THE EFFECT OF CORROSION-MUD TREATMENT ON FATIGUE ACCUMULATED PROPERTIES USING 7049 AL-ALLOY

Qusay K. Mohammed*

***Electromechanical Engineering Department, University of Technology,**

50002@uotechnology.edu.iq

ABSTRACT

The present work deal with the effect of corrosion-mud on constant fatigue and accumulated using 7049 aluminum alloy. Experimental results observed that fatigue life and strength strongly effect by corrosion-mud treatment. The (fatigue life reduction factor percentage) FLRF% can empirically expressed by the equation

$$FLRF\% = 0.004688 * \sigma_f + 3.0372$$

The fatigue strength was reduced to 10% due to mud corrosion fatigue interaction. It was indicated that Miner rule underestimated the mud corrosion fatigue life interaction.

KEYWORDS : 7049 Al alloy, FLRF% , corrosion – mud fatigue interaction , Miner rule

تأثير معاملة التأكل الطيني على خواص الكلال التراكمي باستخدام سبيكة الالمنيوم 7049

د. قصي خالد محمد

قسم الهندسة الكهروميكانيكية – الجامعة التكنولوجية

الخلاصة :

يهدف البحث الحالي الى دراسة تأثير التأكل الطيني على خواص الكلال التراكمي لسبيكة الالمنيوم 7049. النتائج العملية اوضحت ان التآكل الكيمياوي مع الطين يقلل بشكل عالي عمر مقاومة الكلال. نسبة عامل التخفيض لعمر الكلال $FLRF\%$ قد يوصف بالمعادلة

$$FLRF\% = 0.004688 * \sigma_f + 3.0372$$

مقاومة الكلال قلت بنسبة 10% نتيجة لتداخل التآكل الكيمياوية والطين مع الكلال . اتضح ان قاعدة ماينر اعطت تخمين قليل لعمر الكلال المتداخل مع التآكل الكيمياوي مع الطين

الكلمات الرئيسة : سبيكة الالمنيوم 7049 ، نسبة عامل التخفيض في عمر الكلال ، تداخل التآكل الكيمياوي والطين مع الكلال ، قاعدة ماينر .

INTRODUCTION :-

Corrosion-fatigue interaction significantly reduce the fatigue endurance limited and life of component and structures. The corrosion mechanism plays a big role in initiating and propagating the fatigue cracks. Thus the fatigue strength and life is strongly reduced compared to the dry fatigue. Lots of studies have been done on inspecting the combination behavior of fatigue and corrosion recently.[R.H. Oskouei, R.N. Ibrahim, 2011] In addition, the mechanism of corrosion on fatigue crack propagation may be a chemical reaction causing by anodic dissolution and hydrogen embrittlement so called as corrosion-blunting-fracture model for corrosion fatigue crack propagation [G.Biallas,H.J. Maier,2007]. The nature of initiation of fatigue cracks from corrosion pits in 7075-T7351 aluminum alloy was studied. The results show that corrosion pits readily formed around /at constituent particles of the alloying elements [P.S. Pao,S.J. Gill and C.R. Feng,2000].The effect of corrosion severity on fatigue of 7075-T6511 alloy using crack surface marker band analysis and a fracture mechanics model was studied. It was observed that crack nucleation tended to occur at local protrusions into the corded area and after initial sharp degradation the fatigue life became independent of time exposure to corrosion [James T. Burns, Sangshik Kim, Richard P. Gangloff,2010]. The effect of pitting corrosion on high cycle fatigue behavior of plate dog-bone specimens studied. Fatigue crack growth analysis indicated that rate of crack growth for small cracks are higher than those of large cracks[Q.Y. Wang, N. Kawagoishi, Q.Chen,2003]. Corrosion fatigue research on 7075-T6 aluminum alloy in3.5% NaCl solution was conducted. A greater stress concentration was observed around areas associated with both a constituent particles and a crack than either a crack or pit alone [Kimberli Jones, David W. Hoeppner, 2009]. The effect of corrosion pits on the fatigue behaviour of 7075-T6 alloy was investigated. It was found out that the depth of pits increased by interconnection of smaller pits located at the nucleation sites at various depths [K.K. Sankaran, R.Perez, K.V. jata,2001].The viability of a total fatigue life prediction methodology for material with pre-existing corrosion damage was studied. The main conclusion was that a total fatigue life predication methodology was shown to be a mostly successful in predicting the life of precorroded test specimens[K.M.Gruenberg, B.A. Craig, B.M. Hillberry, R.J. Bucci, A.J. Hinkle,2004]. The effect of pitting on the bending fatigue performance of high-strength 7075-T6 aluminum alloy. It was concluded that pit population, pit density as well as pit depth increase with increasing pre-corrosion time[K.genel,2007].The initiation of localized corrosion upon high strength aluminum alloy which is often associated with cathodic intermetallic particles within the alloy was studied [N.Birbilis,M.K. Cavanaugh, R.G. Buchheit,2006]. The present work aims to estimate the behavior of 7049 aluminum alloy tested in constant and variable fatigue loadings treated in prior corrosion and mud for 100 days.

EXPERIMENTAL DETAILS
Material
Chemical composition of this alloy is summarized in **Table (1).** This alloy is frequently used in aircrafts and ships .

Tensile Specimens

Specimens are prepared according to American Society of the International Association for Testing and Materials B55M [Annual Book of ASTM standards]. The thickness of these specimens is (1 mm). The specimen is shown in **Fig. (1)**

Tensile Strength Testing Machine

Tensile test was done at the state company for inspection & engineering rehabilitation (SIER) using (DZ-101) tensile strength testing machine with a capacity of 10000 kg which is shown in **Fig.(2)** .These tests were executed at constant speed of 0.5 mm/min till failure. The mechanical properties of the used alloy are tabulated in **Table (2)** in comparison with standard.

Note that: Three specimens were examined and the average reading is tabulated above.

 Preparation of Fatigue test specimens

Fatigue specimens are a plate with 1 mm thickness for alternating bending test as shown in Fig.(3) were prepared according to standard test method for tension-tension fatigue of materials D3479/3479M-96 to fit the testing machine.

The specimens were fabricated by a cutting die and this die consists of three parts:

1- Punch
2- Die
3- Blank holder

Dimensions of these parts are (160×60×35) mm, (160×120×20) mm, (160×120×40) mm respectively.

The cutting processes were accomplished at two stages, the first stage is piercing 4 holes, and the second stage is cutting the specimens.

Fatigue work plan

All fatigue testing was performed by flat specimen test rig type AVERY 7305 to examine stresses using dynamic and static loads. The frequency of the test machine is 23.4 HZ. All details of the fatigue apparatus is shown in Fig.(4). The specimen applied bending can be adjusted using sliding role. (1) centimeter equal to (10) MPa. [Avery 7305, "users Instructions Manual]

$$\sigma_{b(bending\ stress)} = \frac{1.5 * h * E * \delta}{L_o^2}$$

Where: h is the thickness of the specimen

E is the elastic modulus

δ is the deflection

L_o is the effective length, which can be calculated from the equation

$$L_o = \frac{4L^2 - 2.465\ \delta^2}{4L}$$

L : half the length between specimen holes.

In order to find the angle (θ) in degree it can made a calibration curve between bending deflection and eccentric position angle (θ) in the elastic range.

The calibration line can be shown in **Fig.(5)**

The connecting rod controlled the oscillating spindle which gives the motion to one end of specimen while the other end of specimen is fixed by grips. Angle of twist due to bending can be controlled by eccentric attachment to get the desirable angle range.

RESULTS AND DISCUSSION

Fatigue S-N Results

Fatigue analysis is typically based on the data determined from S-N curve testing the specimens till failure was defined to be the specimen became into two pieces. The first stage of work was to set up the base line data using 12 specimens as received (fatigue testing) and 12 specimens (corrosion fatigue) which were submerged in 0.35% NaCl +mud for 100 days. **Table (3)** shows these results.
The constant fatigue S-N curve equations may be taken the form:

$$\sigma_f = 1480 \, N_f^{-0.173} \quad \text{for dry fatigue} \tag{1}$$

and

$$\sigma_f = 1429 \, N_f^{-0.177} \quad \text{for 100 days corrosion and mud} \tag{2}$$

The behavior of the 7049 Al – alloy can be seen in **Fig.(6)**
The interaction of corrosion and cyclic loading (fatigue) is caused by many factors such electrochemical, metallurgical and mechanical processes at the crack tip. It has been well established that corrosion fatigue for steel, aluminum alloys and titanium alloys works to reduce the strength and life. At present there is no reliable solution for fatigue corrosion of metals.[Alalkawi H.J., Alsaraf S.A., Abdul-Jabbar H,2014]
Equations (1) and (2) gave the fatigue endurance limit under the dry and corrosion with mud for 100 days as given below

FATIGUE LIFE REDUCTION FACTOR (FLRF)

Cumulative Fatigue results

The machine parts are frequently subjected to cumulative fatigue loading (variable loading). The oldest theory for assessment the cumulative fatigue is the Miner rule. This rule based on a linear damage manner and due its simplicity, it is widely used for design purpose [Alalkawi H.J., Abdul-Jabar H. Ali, Saisaban A.F.,2015].
Five specimens were tested for each two stress level loadings the results are given in **Table (5)**
It is clear that the Miner rule underestimates the fatigue life due to the following reasons:
   1- It doesn't take into account the effect of corrosion on damage accumulation.
   2- The predication according to Miner rule depended on a linear damage accumulation while the metallic materials can exhibit highly nonlinear fatigue damage evolution with loading sequences.
This factor may be calculated from the equation [Perrira H.F.S.G., Jesus A.M.P., Ribeiro A.S. , Fethades A.A.,2009]

$$FLRF\% = \frac{\log N_{f(RT)} - \log N_{f(corr)}}{\log N_{f(RT)}} \qquad\qquad (3)$$

Where $N_{f\,(RT)}$ is the number of cycles to failure at room temperature and $N_{f\,(corr)}$ is the number of cycles to failure at 0.35% NaCl + mud (corrosion condition for 100 days). Here the FLRF% factor was calculated for applied stresses namely 500,400,300,200, and 100 MPa. **Table (6)** gives the empirical FLRF% for the used alloy.

The results of fatigue life were based on the application of equations (1) and (2).

It is clear that, **Table (6),** reducing the applied stress gives reducing in FLRF%. At high stress level the cracks grow and propagate in fast way while at low stress they take more time compared with the high stress level [Majeed M.H.,2009]. The relation between FLRF% and applied stress can be observed in **Fig. (7)**

According to **Fig.(7)** corrosion in its various forms must be taken into account in assessing the fatigue behavior of structure and components due to damage introduced by the surrounding circumstances.

CONCLUSIONS

1- The existence of corrosion and mud is significantly reduce the strength and fatigue life of 7049 Al alloy.
2- The relation between the FLRF% and applied stress under corrosion and mud can be expressed linearly as

$$FLRF\% = 0.004688 * \sigma_f + 3.0372$$

3- Corrosion +mud for 100 days gave 10% reduction in fatigue endurance limit.
4- Miner rule underestimate the corrosion mud fatigue life interaction .

Table (1) Chemical composition of (7049A) Al-alloy
[MatWeb.com , Material property data]

Fe	Si	Mn	Cr	Cu	Mg	Zn	others	
0.5	0-0.4	0-0.5	0.05-0.25	1.2-1.9	2.1-3.1	7.2-8.4	Each 0.05; total 0.15	Zr+Ti <0.25; Al - remainder

Table (2) Mechanical Properties of (7049A) Al-alloy

Property	σ_{ut} MPa	σ_y MPa	Elongation	Modulus of Elasticity GPa
EN 573-3: 2009	660-670	570-600	8-9%	72
Experimental	654	582	8%	70

Table 3: Constant Fatigue results

Specimen No.	Applied Stress (MPa)	N_f cycles	N_f Average
1,2,3	416	1600,2010,1800	1804
4,5,6	312	5800,6200,6600	6200
7,8,9	208	67500,71600,82800	73967
10,11,12	156	414000,468500,502000	461500
100 days 0.35 NaCl +mud			
13,14,15	416	1200,1600,900	1234
16,17,18	312	4200,5000,5200	4800
19,20,21	208	50800,44600,41000	45467
22,23,24	156	310000,332000,290800	310934

Table (4) Fatigue endurance limit at 10^7 cycles

Dry fatigue	Corrosion + mud for 100 days fatigue
91 MPa	82 MPa
Percentage reduction	
10%	

Table (5) Results of variable fatigue testing for 100 days in corroded media

No. of samples	Variable stresses	$N_{f\,av.}$	According to linear damage rule
25,26,27,28,29	L-H (200-350)	29800	5420
30,31,32,33,34	H-L (350-200)	12980	5420

Table (6) FLRF% for a range of applied stresses (empirical values)

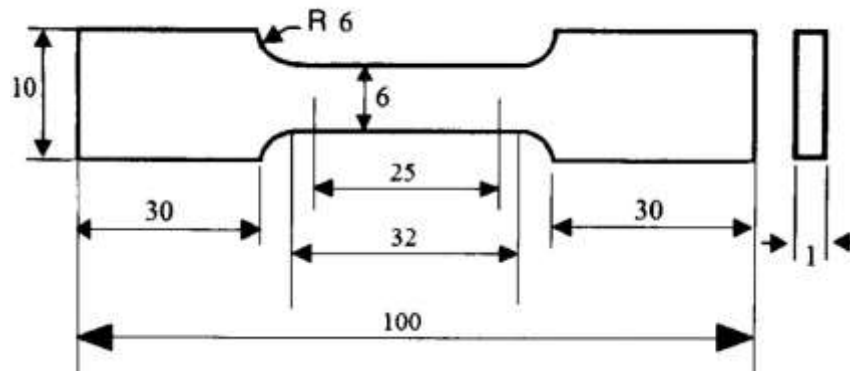| Applied Stress		Applied Stress		Applied Stress		Applied Stress		Applied Stress	
500 MPa		400MPa		300MPa		200MPa		100MPa	
N_f (cycles)		N_f (cycles)		N_f (cycles)		N_f (cycles)		N_f (cycles)	
dry	corr.	Dry	corr.	dry	corr.	dry	corr.	dry	corr.
530	377	1925	1331	10153	6761	105739	66815	5814583	3354330
FLRF%		FLRF%		FLRF%		FLRF%		FLRF%	
5.43		4.87		4.407		3.98		3.531	

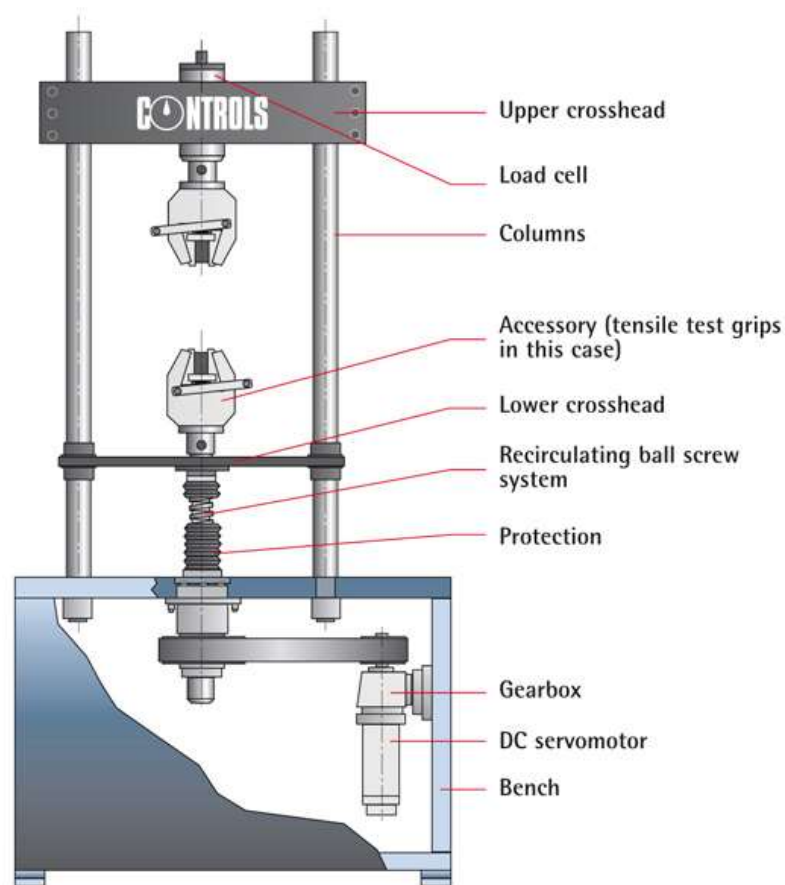Figure (1) Tensile test Specimen Dimensions [ASTM B55M] (All dimensions in mm)
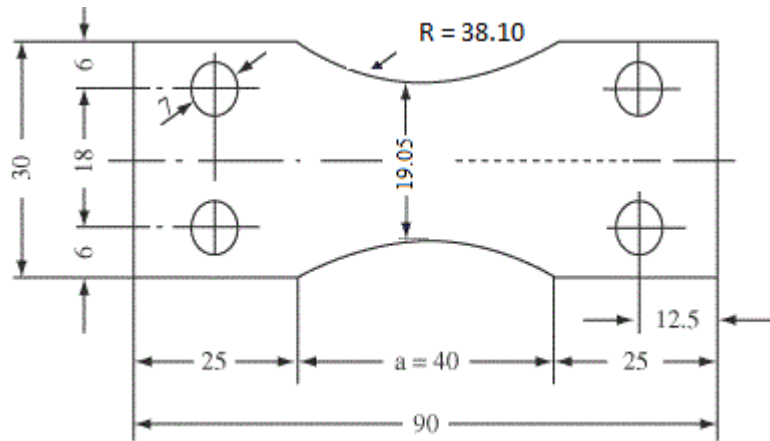

Figure (2) Tensile Test Apparatus

Figure (3) Shape and Dimension for Fatigue specimen (all dimensions in mm)
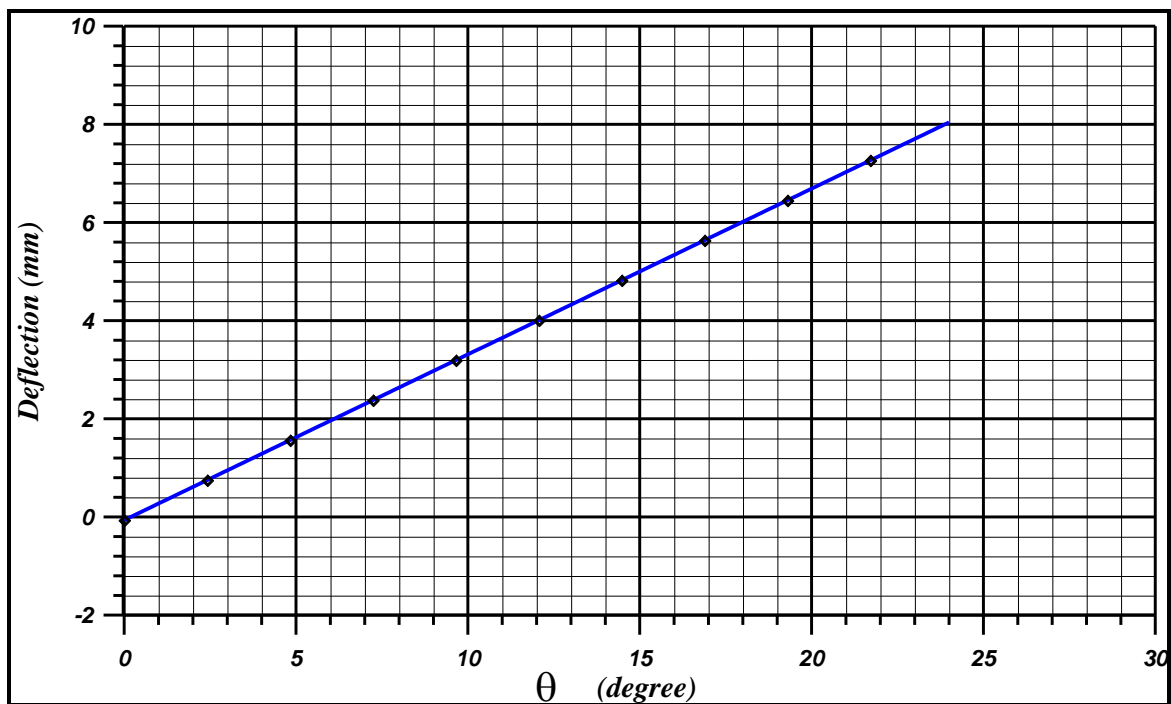
Fig.(4) Fatigue Test Machine Type 7305

Fig. (5) Calibration curve between bending deflection and eccentric position angle (θ)°
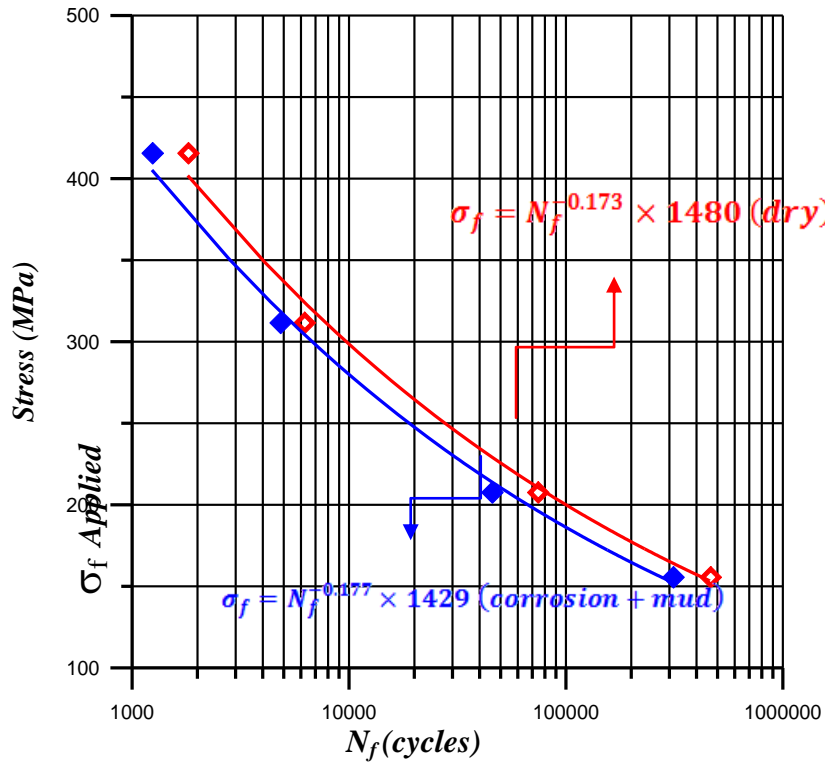
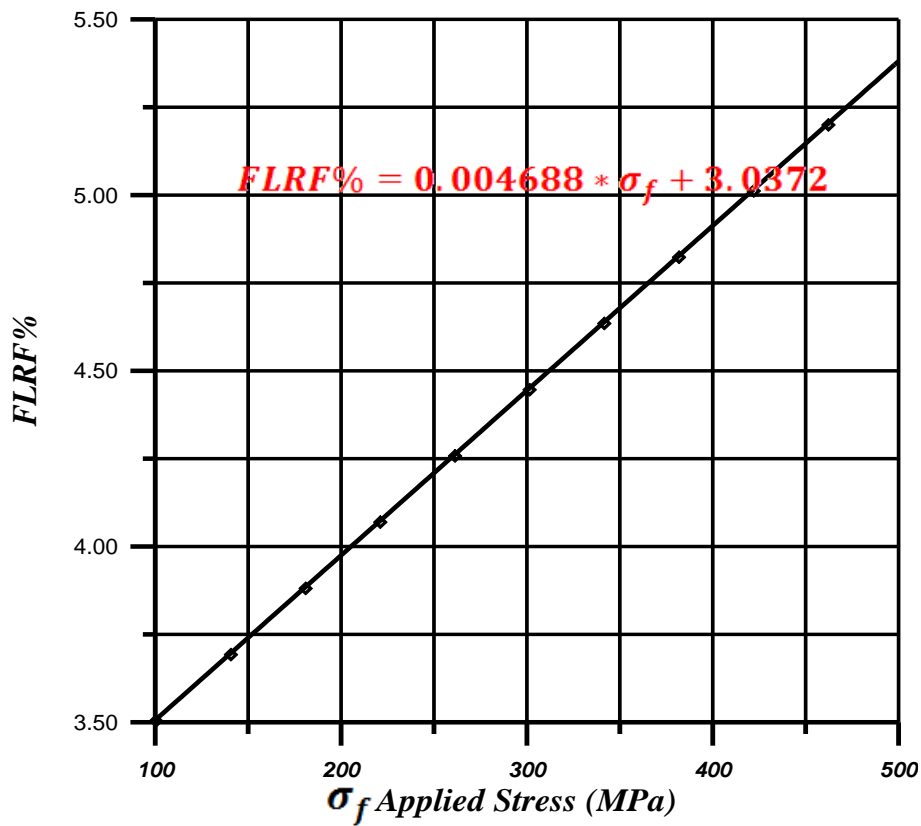Figure (6) S-N curves for dry and corrosion fatigue conditions

$$\sigma_f = N_f^{-0.173} \times 1480 \ (dry)$$

$$\sigma_f = N_f^{-0.177} \times 1429 \ (corrosion + mud)$$

$$FLRF\% = 0.004688 * \sigma_f + 3.0372$$

Fig.(7) FLRF% against applied stresses

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