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ENHANCEMENT OF CUMULATIVE CORROSION-FATIGUE INTERACTION LIVES OF 6061-T6 ALUMINUM ALLOY USING ULTRASONIC IMPACT PEENING PROCESS

Dr. Hussain Jasem Mohammed Al-Alkawi [1], Dr. Amer Hameed Majeed [2], Saba Farhan Naser [3]

1) Prof., Electromechanical Engineering Department, University of Technology, Baghdad, Iraq.
2) Assistant Prof. Material Engineering Department, Mustansiriyah University, Baghdad, Iraq.
3) MSc. Student, Material Engineering Department, Mustansiriyah University, Baghdad, Iraq.

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Abstract: The fatigue behavior of 6061-T6 aluminum alloy under constant and variable amplitude loading was investigated in air for as-received and pre-corroded specimens in 3.5% NaCl corrosive solution for 77 days. The experimental results presented that the tests of fatigue life on pre-corroded samples with and without ultrasonic peening revealed a significant reduction in life related with the presence of corrosion defects before cyclic loading. In state of unpeened specimens the constant S-N fatigue strength curve was decreased by 4.5% due to immersed the specimens in corrosive 3.5% NaCl solution for 77 days, while in state of ultrasonically peened specimens for 10 sec. per line and 2.5 joul energy the reduction of S-N curve decreased to 2.2% due to the beneficial effect of this treatment for increasing the corrosion-fatigue life. The improvement of fatigue life and corrosion-fatigue life of specimens when applying of ultrasonic peening was 8.69% for dry fatigue life and 2.3% for corrosion-fatigue interaction. The results of cumulative corrosion-fatigue tests indicated that the life of corroded specimens under the effect of ultrasonic peening treatment improved to approximately (3% – 2.25%) for low-high and high-low sequences.

Keywords: *Cumulative Corrosion-Fatigue, AA 6061-T6, Ultrasonic Peening,Fatigue Life.*

تحسين عمر الكلال – التأكلي التراكمي المتداخل لسبيكة الالمنيوم 6061-T6 بأستخدام عملية القذف بالموجات فوق الصوتية

الخلاصة: سلوك الكلال لسبيكة الالمنيوم 6061-T6 تحت حمل متغير وثابت السعة تمت دراسته في الهواء لعينة كما وردت ولعينة متأكلة في محلول متأكل NaCl 3.5% لمدة 77 يوم. بينت النتائج العملية بأن فحص عمر الكلال لعينة متأكلة مع وبدون تقنية القذف بالموجات فوق الصوتية اظهر تناقص كبير في العمر متعلق بوجود عيوب التأكل قبل الاجهاد الدوري. في حالة العينات الغير معاملة بتقنية الموجات فوق الصوتية فأن فحص مقاومة الكلال لـ constant S-N curve تقل بنسبة 4.5% بسبب غمر العينات في المحلول المتأكل من 3.5% كلوريد الصوديوم لمدة 77 يوم، بينما في حالة العينات المعاملة بهذه التقنية لمدة 10 ثواني / line وبطاقة 2.5 جول فأن النقصان بـ S-N curve يقل بنسبة 2.2% بسبب التأثير النافع لهذه التقنية في زيادة عمر الكلال المتراكم.التحسن بعمر الكلال والكلال التأكلي للعينات عندما نطبق تقنية الموجات فوق الصوتية يكون 8.69% لعمر الكلال الجاف و 2.3% لعمر الكلال – التأكلي التراكمي. دلت نتائج فحص الكلال التأكلي المتراكم بأن عمر العينات المتأكلة نتيجة تأثير تقنية الموجات فوق الصوتية يزداد الى تقريباً (3%-2.25%) للاجهاد (الواطئ – العالي) و (العالي – الواطئ).

*Corresponding Author sabafrhan_eng@yahoo.com

1. Introduction

A corrosive environment increases the risk of a reduction in fatigue resistance and consequently eliminates fatigue limits. Furthermore, the presence of a severe environment accelerates fatigue cracking. Transportation, oil and gas production and energy generation are examples of engineering structures subjected to a combination of aggressive environments and fluctuating loads [1]. Corrosion fatigue should be distinguished from simple mechanical fatigue because of the difference in crack propagation mechanisms. In corrosion fatigue, the part remains immersed in the corrosive environment thus providing the continued presence of a corrosive species in the fatigue crack tip. Faster crack growth occurs because corrosion mechanisms at the crack tip create material removal and embrittlement phenomena not present in simple mechanical fatigue [2]. Additional surface treatment and protection is necessary to prolong the service life of machine parts [3]. Ultrasonic peening treatment (UPT) or ultrasonic impact treatment (UIT) is a promising technique which brings about severe plastic deformation and allows fast modification of structure and composition of the surface layers [4]. This technique has many industrial applications such as aerospace, ship and marine, automotive, railway, and bridge structures, in which materials with very high strength, fatigue life, corrosion and wear resistance are needed [5].

Daavari and Sadough [6] investigated the effect of UIT on corrosion fatigue behavior of welded steel pipes. The tensile residual stresses caused by different manufacturing methods that were the main reason of reducing the structures lives under conditions of cyclic loading and corrosive environment. The application of UIT was one of the influential and promising processes for developing the fatigue performance of materials. Furthermore, it had some positive action on the corrosion resistance of metals, which was included: closing of surface crack, introducing of compressive residual stresses, increment in surface hardness because increase in dislocation density and corrosion resistance enhancement due to reducing of residual stresses. Ping et al. [7] studied the effect of corrosion-fatigue on 2024-T3 specimens of aluminum alloy.

The results revealed that there was an obvious interaction between the pit growth and development of fatigue damage. The growth of corrosion pits gave raise to cyclic stress and stress concentration in turn accelerated the pits growth. At the same time, the accumulated fatigue damage decreased the mechanical properties of material around the pit and resulted redistribution of stresses around the pit which also influenced the process of pit growth. The corrosion time decreased when the loading frequency increased. Thus the effect of corrosion was weakened and the fatigue life extended. Ramos et al. [8] studied the influence of ultrasonic peening and shot peening on the fatigue life of the aluminum specimens 7475-T7351 alloy.

Their study aim to improve the mechanical properties by using three various peening processes: micro shot peening with beads of two different size (MSP) and ultrasonic peening. UP was promoted more suitably surface finish and reduces the roughness values than micro shot peening. The all three surface peening were capable to enhance fatigue life. For the fatigue test at (R= -1), higher fatigue lives enhancement was obtained. Fatigue strength increased by 35% in comparison with base metal for all of these treatment. This paper presents the effect of UIT technique on the cumulative corrosion-fatigue interaction of 6061-T6 aluminum alloy.

2. Experimental Work

The material used in this work is an aluminum alloy 6061-T6. This alloy has good formability, weldability, corrosion resistance. Good general purpose alloy used for a wide range of structural applications and welded assemblies including railroad cars, pipelines, marine applications, aircrafts, electrical and electronic applications [9]. Chemical analysis of material used (6061-T6 Al alloy) is performed at (Iraq Geological survey, Ministry of Industry and Mineral, Baghdad, Iraq). The results are compared with American standard ASTM B-211 [10], which are listed in table (1) below.

Table 1. Chemical composition of 6061-T6 Al alloy in wt%

Alloying element%	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Standard ASTM B-211	0.4-0.8	Max. 0.7	0.15-0.4	Max. 0.15	0.8-1.2	0.04-0.35	Max. 0.25	Max. 0.15	Bal.
Experimental	0.55	0.36	0.26	0.11	1.07	0.12	0.19	0.09	Bal.

The experimental mechanical properties results are also compared with standard, that are presented in table (2).

Table 2. Mechanical properties of 6061-T6Al alloy

Property	Ultimate tensile strength σ_u (MPa)	Yield strength σ_y (MPa)	Elongation %	Modulus of elasticity GPa
Standard ASTM B-211	310	276	17	68.9
Experimental	316	268	16.5	70

Tensile test is performed at room temperature by using tensile test rig type (WDW-50) at the (Materials Engineering Department, University of Technology, Baghdad, Iraq) to get of the mechanical properties as mentioned above of selected material (6061-T6 Al alloy).

3. Fatigue Test

The fatigue tests can be divided into two categories; which include dry fatigue at room temperature and corrosion-fatigue tests. All tests were done under constant and variable amplitude fatigue loading. Fatigue test was performed by using fatigue testing machine of type (PUNN rotating bending) as shown in figure (1).

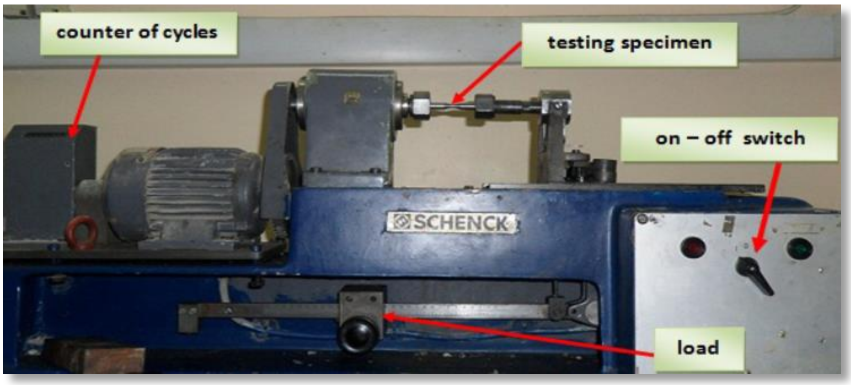

Figure 1. Fatigue rotating bending machine (PUNN SCHENCK)

The cylindrical fatigue specimen manufactures according to the standard specification of (DIN 50113) and the crack initiation and fracture occurred for all tests at the middle point of the specimens as shown in figure (2).

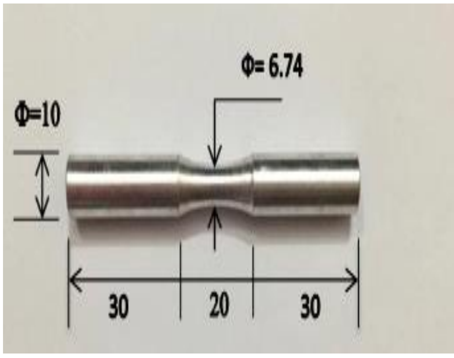

Figure 2. Dimensions of cylindrical fatigue test specimen in (mm) and Fatigue specimens after fatigue failure

4. Ultrasonic Impact Peening (UIP) Device

Ultrasonic peening device introduces the energy of ultrasound into metal through impulse contact surface. This energy is applied into the metal by converting the resonant, harmonic oscillation of an acoustically tuned body to mechanical impulses on a surface. The figure (4) shows UP device and figure (5) shows fatigue specimens before and after UP device. The main technical parameters of UP device are given below [11]:

- Frequency: 20KHZ Voltage: 220v power: 500w.
- The intensity of impact is 10/sec. and the time for one line peening is 20 (sec.).
- Type: portable

The ultrasonic impact treatment is done at (Electromechanical Engineering Department, University of Technology) by using UP device.

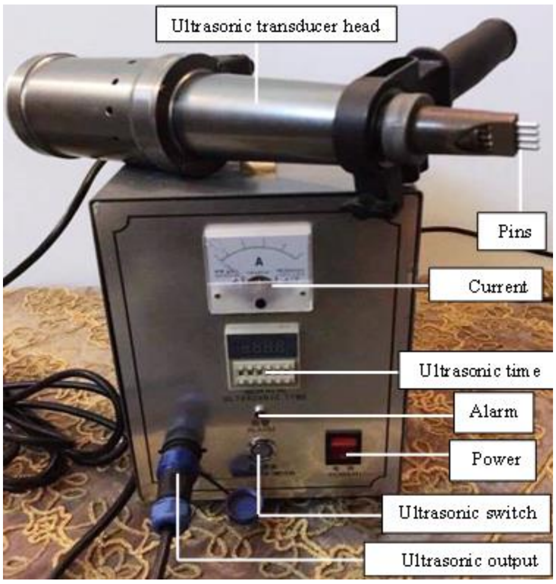

Figure 4. Ultrasonic impact peening device


Before


After

Figure 5. Fatigue specimens before and after UIP device

5. Experimental Results and Discussion

5.1 Constant Amplitude Fatigue Test Results

All the series of fatigue tests as mentioned below are performed at (R= -1) and room temperature (RT=25°C) to get the S-N curves for each condition of tests. The first series of constant amplitude fatigue tests was performed for 24 specimens (dry fatigue) used eight stress levels (80,100,120,140,160,180,200 and 220 MPa) and 15 specimens for (corrosion-fatigue) used five stress levels (80,120,160,200 and 240 MPa), when these specimens were submerged in saline solution of 3.5% NaCl for 77 days. The second series of tests was done for one line of ultrasonic peening using 24 specimens (dry fatigue) and 15 specimens (corrosion-fatigue). This series used the same conditions and stress levels of the first series. The results of these two series are presented in table (3) including the specimens number, applied stresses (MPa), the number of cycles to failure of the specimens (N_f) obtained from the test and their average (N_f av.).

Table 3. Results of constant fatigue test for four conditions with and without UIP

Specimen No.	Applied stress (MPa)	N_f Cycles	N_f av.
		Dry fatigue condition	
1,2,3	220	18000,22600,25000	21867
4,5,6	200	40000,45000,52000	45666
7,8,9	180	65000,77000,88000	74667
10,11,12	160	84000,92000,107000	94333
13,14,15	140	239000,244000,281000	254666
16,17,18	120	298000,307000,313000	306000
19,20,21	100	510800, 525600,534000	523467
22,23,24	80	810600,902000,929000	880533
		Corrosion-fatigue condition for 77 days	
25,26,27	240	6800,8000,7600	7467
28,29,30	200	36500,33000,40000	36500
31,32,33	160	70600,82000,76600	76400
34,35,36	120	206000,218000,212800	212266
37,38,39	80	600300,686000,643200	643167
		Dry fatigue with prior one line UIP	
40,41,42	220	31600,28000,21600	27067
43,44,45	200	56000,60800,66000	60933
46,47,48	180	72000,81000,96000	83000
49,50,51	160	88000,94000,104000	95333
52,53,54	140	254800,270900,282000	269233
55,56,57	120	394000,417000,428600	413200
58,59,60	100	729000,668000,820000	739000
61,62,63	80	994600,1080000,1182000	1085533
		Corrosion-fatigue condition for 77 days with prior one line UIP	
64,65,66	240	7800,10600,9800	9400
67,68,69	200	42600,48800,46000	45800
70,71,72	160	85600,78000,82000	81867
73,74,75	120	244000,235000,238800	239267
76,77,78	80	727600,752000,739200	739600

Basquin law used to express the relationship between the fatigue strength and fatigue life of the metal. This law can be expressed by the following equation [12].

$$\sigma_f = A\, N_f^{\,\alpha} \qquad (1)$$

Where: (σ_f) is the cyclic stress amplitude at failure, (N_f) is the number of cycles to failure and (A), (α) are material constants which are the fitting parameters. From the results of table (3), it is shown that the fatigue life of material used is critical to the corrosive environments. In addition, the material had the longest fatigue life in air but the lowest in salt water. However, as the applied stress increases, the corrosive environments become less effective on the fatigue life of the specimens. When the number of cycles increase, the corrosive environment become more effective on the fatigue strength. The above data are plotted according to Basquin equation in figure (6) which shows the behavior of fatigue life.

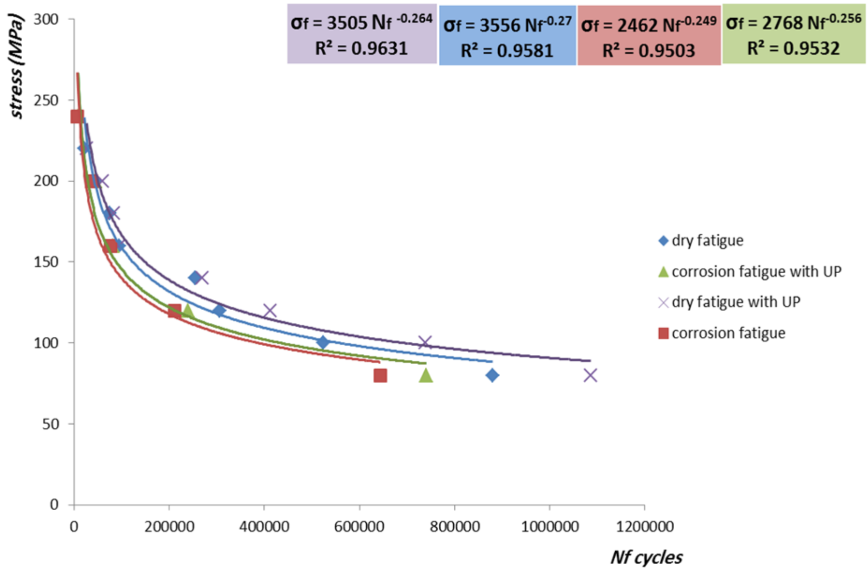

Figure 6. Experimental S-N curves of constant fatigue test for four conditions

Figure (6) shows the S-N curves for four conditions included dry and pre-corroded fatigue specimens for 77 days with and without one line ultrasonic peening. As shown in the figure (6) the behavior of fatigue life of pre-corroded specimens without ultrasonic peening reduced down and of pre-corroded specimens with prior ultrasonic peening decreased slightly as compared with specimens tested in dry condition.

Table (4) presented that the fatigue strength of pre-corroded specimens for 77 days in salt solution was (44 MPa) showing (4.5%) decreased and that of pre-corroded specimens of 77 days with prior one line of UP was (45 MPa) showing (2.2%) decreased as compared with the fatigue strength of dry specimens which was (46 MPa). an approximately (60%) decrease in fatigue strength of 7075-T6 Al-alloy was determined by **Genel** [13] when he used the same conditions of the present work, but the corrosive time was 3 years.

Table 4. Fatigue endurance limit at 10^7 cycles and reduction factor

Condition	Basquin equation	Endurance limit at 10^7 cycles	Reduction factor
Dry fatigue with UIP	$\sigma_f = 3505\ N_f^{-0.264}$	50 MPa	—
Dry fatigue	$\sigma_f = 3556\ N_f^{-0.27}$	46 MPa	
Corrosion fatigue without UIP	$\sigma_f = 2462 N_f^{-0.249}$	44 MPa	4.5%
Corrosion fatigue with UIP	$\sigma_f = 2768\ N_f^{-0.256}$	45 MPa	2.2%

This conclusion is agreed well with what **Alalkawi et al.** [14] concluded. They studied the effect of three type of ultrasonic peening i.e. one line, two lines and three lines surface modification on the mechanical and fatigue properties of (2017-T3 Al-alloy). The experimental results exhibited that the best type of ultrasonic peening was the one line, which gave an improvement about 61% for 1UP, 53% for 2UP and 47% for 3UP as compared to endurance fatigue limit of untreated specimens.

5.2 Cumulative Fatigue Test Results

In this work the variable or cumulative fatigue loading tests are done under two different loading with round specimens. The applied load was 180 MPa for 10^4 cycles and then converts to 100 MPa for the same number of cycles. This procedure was repeated until the failure of the specimen occurred. The results of a cumulative fatigue for dry fatigue and corrosion fatigue for 77 days are illustrated in table (5) & (6).

Table 5. Cumulative fatigue results for dry condition

Specimen No.	Loading sequence (MPa)	N_f cycles	N_f av.
79,80,81	L-H 100-180	107000,122800,135600	121800
82,83,84	H-L 180-100	87600,72800,90100	83500

From the results of table (5) noticed that the value of (Nf av.) for loading sequence (L-H) (100-180) is higher than that for loading sequence (H-L) (180-100), this is agreed well with what happen in real service, because the natural behavior of aluminum is known to be last longer life in (L-H) loading sequence than (H-L) sequence.

Table 6. Cumulative fatigue results for 77 days corrosion condition

Specimen No.	Loading sequence (MPa)	N_f cycles	N_f av.
85,86,87	L-H 100-180	92300,84500,100700	92500
88,89,90	H-L 180-100	64800,70000,82000	72267

The shortened in fatigue life of table (6) due to the effect of electrochemical reaction in corrosive chloride environment. Zupanc and Grum [15] tested 7075-T651 specimens of aluminum alloy in corrosive environment of 5%NaCl and concluded that the fatigue resistance of corroded samples drastically decreased in comparison with un corroded metal because material pitting corrosion. A decrease of fatigue life by a factor of 10% was observed with individual fatigue stresses. Table (7) presented the interaction results of cumulative corrosion fatigue for 77 days with prior one line ultrasonic peening.

Table 7. Interaction results of cumulative corrosion fatigue with prior one line UIP

Specimen No.	Loading sequence (MPa)	N_f cycles	N_f av.
91,92,93	L-H 100-180	121000,132000,142000	131667
94,95,96	H-L 180-100	90600,102000,89600	94067

The experimental data of table (7) shows that the ultrasonic peening technique improved the cumulative corrosion-fatigue life and strength of 6061-T6 Al alloy.

5.3 Cumulative Fatigue Life Improvement Factor (CFLIF %)

The percentage of cumulative fatigue life improvement factor can be calculated by the following equation (2) [16]:

$$\text{CFLIF\%} = \left(\frac{\log \text{Nf (corr.+UP.)} - \log \text{Nf corr.}}{\log \text{Nf (corr.+UP.)}}\right) \times 100 \qquad (2)$$

Where:
Nf (corr.+UP) = No. of cycles to failure at the interaction of corrosion fatigue with ultrasonic peening (UP) for two stress levels.
Nf (corr.) = No. of cycles to failure at corrosion environment for two stress levels.
Table (8) shows the results of CFLIF%.

Table 8. Results of CFLIF% under the interaction of corrosion fatigue for 77 days with prior one line UIP

process	Loading sequences	CFLIF%
Ultrasonic peening	L-H (100-180)	3%
	H-L (180-100)	2.25%

Statnikov et al [17] concluded that residual compressive stress, grain refinement, hardness, corrosion resistance and wear resistance had all been enhanced after UPT. Fatigue life can be increased and in some cases it can be improved by up to 10 times more than in non-UP treated surfaces.

5.4 Linear Damage Rule (LDR)

The Palmgren-Miner theory or (LDR) was the oldest theory proposed for fatigue life predictions due to its simplicity seems to be the more widely used. This theory is written in a mathematical formula as:

$$D = \left[\frac{n_1}{N_{f1}} + \frac{n_2}{N_{f2}}\right] R = 1 \qquad (3)$$

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)
R: is the number of programs

It is most important to note that the (LDR) does not taken into account the various influences on fatigue life, such as the corrosive environment, temperature, and the effect of loading sequences [12].

5.5 The Proposed Non-Linear Model

The proposed model is based on the experimental damage obtained from constant stress amplitude and cumulative testing, S-N curves. This model can be expressed mathematically in the form as following:

For low-high test program

$$D = R^{\propto[\frac{\sigma L}{\sigma H}]} \tag{4}$$

$$R = \frac{N_{f(L-H)}}{\sum n} \tag{5}$$

For high-low test program

$$D = R^{\propto[\frac{\sigma H}{\sigma L}]} \tag{6}$$

$$R = \frac{N_{f(H-L)}}{\sum n} \tag{7}$$

Where:
D: is the fatigue damage
R: is the number of programs
$\propto$: is the slope of S-N curve
n: number of cycles for one program

5.7 Application of Proposed Model and Miner Rule to the Experimental Data

The proposed model and Miner rule (LDR) can be applied to the test results of dry condition, corrosion media for 77 days in salt water and ultrasonic peening-corrosion interaction. The results are tabulated in tables (9), (10) and (11).

Table (9) cumulative fatigue results for dry condition according to Miner and proposed model

Specimen No.	Loading sequence (MPa)	N_f av.	N_f cycles	
			Miner rule (LDR)	Proposed model
69,70,71	L-H (100-180)	121800	113041	86210
72,73,74	H-L (180-100)	83500	113041	56441

Table (10) cumulative fatigue results for 77 days corrosion condition according to Miner and proposed model

Specimen No.	Loading sequence (MPa)	N_f av.	N_f cycles	
			Miner rule (LDR)	Proposed model
75,76,77	L-H (100-180)	92500	66708	53960
78,79,80	H-L (180-100)	72267	66708	37140

Table (11) interaction results for 77 days cumulative corrosion-fatigue with prior one line UIP

Specimen No.	Loading sequence (MPa)	N_f av.	N_f cycles	
			Miner rule	Proposed model
81,82,83	L-H (100-180)	131667	73789	60157
84,85,86	H-L (180-100)	94067	73789	38533

From the above tables (9), (10) and (11), results of cumulative fatigue lives for Miner rule and proposed model which is based on the experimental results. It is indicated that the Miner theory does not shown conservative and accurate prediction for some fatigue specimens life especially in loading sequences (H-L) under dry condition due to their inability to take into consideration the effect of surface treatment and environment like, ultrasonic peening and corrosion, and also the lack of taking account the influence of loading sequences. Miner rule was conservative for other specimens in evaluating the fatigue life under corrosive environment. In state of real service the loading sequence (H-L) consumes a high percent of material life and is proven in the experimental data so the proposed model presents a very safe life in this program.

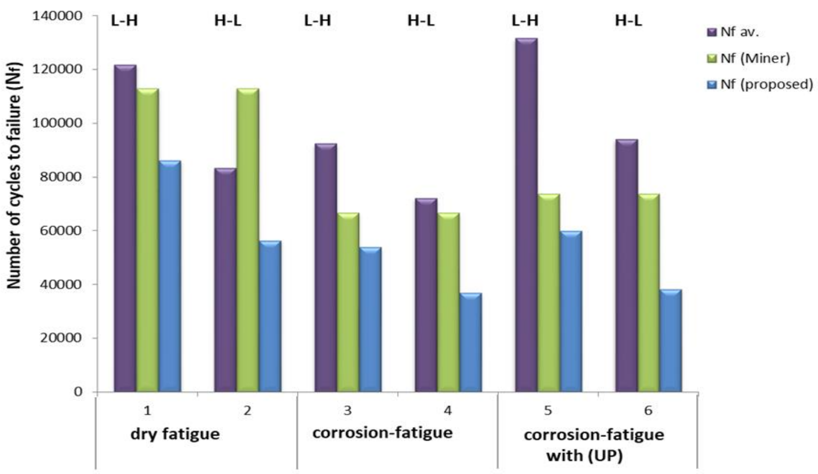

Figure 6. Comparison between experimental, Miner and proposed model lives of aluminum alloy (6061-T6)

Figure (6) presents the comparison between the proposed model and Miner rule relied on experimental results. It is obvious that the proposed model gave much better reliable predications compared with the experimental data and Miner rule. This safe presented model comes from the following reasons:

1. The proposed model designed to be non-linear damage behavior while the Miner rule supposed damage is linear.
2. It takes into account the effect of corrosion, surface treatment and load sequences for calculation the cumulative fatigue life, while Miner rule neglected these effects.

6. Conclusions

From the present work, the effect of corrosive environment and ultrasonic peening on the fatigue life of aluminum alloy (6061-T6) are investigated under stress ratio (R= -1). The following conclusions can be derived:

1. Fatigue strength of pre-corroded specimens with prior ultrasonic peening decreased slightly by a factor of approximately 2%.
2. The improvement percentage of fatigue strength by ultrasonic peening was approximately (9) for dry condition while it was (2) for 77 days corrosion in 3.5% NaCl solution.
3. Ultrasonic peening treatment was a useful method for structures working under corrosion condition in which it improves the cumulative corrosion-fatigue life by a factor of about (2 — 3%) for high-low and low-high loading sequences respectively.

7. References

1. N.I.I. Mansor, S. Abdullah, A.K. Ariffin, J. Syarif (2014). *"A review of the fatigue failure mechanism of metallic materials under a corroded environment"* Engineering Failure Analysis, Vol. 42, PP. 353-365.
2. Matthew Weber, Paul D. Eason, Hüseyin Özdeş, Murat Tiryakioğlu (2017). *"The effect of surface corrosion damage on the fatigue life of 6061-T6 aluminum alloy extrusions"* Materials Science & Engineering A, Vol. 690, PP. 427–432.
3. Uros Trdan, Janez Grum (2014). *"SEM/EDS characterization of laser shock peening effect on localized corrosion of Al alloy in a near natural chloride environment"*, Corrosion Science.
4. S.P. Chenakin, V.S. Filatova, I.N. Makeeva, M.A. Vasylyev (2017). *"Ultrasonic impact treatment of CoCrMo alloy: Surface composition and properties"* Applied Surface Science, Vol. 408, PP. 11-20.
5. Y. Kudryavtsev and J. Kleiman (2005). *"Application of Ultrasonic Peening for Fatigue Life Improvement of Automotive Welded Wheels"* International Institute of Welding.
6. M. Daavari, S.A. Sadough Vanini (2015). *"Corrosion fatigue enhancement of welded steel pipes by ultrasonic impact treatment*" Materials Letters, Vol. 139, PP. 462-466.
7. Ping Hua, Qingchun Menga, Weiping Hub, Fei Shenc, Zhixin Zhan, Linlin Sun (2016). *"A continuum damage mechanics approach coupled with an improved pit*

evolution model for the corrosion fatigue of aluminum alloy" Corrosion Science, Vol. 131, PP. 78-90.

8. R. Ramos, N. Ferreira, J.A.M. Ferreira, C. Capela, A.C. Batista (2016). *"Improvement in fatigue life of Al 7475-T7351 alloy specimens by applying ultrasonic and microshot peening"* International Journal of Fatigue, Vol. 92 Part 1, PP. 87-95.
9. J.R. Davis (2001). *"Aluminum and aluminum alloy"* p351-416, ASM International, PP. 351- 416.
10. B 211-03: Designation (2009). *"Standard Specification for Aluminum and Aluminum-Alloy Bar, Rod and Wire"* ASTM International.
11. www.hzhccs.com. (2014). Device manual.
12. H. J. Alkawi, A. H. Majeed, S. Fahad (2012). *"Estimation of fatigue-corrosion damage and life under variable loading based on modified corrosion fatigue model (MCFM)"* J. Eng. & Dev., Vol. 16, No.4.
13. Genel K. (2007). *"The effect of pitting oN the bending fatigue performance of high-strength aluminum alloy"* Scripta Material, Vol. 57, PP. 297-300.
14. Alalkawi H.J.M, Elkhawad Ali Elfaki, AliYousuf Khenyab (2016). *"Analysis of ultrasonic peening mechanical properties and fatigue damage of 2017A-T3 aluminum alloy"* international journal of energy and environment.
15. U. Zupanca, J. Grum *"Effect of pitting corrosion on fatigue performance of shot-peened aluminium alloy 7075-T651"* Journal of Materials Processing Technology, Vol. 210, PP. 1197–1202, (2010).
16. Alalkawi H. J. M., A. H. Maajeed Z. A. Betti (2015). *"Interaction of corrosion-cumulative fatigue and shot peening of 1100-H12 Aluminum alloy"* Al-Khwarizmi Eng. J., Vol. 11, No. 1, PP. 65- 72.
17. Statnikov E., Korolkov O.V., Vityazev V. N. (2006). *"Physics and mechanism of ultrasonic impact treatment"*, Elsevier 6 June.