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An experimental fatigue study under condition where cyclic corrosion-fatigue interaction occurs

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Abstract
Fatigue caused under corrosive environment is termed as corrosion fatigue. Corrosion fatigue occurs by the combined actions of cyclic loading and a corrosive environment. Attempts have been made to investigate the influence of different corrosive media on fatigue behaviour of 7075-T6 aluminium alloy immersed for 100 days in the corrosive media. Corrosion fatigue tests have been conducted using rotating bending stresses and controlling the stress at stress ratio R= -1 and room temperature (RT).
The corrosive media used in this study were Shatt - Arab water (Sh. A. W.) at (100 fungi colonies). The results indicated that fungi colonies have significant effect on the fatigue strength. And life reduction of fatigue strength at 10^7 cycles for specimens corroded with (Sh.A.W.) at (100 fungi colonies) was 15% compared with dry fatigue strength. The corrosion fatigue lire's under all stress levels were reduced compared to dry fatigue.

Keywords: Corrosion, 7075-T6 aluminium alloy, Fungi colonies.

1. Introduction
Corrosion is known as the chemical or electrochemical reaction between a material, usually a metal, and its environment that produces a deterioration of the material and its properties". In today's world, a stronger demand for corrosion knowledge arises due to several reasons. Among them, the application of new materials requires extensive information concerning [1]. Corrosion is a process of chemical reaction with the metal surface generating bits and voids at the surface. These defects work as a stress raiser and from these defects the crack initiates and propagates. Thus the interaction of corrosion – fatigue is always less in life and strength compared to the fatigue only [2]. Corrosion fatigue occurs by the combined synergistic actions of cyclic loading and a corrosive environment. It is a discontinuous process with crack initiation and growth during transient periods. Al-Alkawi et al [3] tested rotating bending corrosion – fatigue specimens with 3.5% Nacl and they obtained the S-N curve for 2024-T4 aluminium alloy. The main concluded remarks obtained from the above study are the corrosion is significantly effect on the fatigue lives and strength of the 2024-T4 aluminium alloy. Also a comparison was made between the behaviour of 8090-T6 AL alloy with 2024-T4. The experimental results reviled that the 8090-T6 is less

in behaviours (life and strength) compared to 2024-T6. Wang et al [4] examined the response of 7075-T6 aluminium alloy under the corrosion case for high cycle fatigue region. The experimental results showed that the 4 days and 7 days corrosion resulted in surface pits leading to significant reduction in strength and fatigue life.

Harlow and Wei [5] presented two examples of corrosion – fatigue interaction, one for corrosion – fatigue crack growth for 7075-T6 aluminium alloy. They concluded that the corrosion pits play an important factor in the estimation of fatigue life of above examples.

Dooley and Bursik [6] studied the corrosion – fatigue interaction of boilers and they achieved that the corrosion- fatigue cracks may have different appearances, pinhole leak, thick – edged crack and thick – edged blowout or rapture. Also they found that the location of failures happened at bends, welds with the potential for high residual stresses (e.g., fin welds), and locations at attachments are most threatened.

The main goal of this work is to report experimental evidence about the corrosion – fatigue interaction behaviour of 7075-T6 aluminium alloy. In particular the 100 fungi colons corrosion (100 days corroded) on mechanical and fatigue behaviour (strength and life). In other words, this study aims to identify where the interactions between may occur during corrosion – fatigue in the aluminium alloy 7075-T6.

2. Experimental work

2.1 Experimental procedure and material

The material investigated in this paper is (7075-T6) aluminium alloy; this material is widely used in Aircraft fittings, shafts and gears, fuse parts, meter shafts, regulating valve parts, missile parts, worm gears, aircraft, aerospace and many applications. Whose chemical composition is presented in Table 1 compared with the standard [8, 9]. Chemical analysis of the material used was done at S.C. of Geological survey and mining using X-Rays method.

Table 1. Chemical composition of (7075-T6) aluminium alloy in wt%.

Elements	Zn %	Si %	Fe %	Cu %	Mn %	Mg %	Cr %	Ti %	Al %
Standard ASTM B-211, [7]	5.1-6.1	Max. 0.4	Max. 0.5	1.2-2	Max. 0.3	2.1-2.9	0.18-0.28	Max. 0.2	Bal.
Experimental	5.39	0.064	0.229	1.76	0.221	2.03	0.2	0.017	Bal.

2.2 Tensile test (Mechanical properties)

The mechanical properties of (7075-T6) aluminium alloy were obtained according to ASTM B-211 specification. The tensile specimen can be shown in Figure 1 and Table 2 respectively, while the mechanical properties are listed in Table 3.

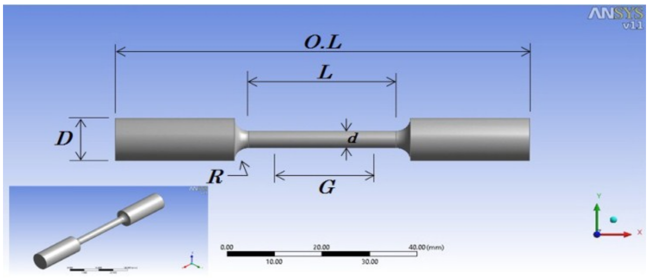

Figure 1. Tensile test specimen (all dimensions in mm) accorded to ASTM (E8/E8M-09) specification [9].

Table 2. Standard shape distance according to ASTM (E8/E8M-09) specification [9].

Symbol	Descriptions	Dimensions in (mm)
D	Diameter of Grip	16
d	Diameter of Gage Length	9
G	Length of Gage	36
L	Length of Reduced Section	45
O.L	Overall Length	87
R	Fillet Radius	8

Table 3. Standard and experimantal mechanical properties of (7075-T6) aluminium alloy.

Elements	σu (MPa)	σy (MPa)	E (GPa)	ϵ% Elongation	Hardness Rockwell
Experimental without corrosion	569	500	72	12 %	51
Standard ASTM B-211 [7]	572	503	72	11 %	53
Corroded with (Sh. A. W.)≅ 100 fungi colonies	532	481	70	13 %	39

The tensile test was conducted using the test machine (Tinius Olsen) with a capacity of 100KN shown in Figure 2 in University of Al-Mustansiriya, Material Engineering Department.

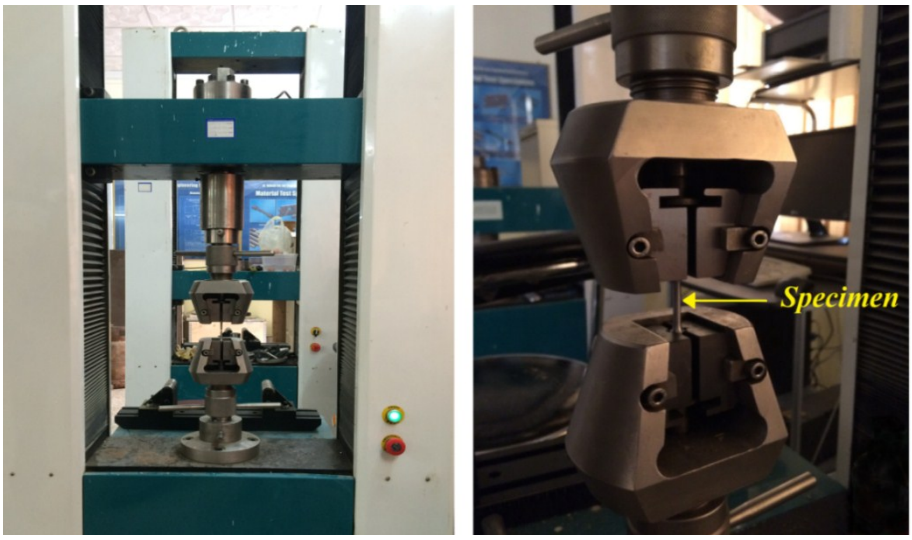

Figure 2. Tensile test machine (Tinius Olsen).

2.3 Fatigue testing machine

A fatigue–testing machine Schenck product of type PUNN rotating bending was used to execute all fatigue tests, with variable and constant amplitude loading as illustrated in Figure 3 [9].

The specimens of the fatigue test which is illustrated in Figure 4, has a circle section and is subjected to vertical load, which created a constant bending moment. The load unit is (N) which can used to determine the applied stress to (σ) in (MPa) using simple bending theory $\sigma = MY/I$, and after substituting the constant values the above equation can be taken the form,

$$\sigma = \frac{1280.369 * P}{d^3} \quad (1)$$

where the value 125.7mm represents the arm of force (P) and d is the minimum diameter of the specimen in millimetre [10].

Figure 3. PUNN rotating bending testing machine [10].

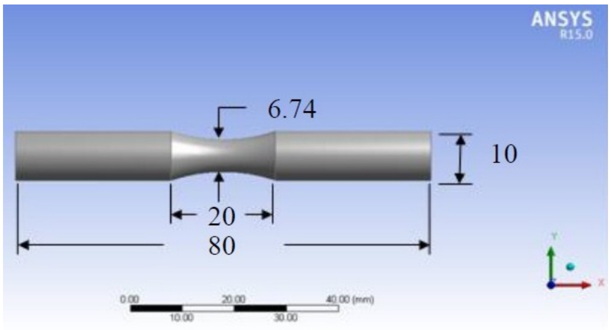

Figure 4. Dimensions of fatigue specimen in millimetre [12].

The specimens numbered and polished. Measurement of surface roughness is carried out by means of perthometer M3A instrument. The output readings were Ra (the centre line average) and Rt (the maximum surface roughness). Table 4 gives the roughness results of selected fatigue specimens.
All the corroded specimens were immersed in a Shatt - Arab water (Sh. A. W.) solution for 100 days. After that the corroded specimens were tested and the chemical analysis of the Shatt - Arab water (Sh. A. W.) solution is given in Table 5.

Table 4. Selected roughness results for fatigue specimens.

Specimen No.	Ra (µm)	Rt (µm)
1	1.9	0.8
2	1.36	0.64
3	1.62	0.62
4	1.5	0.55
5	1.42	0.49

Table 5. Chemical composition tests result of Ions in Shatt - Arab water (Sh. A. W.) in the Lab. (mg/lit).

Minerals (Ion) methods	Gulf water
Alk. As $CaCo_3$ titration	160
Ca titration	616
Mg Calculated	852
Cl titration	5880
SO_4 Turbidity metric	4100
Na Flame-photometric	3800
K Flame-photometric	135
T.D.S gravimetric	17244

3. Results and discussion

3.1 Mechanical properties

The effect of 100 fungi colonies corrosion on the mechanical properties can be shown in Table 6 and Figure 5. It is clear that the tensile strength reduced by 6.5% compared to the experimental while the yield strength reduced from 500 MPa to 481 MPa by 3.8% reduction compared to the measured value. The significant reduction is happen in Rockwell hardness. The surface hardness reduced by 12 i-e 23.5% reduction compared to the actual value. The modulus of elasticity was slility reduced.
The corrosive media creates pits at the surface these pits work as a stress raiser in which reduce the mechanical properties and resulting to weak resistance against failure. The above findings agreed well with that concluded by Dong et al [11].
Zainab A. Betti [2] tested 1100-H12 Al. alloy under 0.35% NaCl corrosion condition and it was found that a significant reduction in mechanical properties occurred for 71 and 101 days corroded specimen's time.
Zainab [2] found a reduction in σ_u for 71 days and 101 days at 0.35% NaCl corroded media 8.41% and 12.15% respectively. It is observed that when corrosion time increase the reduction percentage increase for σ_u , σ_y and hardness for most aluminium alloys.

Table 6. Illustrates the reduction percentage in mechanical properties due to 100 fungi colonies (100 days corroded).

Reduction % in (σu)	Reduction % in (σy)	Reduction % in (E)	Reduction % in (rockwell hardness)
6.5	3.8	2.7	23.5

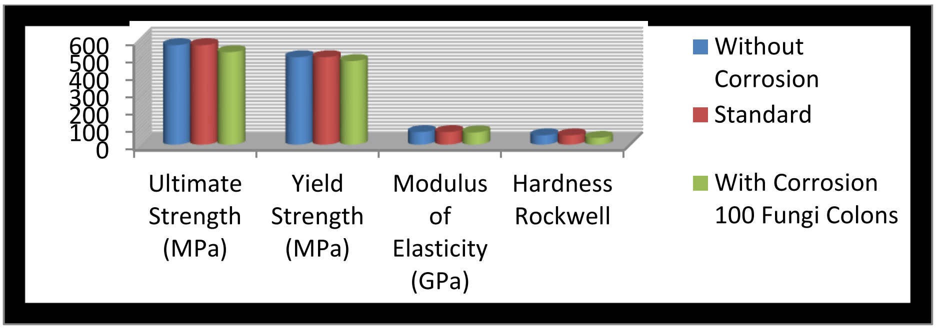

Figure 5. Effect of corrosion on mechanical properties.

3.2 S-N curve

The results obtained from the experimental work are listed and discussed in details through this section. The experimental results include results of dry fatigue and corrosion fatigue under constant amplitude loading to obtain S-N curves (Table 7). The applied stresses were 410,320, 270,180 and 140 MPa based on the tensile behaviour examined for each stress level. It implies that the Basquin relation $\sigma_f = A\, N_f{}^{\alpha}$ is assumed to be applicable for all fatigue cycles with fatigue stress amplitudes.

Table 7. S-N curves as received and corroded with 100 fungi colons data.

Specimen No.	Applied Stress (MPa)	N_f Cycles	$N_{f\,av.}$
		Dry condition	
1,2,3	410	1200,900,750	950
4,5,6	320	8000,6000,6400	6800
7,8,9	270	33000,37000,36800	35600
10,11,12	180	680000,712000,714000	702000
13,14,15	140	$2.7*10^6$, $3.1*10^6$, $4.1*10^6$	$3.3*10^6$
		Corroded with 100 fungi colons	
1,2,3	410	1000,1200,900	1033
4,5,6	320	5000,7000,6500	6167
7,8,9	270	28000,33000,17000	26000
10,11,12	180	710000,625000,480000	605000
13,14,15	140	$1.2*10^6$, $1.07*10^6$, $1.1*10^6$	$1.123*10^6$

Figure 6 shows the variation of corrosion between dry and pre-corroded fatigue specimens. The behaviour of the S-N curve indicates that the fatigue life of pre corroded specimens decreased compared with that of as received specimens. And the fatigue strength is reduced by"15% compared with dry fatigue strength, as given in the Table 8.

Fatigue crack initiation sites are associated with surface defects like pits or other discontinuities. These pits work to reduce the mechanical and fatigue properties of the metal [12]. The fatigue strength of corroded metal always less than the as-received as given in Table 8.

The S-N curve behaviour for 1100-H12 Al. alloy was obtained using the same manner of this work. The Basquin equations which described the S-N curves of the above alloy could be used the formulas [2].

$\sigma_f = 3983\, N_f{}^{-0.232}$ For dry condition and

$\sigma_f = 1293\, N_f{}^{-0.338}$ For corroded condition.

Cheong et al [13] tested 7075-T6 Al. alloy corroded in 3.5%. NaCl and they concluded that a reduction in fatigue strength was obtained as 42% for one year corroded time. While Pao et al [14] examined 7075-T351 Aluminium alloy and they presented a significant reduction in mechanical properties and fatigue strength using 3.5% NaCl solution as medium.

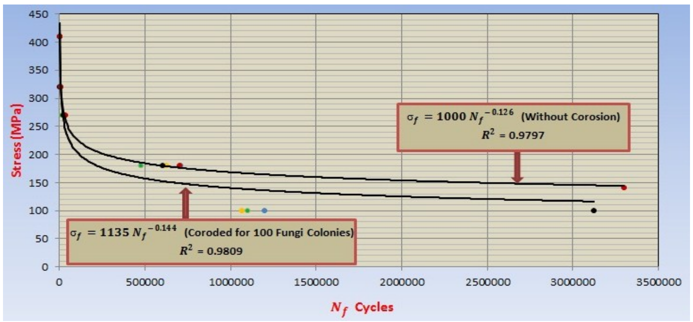

Figure 6. Traditional constant stress amplitude S-N curves for two fatigue conditions.

Table 8. Reduction percentage in endurance fatigue limit due to 100 fungi colons.

Fatigue strength (MPa) as received at 10^7cycles	Fatigue strength (MPa) corroded (100 days) at 10^7cycles	Reduction percentage
131.22	111.4	15 %

4. Conclusions

The behaviour of 7075-T6 Al. alloy under 100 fungi colons corrosion environment interacted with cyclic fatigue loading has been investigated and the following remarks may be drawn:

1. The corrosion – fatigue interaction behaviour of 7075-T6 Al. alloy under immersion in (Shatt-Arab Water) Sh. A. W. solution differs significantly from the behaviour of 3.5% NaCl solution [2].
2. 100 fungi colons solution reduced the mechanical properties of 7075-T6 Al. alloy by 6.5% for ultimate strength, 3.8% for yield strength and 23.5% for Rockwell hardness.
3. The fatigue strength reduction was 15% due to 100 fungi – colons Sh. A. W. solution compared to the dry fatigue limit.
4. Increasing the fungi – colons reducing the mechanical and fatigue properties.

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