Estimation of Corrosion Fatigue from Fatigue in Air, Corrosion Current Density and Impact Strength

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In this paper a relation is proposed to estimate corrosion fatigue strength F_{corr} from fatigue strength in air F_{air}, initial corrosion current density i_{c_o} and impact strength J. The modified relation has been experimentally verified for 5083 and 6135 aluminium alloys in NaCl solution with and without inhibitors. This modified relation is more convenient and less time consuming to estimate corrosion fatigue than that proposed earlier by Endo, Komai and Nakamuro.

Corrosion fatigue accounts for over 75 percent of failures in plants and machines. Acquisition of corrosion fatigue data is quite tedious and time consuming. In 1970, Endo, Komai & Nakamuro (1) proposed an expression by which corrosion fatigue strength could be estimated from corrosion resistance and notch sensitivity. According to them, the product of the initial corrosion current density i_{c_o} (before starting the fatigue test) and and the corrosion fatigue life τ are related to the fatigue notch sensitivity (η) and the damage ratio (K) by the following expression:

$$(K - 1)/\eta = C'\sqrt{i_{c_o}\tau} \qquad (1)$$

Where C' is a constant which depends upon a corrosive medium K = Fatigue strength in air/fatigue strength in corrosion medium

and $\eta = (\beta - 1)/(\alpha - 1)$,
Where

$$\beta = \frac{\text{Fatigue strength of the smooth specimen in air}}{\text{Fatigue strength of the notched specimen in air}}$$

and α is the stress concentration factor at the tip of the notch.

The above expression was experimentally verified by them for various plain carbon steels and an aluminium alloy (7075 - T6) in 1 wt. percent NaCl solution at 2200 rpm.

However estimation of η is time consuming. In the present paper a modified expression is proposed using izod impact strength J of notched specimen in place of fatigue notch sensitivity η. The impact strength is expected to be inversely proportional to η, thus a modified form of equation(1) can be written as

$$K - 1 = C\sqrt{i_{c_o}\tau}\ /J \qquad (2)$$

Where C is a constant having dimensions of $Nm^2/\sqrt{A\ sec}$.

This paper attempts to establish the above proposed modified relationship for evaluating the corrosion properties of 6351 and 5083 aluminium alloys in 3.5 wt. percent NaCl environments without and with additions of $NaNO_2$ and Na_2CrO_4 inhibitors. These wrought alloys were selected because they have a combination of high strength and good corrosion resistance which makes them suitable for marine applications.

EXPERIMENTAL

The nominal composition of the aluminium alloys used along with their mechanical properties is given in Table 1. The alloy 6351 was in solution treated and age hardened condition (T6 temper) whereas the alloy 5083 was in annealed state (O temper). These alloys were procured from M/S Indian Aluminium Company, Alwaye, Kerala.

CORROSION FATIGUE TESTING

Corrosion fatigue tests have been conducted on an indigenously designed and fabricated rotating

TABLE 1

NOMINAL COMPOSITION OF ALUMINIUM ALLOYS & THIER MECHANICAL PROPERTIES

Sl. No.	Designation	Wt. percent Si	Mg	Mn	Impact strength (Izod) Nm	Tensile strength MPa
1.	6351	1.0	0.9	0.7	21.9	338
2.	5083	-	5.0	1.0	50.0	290

cantilever beam fatigue testing machine of 0.4 KW running at a speed of 2250 rpm with zero mean stress. Six wicks of 2 mm diameter were used for supplying the corrodant to the specimen surface at the rate of about 10 ml per minute. The temperature of the corrodants were 30 ± 4°C. Compositions of the various corrodants employed are given in Table 2.

The shape and dimensions of the sample used for fatigue test are shown in Fig. 1a Fatigue testing machine is shown in Fig. 1. Surface of the specimen was finished and finally polished in longtudinal direction using 4/0 emery paper at 30 rpm so that machaning marks are eliminated and the quality of the surface is reproducible.

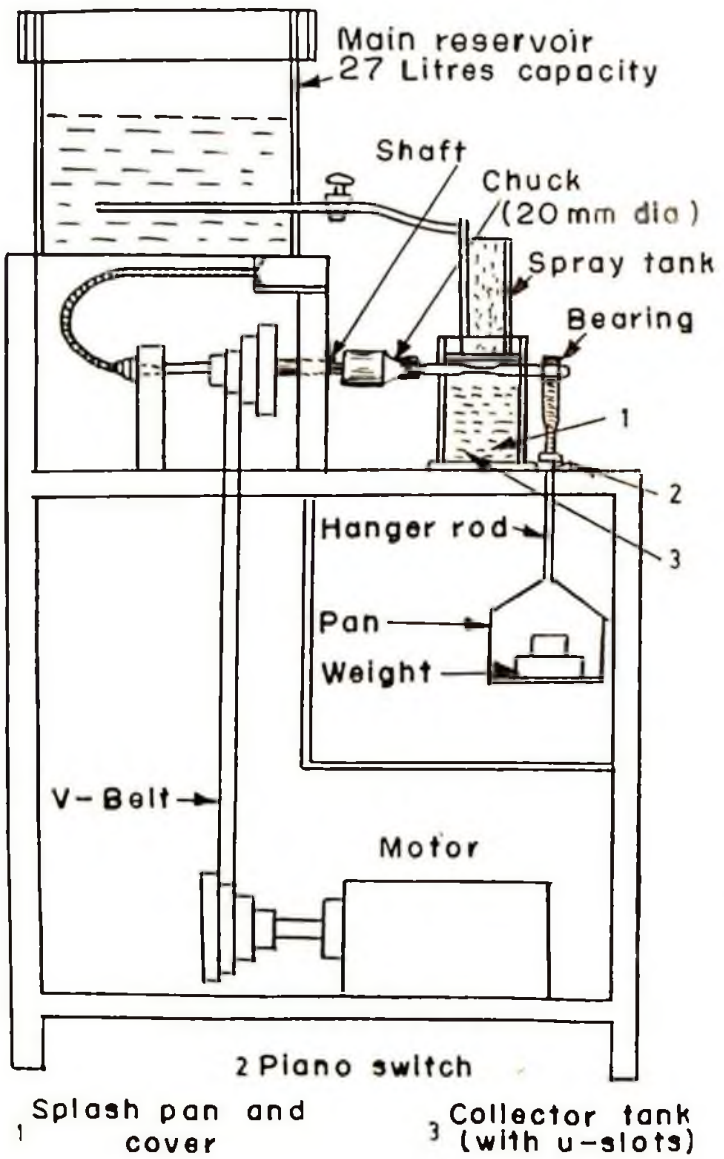


Fig. 1 Elevation of corrosion fatigue testing machine.

CORROSION STUDIES

Corrosion current density i_{corr} was determined by polarisation studies using galvanostatic method. Corrosion resistance of the alloys also was determined by weight loss method and the inhibitor efficiencies calculated. Results of corrosion studies are summerized in Table 3. It can be seen from this table that the alloy 6351 is more resistant to corrosion than the alloy 5083 in all the media studied. The inhibitor efficiency (on weight loss basis) is more for 0.5 percent Na_2CrO_4 than for 0.5 percent $NaNO_2$ for both the alloys.

CORROSION FATIGUE STUDIES

Stress (S)vs log number of revolutions (N) curves of the two aluminium alloys are shown in Figs. 2 and 3. From these figures it is seen that the 3.5 Wt. percent NaCl environment reduces the fatigue stress values considerably for a given number of cycles and the addition of 0.5 mol/litre Na_2CrO_4 inhibitor is more effective in reducing the corrosion fatigue damage as compared to the same amount of $NaNO_2$. Corrosion fatigue curves do not show any endurance limit as shown by ferrous metals in air. Hence in the present work 10^7 cycles as fatigue life was chosen for estimating the fatigue strength F. The corrosion fatigue efficiencies (ϵ) of the inhibitors were calculated as follows:

$$\epsilon = \frac{F_{(corrodant + Inhibitor)} - F_{corrodant}}{F_{air} - F_{corrodant}}$$

Where F is the fatigue strength at 10^7 cycles. The results are given Table 4.

From Table 4, it can be seen that although 6351 alloy is superior to 5083 alloy in the air fatigue behaviour, the fatigue performance of 5083 alloy is better in salt water environment. In air, superiority of 6351 alloy is due to better tensile strength but the alloy is losing the superiority

TABLE 2

COMPOSITION OF VARIOUS CORRODANTS

Sl. No.	Corrodant	Constituents	Concentration g/litre	Concentration moles/litre
1.	Salt solution	NaCl	35.0	0.6
2.	Salt solution Nitrite inhibitor	NaCl NaNO	35.0 3.7	0.6 0.5
3.	Salt solution chromate inhibitor	NaCl Na Cro	35.0 10.0	0.6 0.5

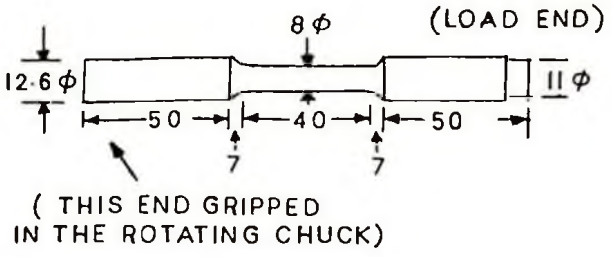


Fig. 1a Corrosion Fatigue Testing Specimen (All diamensions in mm)

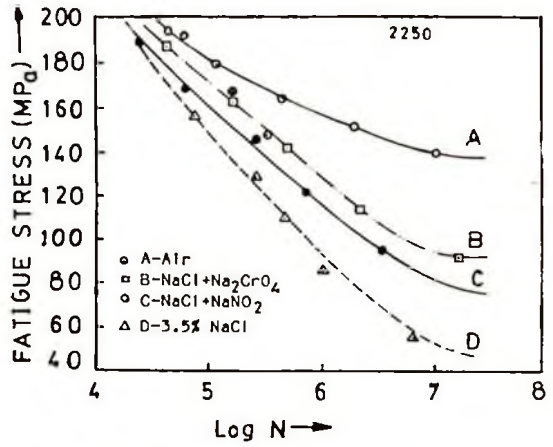


Fig. 2 Air and Corrosion Fatigue Curves for the alloy 6351

TABLE 3

CORROSION BEHAVIOUR OF ALUMINIUM ALLOYS

Alloy	Medium	wt. loss*	i_{Co} (A/m^2)	(ϵ) % **
6351	3.5 % NaCl	0.179	0.0338	-
	3.5 % NaCl + 0.5 % $NaNO_2$	0.093	0.0302	48.0
	3.5 % NaCl + 0.5 % Na_2CrO_4	0.045	0.0229	74.9
5083	3.5 % NaCl	1.039	0.03467	-
	3.5 % NaCl + 0.5 % $NaNO_2$	0.398	0.0302	61.7
	3.5 % NaCl + 0.5 % Na_2CrO_4	0.113	0.0263	89.1

* Weight loss in milligrams/(decimeter^2, day) mdd.

** Inhibitor efficiency - on weight loss basis.

in corrosion fatigue because of the presence of Mg_2Si precipitates; This may increase the tendency of the alloy towards pitting corrosion, thus producing potential sites for crack initiation. It is also noticed that Na_2CrO_4 is more efficient than $NaNO_2$ in reducing the corrosion fatigue of both the alloys in salt water.

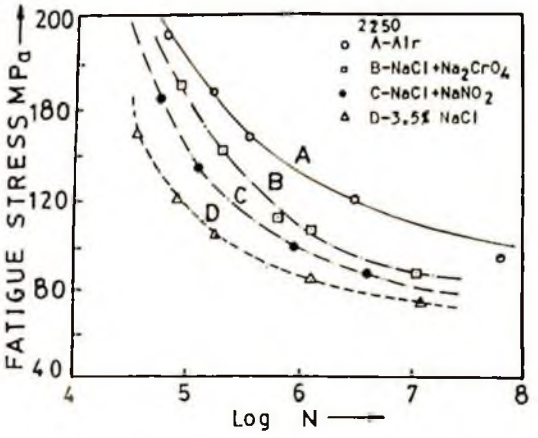


Fig. 3 Air and Corrosion Fatigue Curves for the Alloy 5083

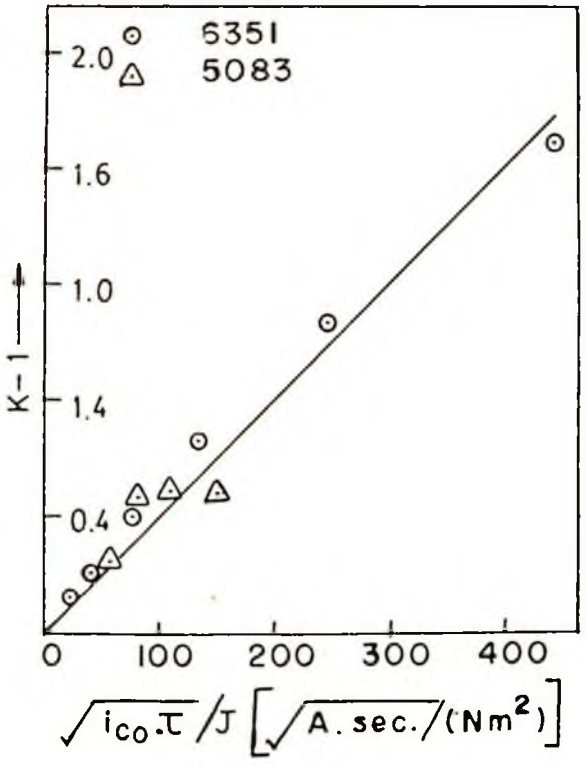


Fig. 4 Relation Between K & $\sqrt{i_{Co}\tau}$ /J in 3.5 Wt % NaCl.

In order to verify the validity of the proposed modified relation, experimental values of (K - 1) have been plotted against $\sqrt{i_{c_0}\tau}$. /J taking origin as one of the points (Fig. 4, 5, and 6). It can be seen that a linear dependance of (K - 1) with $\sqrt{i_{c_0}\tau}$ /J is obtained in both corrodant and inhibited media.

The values of constant C for various corrosive environments are calculated from the slopes of the graphs and listed in Table 5. Higher values of C implies more aggressiveness of a corrodant to cause corrosion fatigue damage. Damage ratio can be predicted for any given fatigue life. Thus the estimation of the constant C completely defines the corrosion fatigue behaviour of aluminium alloys in a particular medium.

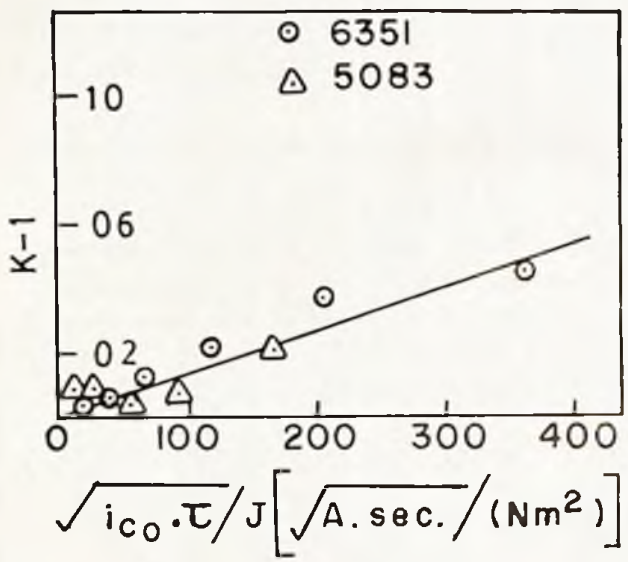


Fig. 5 Relation Between K and $\sqrt{i_{c_0}.\tau}/J$ IN 3.5% NaCl + 1.0 mol/Lit Na_2CrO_4 $2H_2O$.

TABLE 4

FATIGUE STRENGTHS AND INHIBITOR EFFICIENCIES

Property/Alloy	6351	5083
F_{air} (MPa)	139.0	111.0
F_{NaCl} (MPa)	52.5	75.0
$F_{(NaCl + NaNO_2)}$ (MPa)	82.0	83.0
$F_{(NaCl + Na_2CrO_4)}$ (MPa)	96.0	87.0
ϵ of Na_2CrO_4 %	50.3	33.3
ϵ of $NaNO_2$ %	34.1	22.2

CONCLUSION

1. Addition of sodium chromate inhibitor is more effective in reducing corrosion fatigue damage for both aluminium alloys 6135 & 5083.

2. The performance of the alloy 5083 in corrosion fatigue is better than that of 6135 though the performance of 6135 is better than that of 5083 in air fatigue.

3. The proposed modified relation to estimate corrosion fatigue strength from air fatigue strength, initial corrosion current density and impact strength holds good for both the aluminium alloys 6135 and 5083 in salt solution with and without the inhibitors.

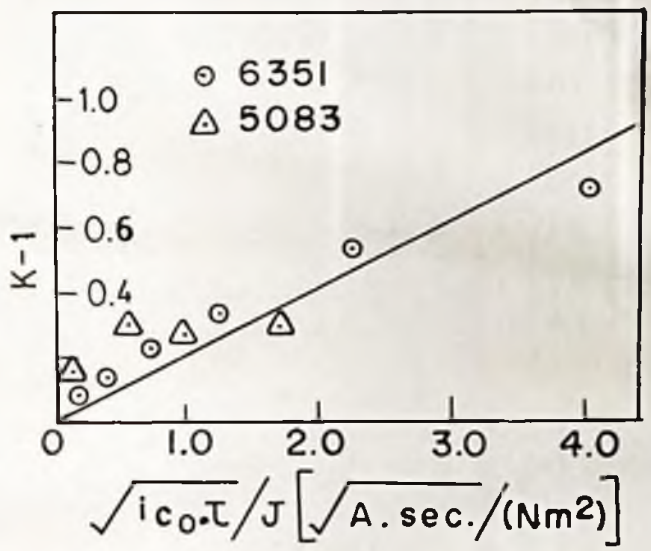


Fig. 6 Relation Between K and $\sqrt{i_{c_0}.\tau}/J$ IN 3.5 Wt % NaCl + 0.5 mol/Lit $NaNO_2$

TABLE 5

ESTIMATED VALUES OF 'C'

Sl.No.	Corrosive medium	C(Nm^2 / $\sqrt{A.sec.}$)
1.	3.5 % NaCl	0.41
2.	3.5 % NaCl + 0.5 mol/litre $NaNO_2$	0.175
3.	3.5 % NaCl + 0.5 mol/litre Na_2CrO_4	0.125

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A N N O U N C E M E N T

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