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Cumulative Fatigue damage of AA7075-T6 under Shot Peening and Ultrasonic Surface Treatments

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ABSTRACT

One of the important aspects of mechanical design is improving fatigue life.; In this work, the effect of Ultrasonic impact treatment (UIP) and shot peening (SP)on constant cumulative fatigue life and fatigue strength of AA7075-T6 were studied; The sample group was machined and primed, and some specimens were treated using ultrasonic impact therapy (UIT) with one line of peening. Fatigue experiments were conducted under constant and variable amplitude (R=-1) at ambient temperature to determine the fatigue life of the S-N curve and fatigue strength during treatment 3.46% and 8.57% at 107 cycles for (UIT) and (SP). Cumulative fatigue damage testing was carried out for two steps loading it is observed that the fatigue life for SP and UIP treated specimens was improved compared to the unpeeled results. The fatigue endurance limit was enhanced by 35% for UIT and 54% for SP. The fatigue life for both treatments was much improved compared to as-received metal. These results also show a strong tendency of increasing fatigue strength after application of (UIT) and (SP) with an increase in mechanical properties of the material used.

1. Introduction

Fatigue is described as a crack or damage of structure or component subjected to dynamic load. Damage can be defined as localized plastic deformation leading to crack development. practically, fatigue failure is taking about 90% of mechanical failure [1] Fatigue failure happens when a material subject to fluctuating stresses. The failure stress occurs less than the yield stress, which influences the crack surface to reach a certain length and become a catastrophic failure [2]. The fatigue hardness of alloy improves during surface treatments by introducing compressive residual stress (CRS) on the surface which guidance to produce an obstacle to crack production. Surface treatments such as shot peening (SP) and (UIT) are one of the better ways to enhance the fatigue strength on metal. Conventional (SP)is used to improve the mechanical properties and fatigue life by making residual compressive stress on the surface of the material. A surface material with SP will be inclined and changed residual stresses, hardness, texture, dislocation density, and crack. Controlling the process of shot peening was reviewed [3], While ultrasonic peening is used to enhance properties but dissimilar the SP in this process the shot is put into a random whirling motion inside a component-specific peening to action on the component. The effect of the peening action really depends on the pattern of the sine wave relative to the component. The principal feature

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of such a process could give a smooth surface compared with SP due to using a polished ball. Furthermore, it can give much energy in a short period due to a high frequency [4].

Kenosi et al [5] Investigated surface roughness, microstructure stress, and microhardness using on the shot peening and Laser shot peening AA7075-T651 stipulated aeronautical aluminum alloy. It was found that the SP and the LSP processes make compressive residual stresses (CRS) in AA7075-T651. (CRS) were found to be deeper in the LSP compare with those make through SP. The surface roughness was higher in (SP) specimens compared with the (LSP) treated specimen. No significant improvements have been made to the micro - structural of the peened specimen in both circumstances. The SP resulted in obdurate regions within the AA7075-T651 surface layer; with LSP produce higher microhardness in comparison to SP. Ferreira et al. [6] Effect on fatigue life of the (UIP) and (SP) AA7475 models. The aim of their examination is to modify the surface by means of a variety of three peening measures: miniature shot peening (MSP) with spots of two unmistakable sizes (MSP) and (UP). Ultrasonic peening was advanced even more sensibly with surface finishing and less unpleasant than with scaled-down (SP). Each of the three-surface peening was equipped for cutting edge fatigue life. In the case of fatigue testing at (R=-1), higher fatigue lifespan was acquired due to (UIP) and (SP). Fatigue strength increased by 35 per cent during the metals investigation in examination with base metal these treatments. Allawi et al [7] The findings of the study showed that the fatigue life analysis of the eroded specimens with and without ultrasonic peening exhibited a substantial lessening in life associated with the presence of corrosion insufficiency prior to cyclic loading. Expansion of fatigue life and fatigue life of specimens for ultrasonic peening was 8.69 percent for dry fatigue life and 2.3 percent for corrosion fatigue communication. The impact of cumulative corrosion fatigue tests has also shown that lifespan of the eroded specimens as a result of the UIT has enhanced to around (3 per cent-2.25 per cent) for low-and high-low sequences. The present study focuses on the effect of (UIT) and (SP) techniques on cumulative fatigue damage and on improving the mechanical properties and fatigue behavior of the surface treatment compound AA 7075-T6 instead of only one conventional surface treatment, resulting in a duplicate improvement of the surface treatment.

Cumulative fatigue damage (CFD) is an old aspect, but not yet determined problem [8]. Miner first expressed the concept in an accurate form as [9]

$$D=\sum \frac{n_i}{N_{f_i}} = 1 \qquad (1)$$

where D is the cumulative fatigue damage and ni, Nfi is the applied cycles and the number of cycles to failure under i-th constant S-N curve stress level respectively.

$$\sigma_f = a\,N_f^{\,b} \qquad (2)$$

Basquin law applied to expression the relation between fatigue life of the metal and the fatigue strength and can be express by equation [10]. (σf) is the amplitude of cyclic stress at failure; (Nf) is the number of failure cycles, where a, b. The fitting parameters are constants of the material.

$$D= [\frac{n_1}{N_{F_1}} + \frac{n_2}{N_{F_2}}]R=1 \qquad (3)$$

The more general implementation seems to be the most popular Linear Damage Rule (LDR) theory proposed for fatigue existence predictions because of its simplicity. The exact formula is used to formulate this theory as (3). The (LDR) takes note of the variations, such as temperature, in fatigue life. The product of sequence loading [11]. For the present work: n = 5000 cycles.

2. Experimental work

This part is introducing the materials which are utilized in this examination, its chemical composition, the equipment and the standard samples geometry.

2.1 Materials used

Aluminium alloys are commonly used for structural applications in the aerospace, automobile, and construction industries for their high specification reliability, strong corrosion resistance, and low cost. The material used in this work is aluminium. Of all working aluminum alloys, the aluminum alloy 7075 has the highest strength. However, due to age-hardening alloys, other corrosion formalities such as pitting corrosion, stress corrosion cracking, intergranular corrosion are susceptible, particularly in the chloride surrounding region. [12-14].

2.2 Chemical analysis and mechanical properties

The chemical study of Al 7075-T6 alloys was conducted at the (Iraq Geological Survey, Ministry of Industry and Mineral, Baghdad, Iraq).

2.3 Tensile test

Tensile tests that were conducted at (RT) to determine the experimental mechanical properties listed in the Table (4) were measured using (WDW- 50) tensile test apparatus with a capability of 200KN. The shape and dimensions of the tensile specimen are shown in the Figure (1). The tensile specimen was chosen according to (ASTM E8/E8M).

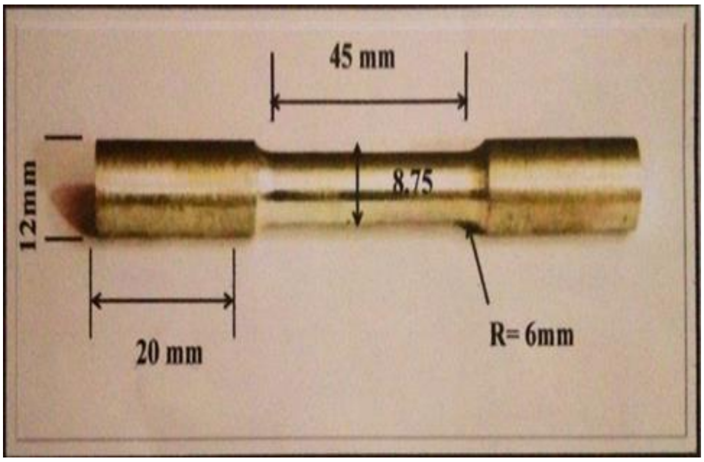

Figure 1. Tensile Test specimen with Dimensions in (mm), Based on (ASTM(E8/E8M) [15]

2.4 Fatigue Test

The sample is made using a programmable CNC lathing machine. According to the basic specification of the cylinder fatigue study (DIN 50113). The fatigue test sample and its configuration are shown in Figure (2).

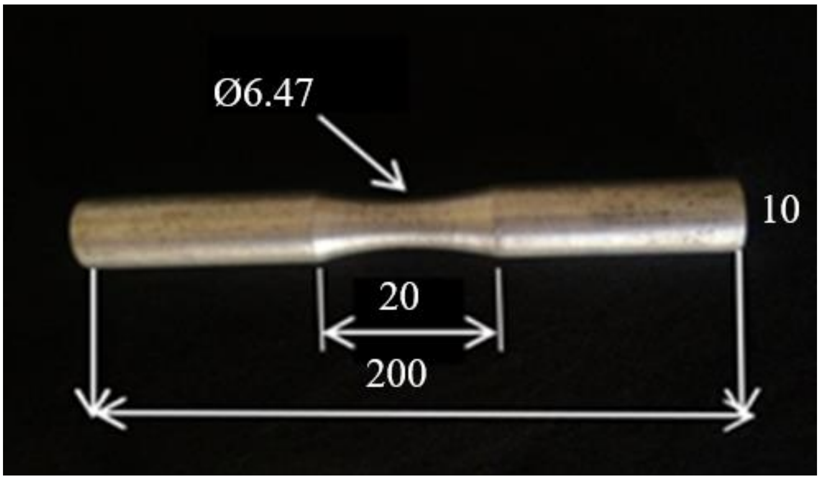

Figure 2. fatigue test specimen with Dimensions in (mm)[15]

By using the method of fatigue testing system (PUNN rotating bending), the fatigue test was done (3) shows that. Under constant and variable amplitude fatigue loading, both experiments were completed. Fatigue tests were conducted by all the specimens in the department of electromechanical engineering laboratories, University of Technology. At stress ratio R=-1 (minimum stress to maximum stress in the periodic cycle) and room temperature, the tests were performed (RT).

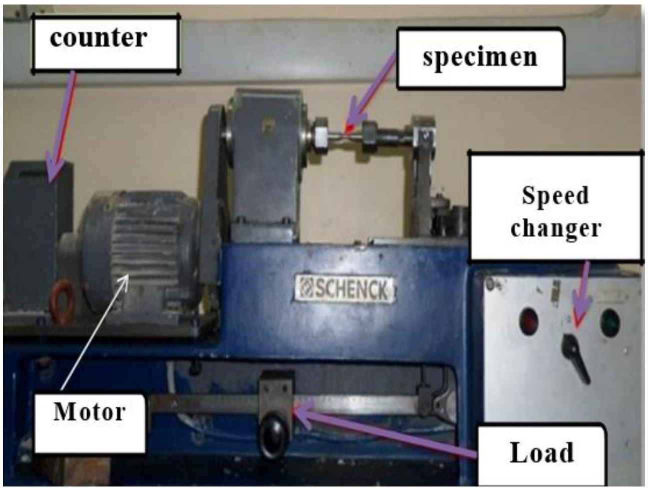

Figure 3. Fatigue rotating bending machine

2.5 Ultrasonic Impact Peening (UIP) device

(UIT) the machine is used to enhance the surface properties. The surface of the fatigue specimen was subjected to 20 thousand times per second the Figure (4) presents UIP device. One of the very promised methods in the cold treatment of particularly welded structures, Metallic materials are the ultrasonic peening process that during the pay contact surface inserts the energy of ultrasound into metal. By converting the ringing, the harmonic pulse of an acoustically tuned body, to mechanical impulses on a rock, this energy is used in the metal. The major technical parameters of UIP device are offered below [16]: The Main parameters of (UIT) device can be tabulated in Table (1).

Table1. The main technical parameters of Ultrasonic impact peening

Type of device	Portable
Gun weight	4Kg
Output Frequency	20KHZ
Output power	500W
The time for one line peening	15sec

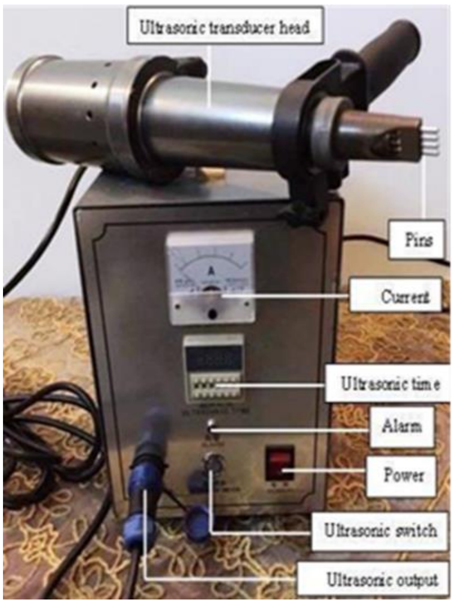

Figure 4. Ultrasonic impact peening

2.6 Shot peening

The peening was prepared in a special apparatus (Shot Tumblast control panel model STBOB) shows as illustrates Figure (5) using a steel ball with diameter 2.25mm and velocity 40 mm/min and pressure 12 bar to create plastic deformation on the external surface. the time for one line peening is 10 min according to Mohamed et al [17]. The Main parameters of (SP) device can be tabulated in a Table (2).

Table 1. The main technical parameters of shot peening device

Pressure	12 bar
Speed	40 mm/min
Distance	150mm
Shot size	2.25mm
Goverage	100%
Pressure	12 bar

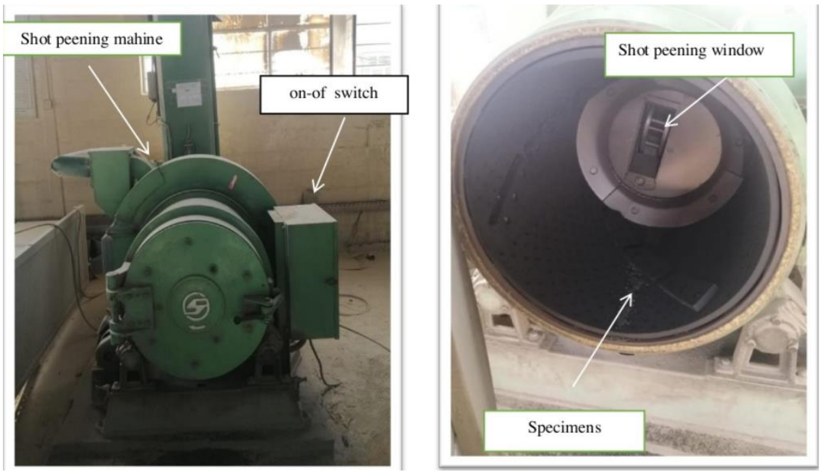

Figure 5. The shot peening device

3. Experimental results and discussion

3.1 Chemical and mechanical result

The results are compared with the US standard ASTM B-211[18], as seen in Table (3) below. The effects of the experimental mechanical properties are also related to the norm mentioned in the Table (4).

Table 3. Chemical composition of 7075-T6 Al alloy in wt%

Al	other	Ti	Zn	Cr	Mn	Mg	Cu	Fe	Si	AA7075-T6
Balance	0.09	0.032	5.61	0.19	0.12	2.2	1.87	0.3	0.28	EXPERMENTIAL
Balance	≤ 0.15	≤ 0.2	5.1 6.1	0.18 0.28	≤ 0.3	2.1 2.9	1.2 2.0	≤ 0.5	≤ 0.4	STANDARD [18]

Table 4. Mechanical properties of 7075-T6Al alloy

UTS (Mpa)	Ys (Mpa)	Ductility %	E (GPa)	HR	σ E.L (MPa)	Test
564	489	12	72	89	168 At 10^7 Cycles	EXPERIMENTED
572	503	11	69-73	87	159 At 10^8 cycles	STANDARD [18]

3.2 Constant amplitude fatigue test results

All the sequence of fatigue experiments as listed below was carried out at room temperature (RT=25 ° C) and (R= -1) to achieve the S-N curves for each test state. The current work is focused on an experimental program that included 54 fatigue samples. For 12 specimens (dry fatigue) using stress levels, fatigue tests at (constant amplitude) were performed (564,451,338, and 226 MPa) and 12specimens for (Ultrasonic impact peening) used the same stress and 12 specimens for (shot peening) used the same stress levels. The (SP) was done at 10 minutes and UIT done at 10-15sec (one line). The result of this series is listed in Table (5) keeping the number of specimens, the number of stresses applied (MPa), the number of failures cycles the specimens (Nf) have from the test and their mean number of failure cycles (Nf) from the test (Nf av).

Table 5. S-N curve results of Al 7075-T6 alloy with different surface treatments

Specimen No.	Applied stress (MPa)	N_f Cycles	N_f av.
Dry fatigue condition			
1,2,3	564	4000, 3800, 6700	4833
4,5,6	451	31600, 28700,41000	33766
7,8,9	338	107600,112500,121000	113700
10,11,12	226	410600,520800,531000	487466
Fatigue with prior one-line UIP			
13,14,15	564	8200,11500,9200	9633
16,17,18	451	46000,51800,64000	53933
19,20,21	338	210000,185000,195000	196666
22,23,24	226	612000,811000,644000	689000
Fatigue with prior 10-minute time SP			
25,26,27	564	12000,16000,20800	16266
28,29,30	451	76000,64800,70800	70533
31,32,33	338	298000,317000,307800	307600
34,35,36	226	882000,867000,1060000	936333

The above data are plotted according to Basquin equation in Figure (6) which shows the behavior of constant fatigue S-N Curve

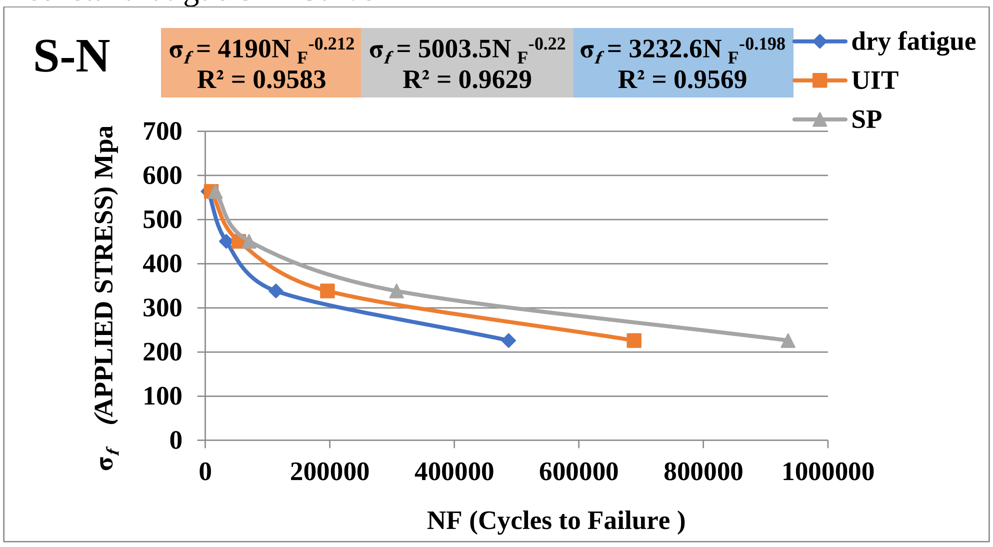

Figure 6. Experimental S-N curves of constant fatigue test for conditions

For three conditions, dry and weariness with and without one-line ultrasonic peening and shot peening, Figure (6) clarifies the S-N. The exhibition of fatigue life of examples without ultrasonic peening decreased as seen in Figure (6) and examples of earlier ultrasonic peening and shot peening decreased slightly as comparing and examples attempted in dry state. presents the outcomes for cases without and with treatment, by using the data in the Table (5).

The IF (Improvement factor for fatigue endurance limit) is calculated according to the equation below:

$$IF= \frac{N_F(\text{UIT OR SP}) - N\ Dry}{N_F(\text{UIT or SP})} * 100\% \quad (4)$$

This limit depends on the material used and shot peening process and Ultrasonic peening as shown in Table (6).

Table 6. Fatigue endurance limit at 10^7 cycles and Improvement factor (IF)

Condition	R^2	S-N curve equation	Endurance limit at 10^7 cycles (MPa)	Improvement Factor (IF)
Dry fatigue	0.96	$\sigma f = 3232\ Nf^{-0.198}$	132.9	-
UIT	0.96	$\sigma f = 4190\ Nf^{-0.212}$	137.5	3.46%
SP	0.96	$\sigma f = 5003\ Nf^{-0.22}$	144.3	8.57%

The result of this series has brought some comments in the operation of fatigue behavior of AA7075-T6 under constant loading shown in figure (6) the fatigue endurance limits of shot-peened specimens were increased by 8.57% and 3.46% for SP and UIP respectively. The improvement is due to compressive stresses generated on the surface of the sample. The effect of these surface treatments rises the SN curve level. The results are similar to that found by [19][20].

3.3 Cumulative fatigue test results

In this work the variable or cumulative fatigue loading tests were carried out under two different loading with round specimens. The applied load was 500MPa for 104 cycles and then converts to 300 MPa for the same number of cycles. This procedure was repeated until the failure of the specimen occurred. The influnce of a cumulative fatigue for dry fatigue and different surface treatment are illustrated in Tables (7), (8) and (9).

Table 7. Cumulative fatigue results for dry condition

Specimen No.	Loading sequence (MPa)	N_f cycles	N_f av.
37,38,39	L-H 300- 500	62600, 50800, 48000	53800
40,41,42	H-L 500- 300	23000, 34000, 38600	31867

From the after-effects of Table (6), the value of (Nf av.) for load series (L-H) (300-500) was shown to be higher than for load arrangement (H-L) (500-300), This is well agreed with what happens in actual assistance on the ground that aluminum's characteristic action is provided to sustain a longer life than (H-L) succession in (L-H) stacking classification.

Table 8. Cumulative fatigue results of UIP

Specimen No.	Loading sequence (MPa)	N_f cycles	N_f av.
43,44,45	L-H 300- 500	70600,55 000,6180 0	62466
46,47,48	H-L 500- 300	30200,40 600,3860 0	36466

It is clear that, the ultrasonic treatment of AA7075-T6 specimens enhanced the cumulative fatigue life in both cases for low-high and high-low fatigue tests. Table (9) presented the results of cumulative fatigue Shot peening.

Table 9. Cumulative fatigue results of SP

Specimen No.	Loading sequence (MPa)	N_f cycles	N_f av.
49,50,51	L-H 300-500	88100,90600,76000	84900
52,53,54	H-L 500-300	40600,36000,46500	41033

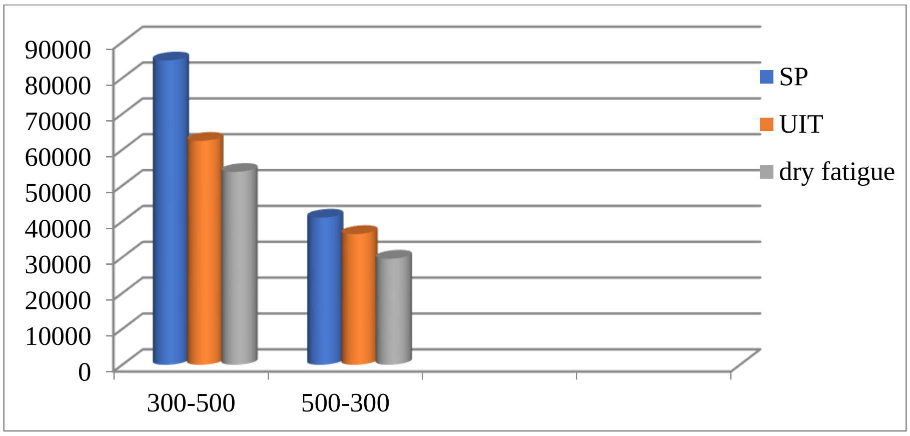

Figure 7. Effect UIT and SP on cumulative fatigue life

Shot peening technique improved the cumulative fatigue life and strength of 7075-T6 Al alloy. Figure (7) presents the comparison between the UIT and SP. It is obvious that the SP gave much better enhanced compared with UIT. The improvement in cumulative fatigue lives can be seen in Table (10).

Table 10. shows the improvement factor (IF) for cumulative fatigue live

Condition	Loading sequences (MPa)	Improvement factor (IF)
Dry Fatigue	300-500	-
	500-300	-
UIT	300-500	13.9%
	500-300	12.6%
SP	300-500	36.6%
	500-300	22.3%

The cumulative fatigue lives for low-high and high-low loading respectively were increased by 13.9 percent and 12.6 percent for UIT and the cumulative fatigue lives were increased by 36.6 percent and 22.3 percent for low-high and high-low loading respectively for SP. Statnikov et al [21Finally, after UT, residual compressive stress, corrosion tolerance, grain refinement, hardness, and wear resistance were all excellent. Fatigue life can be increased and can often be improved very well by up to many times more than in non-UP treated surfaces. The upgrade in fatigue strength and life by (UIT) is gotten essentially by lessening the tensile stresses and developing the compressive residual stresses at the metal surface.The (UIT) treatment supply good fatigue characteristics in compare with shot peening and hammer peening [22] The other reason is increasing the mechanical properties of specimens treated by (UIT).

3.4 Linear Damage Rule (LDR)

LDR is applicable to the dry state test results., fatigue with shot, and fatigue with ultrasonic peening. The results are tabulated in Tables 11 It is proposed that because of their capacity to comprehend about the effects of surface handling, the Miner theory does not demonstrate conservative and precise estimation for certain fatigue specimen's life basically in loading successions (H-L) under dry conditions. and climate due to Miner rule supposed damage occurs linearly but actually, the damage is a non-linear trend [23] and Miner rule neglected the effect of corrosion, surface treatment, and load sequences for calculation the cumulative fatigue life. The increase in fatigue lives Can be explained by the existence of compressive residual stresses. The results are similar to those found by [24]. This is related to the advantage result of UIT which is obtain principally by reliving Tensile residual stress and the production of residual compressive stresses on the material's surface layers. [25].

Table 11. Cumulative fatigue results for condition according to Miner

Condition	Loading sequence (MPa)	$N_{f\ av}$	Life improvement	N_{Miner}
Dry fatigue	L-H (300-500)	53800	-	323017
	H-L (500-300)	31867		323017
UIT	L-H (300-500)	62466	35%	41551
	H-L (500-300)	36466		41551
SP	L-H (300-500)	84900	54%	71067
	H-L (500-300)	41033		71067

4. Conclusion

1. The constant fatigue properties are considerably enhanced by (UIT) and (SP) techniques. The fatigue strength at 107 cycles is improved by 3.46% and 8.57% for UIT and SP respectively.
2. Cumulative fatigue life was increased by 13.9 percent and 12.6 percent for low-high and high-low loading by UIT, respectively, while 36.6 percent and 22.3 percent were increased for low-high and high-low loading by SP, respectively, and fatigue life was improved by 36 percent and 54 percent for UIT and SP.
3. The (UIT) and (SP) techniques are a suitable method for hardening the surface of metals due to the formation of a hard layer by increasing compressive residual stresses.
4. The Miner theory does not follow the conservative and detailed prediction of the life of certain fatigue specimens

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