Fungi Colonies Effect on Fatigue Behavior of 7075Al Alloy

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ABSTRACT
The effect of fungi colonies on fatigue of 7075 aluminum alloys was studied for specimens corroded at different media. 57 specimens of aluminum alloys were submerged in Shat-Arab water (Sh.A.W) for four months at different conditions (at light media (9 fungi colonies), dark media (80 fungi colonies))and then applying constant fatigue tests after removing the specimens from the corrosion media . The results show that the fungi colonies can corroded Al alloy the reduction of pre-corroded specimens at light media (9 fungi colonies) was 13% and for specimens at dark media (80 fungi colonies) was 22% , and a nonlinear damage model was proposed to predict the cumulative corrosion fatigue life
Keywords: Shatt Arab Water, corrosion fatigue, fungi colonies

INTRODUCTION
The sea is the largest natural environment inhabited by microbes. Fungi, bacteria, algae, protozoa, molds and yeast are major groups of microorganisms found in the sea. The number of microorganisms is more in coastal waters and it gradually decreases in the open sea. Fungal organisms and other Bacteria also play an important role in biogeo chemical transformation in soil [1]. When microbial deposits form on the surface of a metal, they often behave as inert deposits on the surface, shielding the area below from electrolyte. A differential aeration cell forms, even for a very small colony. The area directly under the colony will become the anode and the metallic surface just outside the contact area will support the reduction of oxygen reaction and become the cathode. Metal dissolution will occur under the microbial deposit, and resembles as pits [2].

Aerospace structural materials such as aluminum 7075-T7351is susceptible to pitting when operated in a corrosive environment. Corrosion pits can readily act as crack initiation regions due to the metallurgical damage in addition to the stress concentration influences [3]. Wang et al. (2003)[4] studied influence of pre-existing corrosion pits on the fatigue behavior of 7075/T6 aluminum. The results indicate that the presence of pre-existing corrosion pits, produced by 1-day, 4-day, and 7-day immersion in salt water significantly reduces the fatigue life of the aluminum alloy by a factor of 10–100. Amadi et. al. (2007)[5]studied the mechanisms of microbial

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corrosion of aluminum alloys were. Result shows that the Dodecanoate anions recently proposed as the main metabolic product leading to the passivity breakdown of aluminum alloys show no effect on the pitting process, either in the absence or presence of chloride. The acidic metabolites produced by "Cladosporium resinae" are able to facilitate the breakdown of the passive oxide film by chloride anions decreasing the pitting potential value. Chlistovsky et.al.(2007)[6] examined the behavior of 7075-T651 aluminum alloy corrosion-fatigue. The specimens were fatigue tested while they were fully immersed in an aerated and recirculated 3.5 wt% NaCl simulated seawater solution. A damage analysis showed that the presence of the corrosive environment accelerated the damage accumulation rate to a greater extent than that observed in air, particularly at low stress ranges. Genel (2007) [7] studied the effect of pitting corrosion produced by prior immersion in 3.5% NaCl solution on the fatigue behavior of 7075-T6 aluminum alloys. The result showed that the Pits, once formed, act as stress concentration sites and can also facilitate fatigue crack initiation when the stress intensity factor reaches the threshold value or promotes crack growth. Depending on the pit severity, the degradation in fatigue strength can be as much as approximately 60% . Rao et. al. (2014)[8]studied the effect of the high power diode laser (HPDL) on surface melting of a 7075-T651 aluminum alloy to improve corrosion resistance. The result shows that the corrosion current reduced by 5 times in laser melted surface coMPared to un-treated substrate. The corrosion rates drastically decreased after LSM material. The improvement in corrosion resistance result from the refined and elimination of detrimental constituent particles and grain boundary network present in wrought structure. The most studies on corrosion fatigue was used 3.5% NaCl aqueous solution (mixture of sodium chloride (NaCl) salt and tap water) but, In this study the Shatt Arab water that brings from Al-Basra was used to corroded the Al alloy specimens.

Experimental work

The experimental work begins firstly by analyzing the chemical composition of the selected materials Aluminum alloy (AA7075T6) and (Sh.A.W) which was used for corroded the Aluminum alloy then testing the mechanical properties of Aluminum alloy at room temperature. Secondly, subjected the Aluminum alloy to different media, for same period of time, thirdly determine the effect of this different corroded media on the fatigue strength

Chemical analysis

The tested material is 7075 aluminum alloy widely used in many applications like (Aircraft fittings, gears and shafts, fuse parts, meter shafts and gears, missile parts, regulating valve parts, worm gears, keys, aircraft, aerospace and defense applications; bike frames, all-terrain vehicle (ATV) sprockets) [9].The chemical analysis of this alloy was carried out at (State Company for Inspection and Engineering Rehabilitation (SIER) in Iraq). The results, which are compared to American Standard ASTM B-211[10], are summarized in Table (1) below, while the mechanical properties are listed in Table (2):

Table (1): Chemical composition of 7075 Al-alloy in wt%

	Zn%	Si%	Fe%	Cu%	Mn%	Mg%	Cr%	Ti%	Al%
ASTM B-211 [10]	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.

Measured	5.39	0.064	0.229	1.76	0.221	2.03	0.2	0.017	Bal.

Table (2): Mechanical properties of 7075T6 Al- alloy

Property	Ultimate tensile strength σt MPa	Yield strength σy MPa	Elongation % In 100 mm	Modulus of elasticity GN/ m2
ASTM B-211 [10]	572	503	11%	71.7
Measured	573	504	11%	72

The chemical analysis of the sea water that used in this study was carried out at (the central environmental laboratory) which used to corrode the Al alloy specimens and the result listed in table (3):

Table (3): Chemical Tests result of Ions in the Gulf Water in the Lab. (mg/lit)

Minerals (Ion)	methods	Golf water
Alk. as CaCo3	titration	160
Ca	titration	616
Mg	Calculated	852
Cl	titration	5880
SO4	Turbidity metric	4100
Na	Flame-photometric	3800
K	Flame-photometric	135
T.D.S	gravimetric	17244

Fatigue Testing:

A fatigue test has been done at University of Technology by fatigue testing machine of type PUNN rotating bending is used to test all fatigue specimens, with constant and variable loading, as illustrated in Figure(1).

Figure (1): PUN N rotary fatigue bending machine.

The fatigue specimen which is shown in Figure (2) had a round cross section and was subjected to an applied load, which created a constant bending moment. A stationary moment applied to a rotating specimen caused the stress at any point on the outer surface of the specimen to go from zero to a maximum tension stress, back to zero and finally to a compressive stress. Thus, the stress state is one that is completely reversed in nature [11].

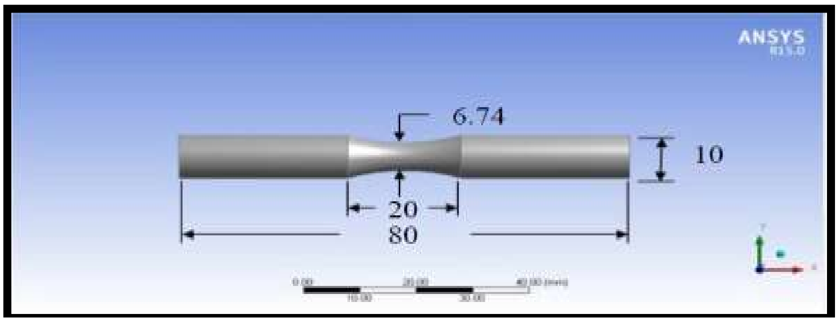

Figure (2): Fatigue test specimen dimensions in millimeter according to (DIN 50113) standard specification [12].

Results and Discussion:

Constant Amplitude Fatigue Results:

The first series of tests were carried out at constant amplitude loading to obtain S-N curves for dry fatigue ,corroded at light media (9fungi colonies),and corroded at dark media (80fungi colonies). The applied stresses were 400,300,250,175 and 150 MPa 3 specimens for each load base on the tensile behavior 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 constant stress amplitudes the fatigue [3].

Table (4): Fatigue results for two condition of testing

Specimen No.	Applied stress MPa	N_f Cycles	$N_{f\ av.}$
Dry condition			
1,2,3	400	1000,2000,1000	1500
4,5,6	300	5000,6000,12000	7666
7,8,9	250	30000,35000,10000	25000
10,11,12	175	1488600,1268000,1359400	1372000
13,14,15	150	2765000,2625000,2924000	2771333
corroded at light media (9fungi colonies)for four months			
16,17,18	400	3000,1000,1000	1666
19,20,21	300	6000,10000,8000	8000
22,23,24	250	30000,35000,10000	25000
25,26,27	175	782000,810000,550000	714000
28,29,30	150	1136000,1130000,1142000	1136000
corroded at dark media (80fungi colonies)for four months			
31,32,33	400	1000,1000,1000	1000
34,35,36	300	6000,7000,6000	6500
37,38,39	250	20000,17000,23000	20000
40,41,42	175	50000,39000,46000	45000
43,44,45	150	809000,799000,801000	803000

The experimental results of Table (4) can now be plotted in linear coordinates. It is clear that the fatigue behavior of 7075 Al alloy S-N curves are similar for the conditions of testing mentioned above at the region of high stress fatigue (low cycle fatigue).This finding may be related to the high applied load dominated parameter not to the corrosion cracking [13][14].

But the behavior of fatigue at high cycle region seems to be different, especially at stresses close to the fatigue limit. It is observed that the S-N curve reduced down in case of pre-corroded condition. The results of Table (4) can now be plotted in figure (3).

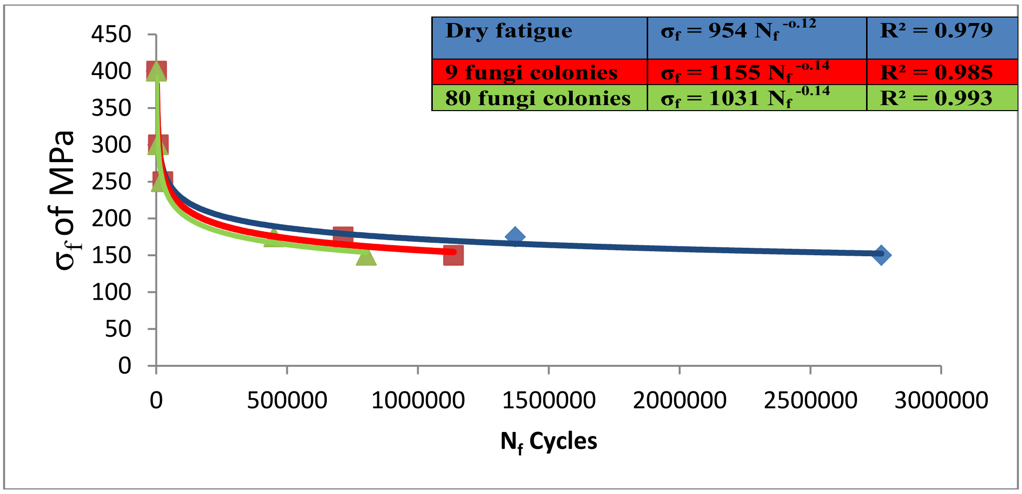

Figure (3): Conventional constant stress amplitude S-N curves for dry and corrosion fatigue conditions

The figure (3) shows the S-N curves for dry and pre-corroded fatigue specimens for four months. As shown in the figure the fatigue strength at 10^7 cycles (endurance fatigue limit) decreased. The fatigue strength of dry specimens was 138 MPa while that of pre-corroded specimens at light media (9 fungi colonies) was 121 MPa showing 13% decreases and pre-corroded specimens at dark media (80 fungi colonies) was 108 MPa showing 22% decreases . **Cheong et.al.** tested 7075-T6 Al alloy under constant fatigue loading and before fatigue testing specimens were submersed in 3.5 % NaCl solution for one week and two months. They concluded that the fatigue strengths after one week and two months exposure to the corrosive environment decreased to 150 MPa (about 27% loss) and 125 MPa (about 39% loss) , respectively. While the fatigue strength of specimens pre-corroded between one month and one year did not show a big difference [14]. Pao .et .al tested 7075-T351 Aluminum alloy under fatigue loading using the 3.5%NaCl solution as a medium. They found that the threshold stress levels are significantly reduced due to the presence of corrosion pits. The presence of a corrosive environment during fatigue loading eliminates the fatigue limit for the metal used[15].

Table (5): Endurance limit at 10^7 cycles and Reduction Factor (RF)

Condition	Equations	Endurance limit cycles at 10^7	(RF)
Dry fatigue	$\sigma f = 954\ Nf^{-0.12}$	138	
Corrosion fatigue(9 fungi colonies)	$\sigma f = 1155\ Nf^{-0.14}$	121	12.3 %

Corrosion fatigue(80 fungi colonies)	$\sigma f = 1031\ Nf^{-0.14}$	108	21.76%

Fungi are not directly corrosive to the metals, however the deposit of fungi on the metal surfaces produce differential concentration cells and interfere with action of corrosion inhibitors by shielding the metal surfaces from it causing corrosion [16].

Corrosion – cumulative fatigue damage results

The cumulative amplitude loading fatigue tests with round specimens were performed under two different loadings .the applied loads were 300 MPa for 10^5 cycle and then convert to 150 MPa for10^5 cycle. This sequence was repeated till failure.

Table (6): Corrosion-cumulative fatigue damage results of 7075 T6 Al alloy

Specimen No.	Loading sequence (MPa	Nf Cycles	Nf av.
corroded with 80 fungi colonies			
46,47,48	L-H 150-300	17000,11000,8000	12000
49,50,51	H-L 300-150	6000,7000,6000	6500

Miners rule linear model:

Among the several theories proposed for fatigue-life predictions, the Palmgren-Miner (PM) theory because of its simplicity seems to be the most widely used. Mathematically this theory may be written as

$$\left[\frac{n_1}{N_{f1}}\right]_{\sigma 1} + \left[\frac{n_2}{N_{f2}}\right]_{\sigma 2} = 1 \qquad \ldots(1)$$

Where n_1 is the applied number of cycles for σ_1
n_2 is the applied number of cycles for σ_2
N_{f1} is the number of cycle to failure at σ_1 (obtained from S-N curve)
N_{f2} is the number of cycle to failure at σ_2 (obtained from S-N curve)
it is important to note that the (PM) theory no provisions are made to take into account the various effects on fatigue life, such as the environment factor i-e the corrosion effects, and loading sequence effect low-high or high-low stress loading [11].

The proposed non-linear model:

Non – linear cumulative fatigue damage formulas one for low-high loading sequences and the other for high- low loading, were derived from the experimental obtained from cumulative testing and constant stress amplitude tests, S-N curves. These formulas may be expressed mathematically in the form.

For low-high loading

$$\boldsymbol{D} = \frac{\left(\frac{Acor.\times\propto cor}{Adry\times\propto dry}\right)^{\left(\frac{\sigma H}{\sigma L}\right)}}{\sqrt{n.f.c.}} \qquad \textbf{...(2)}$$

And for high-low loading

$$\boldsymbol{D} = \frac{\left(\frac{Acor.\times\propto cor}{Adry\times\propto dry}\right)^{\left(\frac{\sigma L}{\sigma H}\right)}}{\sqrt{n.f.c}} \qquad \textbf{...(3)}$$

Where: A_{corr} ,A_{dry} ,α_{dry} α_{corr} .Curve fitting parameters for dry fatigue and corrosion fatigue respectively. σ_H, high stress σ_L, low stress. And n. f. c. is number of fungi colonies.

The results of experimental, Miner rule and proposed model are illustrated in Table (7)

Table (7): Cumulative fatigue results specimens corroded with 80 fungi colonies according to Miner &Proposed Model

Specimen No.	Loading sequence (MPa)	$N_{f\,av.}$	N_f Cycles	
			Miner rule	Proposed Model
52,53,54	L-H 150-300	12000	13413	2384
55,56,57	H-L 300-150	6500	13413	1684

The comparison between the proposed model and Miner rule based on experiment results is made on table (7). It is observed that the Miner rule predication are not accurate (overestimated the fatigue life).While the proposed model gives safe predications. The reasons may be related the following parameters:

1. The proposed model designed to be non-linear damage behaviour.
2. It takes into account the effect of corrosion and loading sequences in predication the cumulative fatigue life.

Conclusions:

From the current work on the interaction of cumulative corrosion-fatigue of 7075 Al alloy, the following remarks can be derived:

1- The fungi colonies can be growth on the aluminium surface.
2- The fungi can reduce the fatigue strength.
3- Fungi corroded the aluminium surface and cause a pit on it which it the main reason for the redaction in the fatigue strength.
4- Shatt – Arab water consider suitable media to growth the fungi.
5- The proposed model (non-linear damage model) showed safe life fatigue predictions under interaction of corrosion - fatigue
6- The proposed model was the most appropriate from Miner rule.

REFERENCES

[1] Sundararajan T., Anthoniraj S., Kannan N., Muthukaruppan S.M. "Microbiology" Ch.10, COLLEGE ROAD, CHENNAI-600 006 (2004).

[2] Jones D.A., Principles and Prevention of Corrosion, 2nd edit., Macmillan Publishing Company, New York (1992).

[3] Garcia D. B., Forman R. D. " Evaluation of Fatigue Crack Initiation From Corroded Hemispherical Notches In Aerospace Structural Materials" Fatigue & fracture of engineering materials & structures" Vol. 35, pp. 122–140, Issue 2, (2012).

[4] Wang Q.Y., Kawagoishi N., Chen Q. "Effect Of Pitting Corrosion On Very High Cycle Fatigue Behavior" Scripta Materialia, Vol.49, PP. 711–716, (2003).

[5] Amadi A., Ukpaka C.P. , B.N. Jacob " The Mechanisms Of Microbial Corrosion Of Aluminum Alloys" Jr. of Industrial Pollution Control Vol.23, No.2, pp 197-208(2007).

[6] Chlistovsky R.M., Heffernan P.J., Duquesnay D.L. " Corrosion-Fatigue Behavior of 7075-T651 Aluminum Alloy Subjected To Periodic Overloads" International Journal of Fatigue, 29 1941-1949(2007).
[7] Genel K. “Numerical Investigation On Stress Concentration Of Corrosion Pit” ScriptaMaterialia, Vol. 57 pp.297–300 (2007).
[8] Rao A.C., Vasu V., Shariff S.M., Srinadh K.V. " Improvement of Corrosion Resistance By Laser Surface Melting Of 7075 Aluminum Alloy" AIMTDR, Vol.5,pp.395-401(2014)
[9] ASM (Aerospace Specification Metals) Material Data Sheet, asm.matweb.com (2015).
[10] Designation: B 211 – 03 "Standard Specification for Aluminum and Aluminum-Alloy Bar, Rod, and Wire" ASTM International, (2009)
[11] Al- alkawi H.J., Majeed A.H. , Fahad S.A. "Estimation Of Fatigue-Corrosion Damage And Life Under Variable Loading Based On Modified Corrosion Fatigue Model (MCFM)" Journal of Engineering and Development, Vol. 16, No.4,pp.445-437, ISSN 1813- 7822(2012).
[12] Alalkawi H. J, Kareem F. A., and A. A.Ali, "Prediction of Fatigue-Creep Interaction Life of Aluminum Alloy AA7349 Using Electromechanical Devices ", Engineering and Technology Journal, VoL.33, N0.3, (2015).
[13] Bayoumi M. R. "Fatigue Behaviour Of a Commercial Aluminum Alloy In Sea Water At Different Temperatures", Eng. frac. mechs., Vol.45, pp .297-307, (1993).
[14] Cheong K.S, Nam J. H., Lee J. H.,. Kim T. H " Effects Of Shot Peening On The Corrosion Fatigue Life of Al 7075-T6 ", ICSP9: Shot peening (2005).
[15] Pao P.S., Gill S.J., Feng C.R., "On fatigue crack initiation from corrosion pits in 7075-T7351 aluminum alloy" Scripta Materialia ,Vol. 43, pp.391-396, (2000).
[15] Charng T., and Lansing F. "Review Of Corrosion Causes And Corrosion Control In a Technical Facility", NASA Technical Reports, TDA Progress Report, pp 145, (1982).