{0.2}$ Y.S	$\sigma_{0.2}/\sigma_B$ (%)	El.(%)	R.A.(%)	K_{IC}, kg·$\sqrt{mm}$/mm² at R.T.	
						Mach.N. r=0.07	Fatigue Crack
160	162.9	140.8	86.5	12.0	46.6	300	209.6
190	194.6	159.3	81.9	12.4	48.1	317	179.0

Table.2 Fatigue Cracking Condition. Span= 80mm.

	160						190					
Load Level.	Load. kg	Moment. kg-m.	σ Skin	σ_s/σ_{YS}	Time for 2mm	N x10³	Load kg	Moment kg-m	σ Skin	σ_s/σ_{YS}	Time for 2mm	N x10³
Low F.L.	900	18.0	21.1	0.149	30'	180	1000	20	23.4	0.146	25'	120
Med.F.L.	1280	25.6	30.0	0.213	10'	45	1370	27	31.6	0.198	9'	30
High F.L.	1800	36.0	42.2	0.299	3'	15	2050	41	48.0	0.301	3'	15

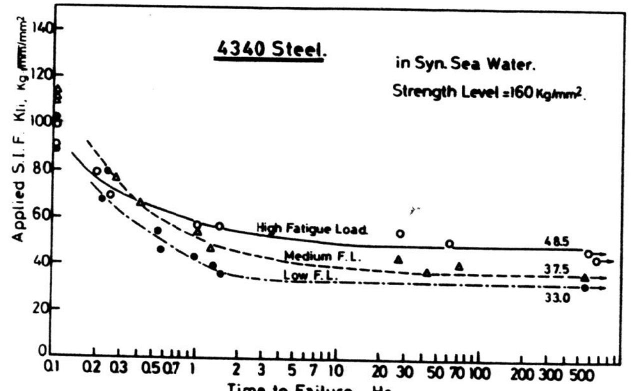

Fig. 1 Delayed Failure Curves of 4340 Steel, 160 kg/mm Level with Different Fatigue Crack Conditions in Syn. Sea Water.

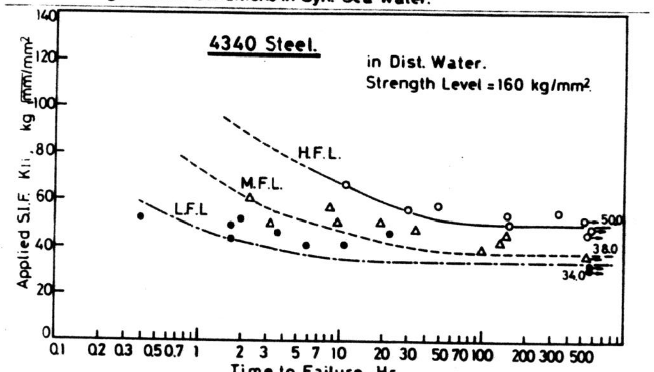

Fig. 2 Delayed Failure Curves of 4340 Steel, 160 kg/mm² Level with Different Fatigue Crack Conditions in Dist Water.

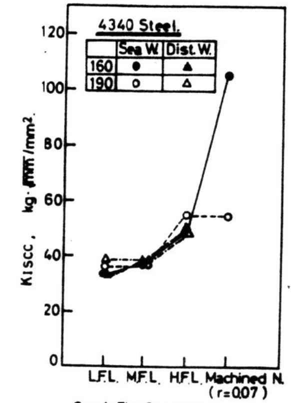

Fig.3 Influence of Crack Tip on Kiscc of 4340 Steel in Aqueous Solutions.