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Analysis of ultrasonic peening mechanical properties and fatigue damage of 2017A-T3 Aluminum alloy

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Abstract
Mechanical surface treatment like laser peening (LP), shot peening (SP) and ultrasonic peening (UP) are used to enhance the mechanical and fatigue material properties. In the current work, ultrasonic peening (UP) technique has been selected used to surface treatment of 2017A-T3 Al-alloy so as to enhance the mechanical and fatigue properties of the these alloy. Mechanical properties and constant fatigue testes has been performed at room temperature (RT) and stress ratio R= -1. Three type of UP surface treatment were done, i-e one line (1UP), two lines (2UP) and three lines (3UP) at surface test specimens. The experimental analysis of results indicated that, all the above three types of UP improved the mechanical properties i-e σ_u and σ_y by 10,3%, 30.7% increase for 1UP, 9.4%, 29.6% for 2UP and 6.6%, 27% for 3UP respectively. But the best enhancement was obtained for the (1UP).Fatigue at constant amplitude tests has also done for the above three types and compared to the unpeened one. The results showed that the (1UP) is better for fatigue life improvement; it is 160% at load 200 MPa and 180% at load 175 MPa respectively.

Keywords: 2017A-T3 Al-alloy; Mechanical properties; Constant and variable fatigue tests; Ultrasonic peening surface treatment.

1. Introduction
Ultrasonic peening (UP) is a recently progressed way for the betterment of fatigue strength of basically, welded joints and frames. By using this method, geometry of weld toe can be improved for reducing the stress concentration. In addition, elimination of tensile residual stresses, effort of compressive residual stresses and shutting of cracks, voids and bore are prospective, too. Tests evidenced that under yet treatment by ultrasonic peening, a better mechanical and corrosion resistance is carried out [1].
Ultrasonic peening treatment (UPT) has been used to enhance the fatigue realization of the flash welded joint. Microstructure, hardness, wears resistance, corrosion resistance. Effect show that fatigue strength, wear resistance and corrosion resistance of the welded joint were increased due to the surface strengthening creates by UPT [2].
When UPT time and surface harshness were maximum, the fatigue strength was coupled that of unpeened steel. This perhaps due to the formation of little tucks fault and the insertion of compressive

stress in the metal. However, long curing times valley to an important decrease in the fatigue strength to scales depress than those for uncured specimens [3].
The implications of sharp plastic deformation caused by ultrasonic impact treatment (UIT) and the electric discharge surface alloying (EDSA) with chromium on the stress-controlled fatigue restraint of low-carbon steel 20GL has been studied. The improved fatigue strength and extended life period of the low-carbon steel samples next UIT operations are accomplished to be connected with the subsurface crack nucleation [4].
The impact treatment of the alloy in air gave rise to an increase in the microhardness and improvement of tribological properties [5]. Thomas Rousseau et al [6] clarify the impact of the number of beads applied in the operation on the cure surface. Two INCONEL 690 specimens were peened with various bead amounts through a short time to gain coverage less than 100%. The surface dissection of the peened specimen presented that the number of beads highly influenced the number of shocks and their depth issue. The study exhibited that in the present peening arrangement, an increasing number of beads concentrated the compressive residual stress onto the peened surface. J. Marteau et al [7] are concentrated on the selection of a relation between face hardening and roughness produced by ultrasonic treatment. A way is used to AISI 316L sample peening using various processing cases. The real macroscopic hardness is specified and used to locate the roof roughness parameter and tabulate that affords the best relation between hardness and roughness. A relation is specified between roughness parameter and hardness employing a rise-pass filter with a cut-off of 100 μm. This power duty was identified at a tally that agrees to the size of the shot hit.
The current work aims to improve the mechanical and fatigue properties of 2017A-T3 AL- alloy using (UP). 2017A {a letter (A) with a number which indicates to the type of alloy} is the Aluminum Association (AA) designation for this material. In European standards, it will typically be given as EN AW-2017A [8].

2. Experimental work

2.1 Material

In this work 2017A-T3 {(Al Cu4 Mg Si (A)} was chosen because of their good strength properties. It is widely used in aviation fields and low specific gravity allow one to extensively use this alloy in various fields of industry, e.g. Civil engineering, aircraft industry and machine industry [9]. The 2017A-T3 aluminum alloy, submit of this study as the 2024 aluminum alloy in planes and space frame where constant tensile features, damage allowance and formability are desired. The 2024 have exchange the 2017 aluminum alloy dam to its high yield strength as the prevailing 2xxx series airplanes [10].
The chemical composition of this alloy (in wt%) is given in Table 1 compared with standard B211. The experimental chemical composition analysis were done in Company for Inspection and Engineering Rehabilitate(C.I.E.R),IRAQ. The tensile test specimen prepared according to (ASTM-B211), have been used tensile test rig at (University of Technology Baghdad), Figure 1 shows the tensile machine.
The performance of all fatigue specimen under dynamic loading was achieved below the rotating bending conditions (R=-1), employing a fatigue test machine (SCHENCK PUNN). The static tensile properties are giving in Table 2.

Table 1. Experimental and standard chemical composition of 2017A-T3 Al-alloy, wt%.

Elements	Zn	Ti	Cr	Fe	Cu	Mg	Mn	Si	Al
Standard (B211)	max. 0.25	max. 0.15	max. 0.1	max. 0.7	3.5-4.5	0.4-0.8	0.4-1	0.2-0.8	Balance
experimental	0.02	0.08	0.01	0.39	4.07	0.70	0.56	0.52	Balance

Table 2. Mechanical properties of 2017A-T3 alloy.

Property	σ_u (MPa)	σ_y (MPa)	E (GPa)	μ	EI%	Fatigue strength (MPa)	Shear modulus (GPa)	Shear Strangth (MPa)	(HB)
Standard	450	280	72	0.33	22	124	27	262	105
Exp.	435	270	73	0.33	21	127	26	265	107

The modulus of elasticity E was calculated from the slop of stress- strain curve by using the equation; $E = \frac{\Delta\sigma}{\Delta\epsilon}$ While the passions ratio was calculated from the equation; $\mu = \frac{\frac{\Delta D}{D}}{\frac{\Delta L}{L}}$ Where D is the diameter of tensile specimen.

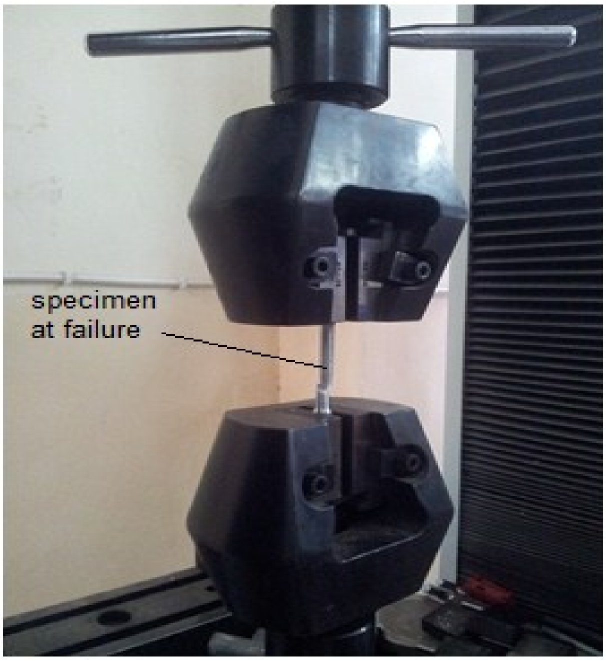

Figure 1. Tensile test rig.

2.2 Ultrasonic peening (UP) device

UP device offers the energy of ultrasound into metal during surface impulse touch. This energy is inserting into the metal by transform the ringing / harmonic oscillation of an acoustically toned frame to mechanical shot on a surface [11]. The UP device can be illustrated in Figure 2. The main technical parameters of UP device are given below.

Figure 2. Ultrasonic peening device type HC-S-1.

Technical parameters [11], - G.W:15kgs, Measurement: 0.4CBM

- Frequency: 20KHZ Voltage: 220v power: 500w, - Usage: metal welding aging treatment.

2.3 Fatigue specimen

The fatigue specimen geometry is exhibit in Figure 3. The indicator section shown an hour shaped with minimum diameter of 6.47 mm, as specified in standard testing DIN 50113.

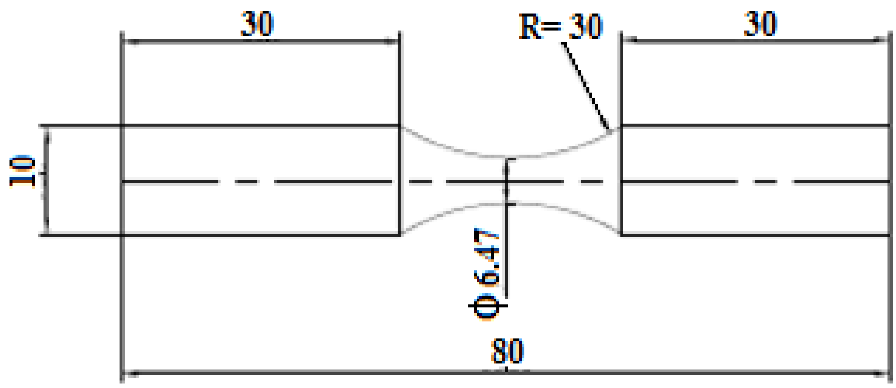

Figure 3. Geometry of fatigue specimen's dimensions in millimeter according to (DIN 50113) used standard specification.

Specimens were machined from as received aluminum alloy 2017A-T3 rods of one meter length and 12mm in diameter. The specimens are 80mm long, 10mm large diameter and 6.47mm min. diameter with a radius of curvature of 30mm. A particular attention is paying to the forming of the samples. Previous studies on the effect of manufacture on fatigue life of mineral materials observed that the industrialization operation straight influence their fatigue restraint [12, 13].

2.4 Fatigue test

The fatigue test is a cyclic bending loading procedure. The purpose of the test is to generate S-N data (stress vs. Number of cycles) for each specimen. Rotating bending fatigue machine test of type (SCHENCK PUNN) has been used to test specimens of (2017A-T3) under different stresses after laser treatment.

The samples were tested by a fatigue test machine which used to constant fatigue tests, as illustrated in Figure 4. The specimen was subjected to an applied load. All tests were done at R= -1. The cycle frequency was 106 Hz, the rotating speed used is (6350 cycle /min).

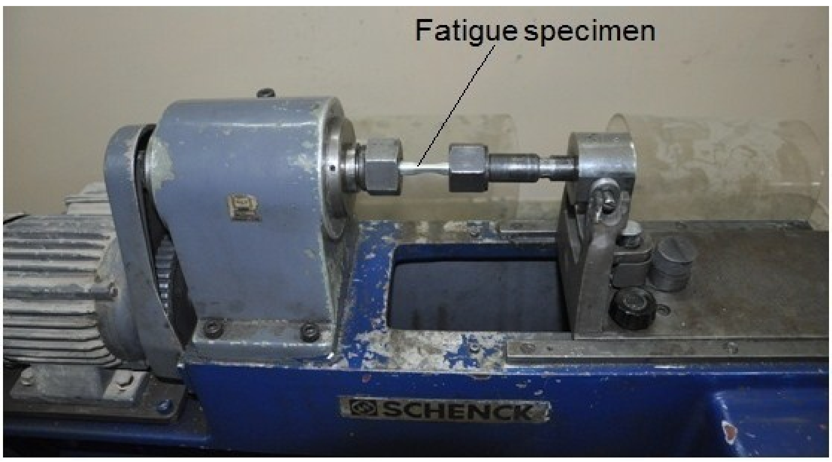

Figure 4. Fatigue testing machine type SCHENCK PUNN.

2.5 Fatigue test program

Fatigue analysis is normally based on the results obtained from S-N curve then the first step was established the constant continuous cycling S-N curve. (14) specimens were tested under room temperature control stress unpeened. The second step (14) specimens were tested to find the S-N curve with one line ultrasonic peening (1UP). The third step (14) specimens were tested to find the S-N curve with two line ultrasonic peening (2UP), The forth step (14) specimens were tested to find the S-N curve with three line ultrasonic peening (3UP), in order to do a comparison in life and strength.

3. Results and discussion

3.1 Mechanical properties under ultrasonic peening

To improve the mechanical properties a many of curative operation used one line peening (1UP), two lines peening (2UP) and three lines peening (3UP).

By this processes, geometry of surface can be modified for reducing the tensile residual stresses.

The average three reading measured ultimate and yield strength for the four conditions above are summarized in Table 3 and plotted in Figures 5, 6. Table 3 comprises the results before and after tensile test of the specimens which treated with and without ultrasonic peening.

Table 3. Tensile test results for three categories of ultrasonic peening.

Condition	One line UP1		Two line UP2		Three line UP3		unpeend
		increase		increase		increase	
σ_u (MPa)	480	10.3%	476	9.4%	466	6.6%	435
σ_y (MPa)	353	30.7%	350	29.6%	343	27%	270
E(Gpa)	72		72		71		73

Were E (GPa) is Young's modulus.

It is famed that the hardening of this alloy emerge from Al2Cu and Al2CuMg precipitation, as long as that the particles are delicately and violently divided [14]. The tensile stress-strain curves of the four conditions given in Figure 5.

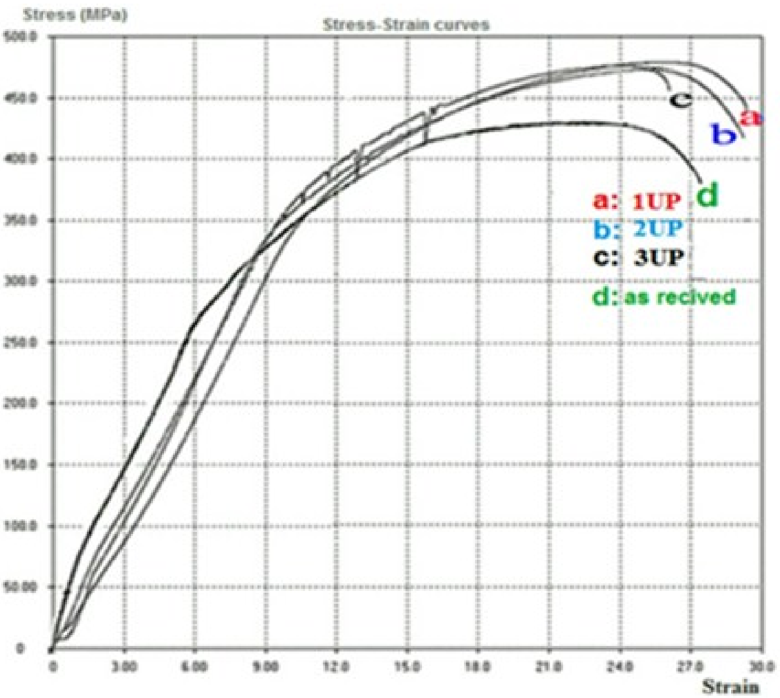

Figure 5. Three conditions of UP stress-strain curves compared with as received data.

As can be seen in Figure 5, and Figure 6, the lowest values of σ_u and σ_y are obtained for the as-received 2017A-T3.The maximum improvement for σ_u is found to be 10.3% and 30.7% σ_y increase for 1UP. The comparison displayed that the utmost and the yield strengths are always higher under UP (ultrasonic peening) than under as-received condition. More specifically, the utmost strength exhibit in the criterion is (435). By comparison under 1UP, 2UP and 3UP, the ultimate strength rate acquired in this study are

480,476 and 466 MPa respectively, indicating a 10.3%, 9.4% and 6.6% increase in ultimate strength. The mentioned test results visibly point that proportion rise of utmost strength decreases progressively as the number of treating line increases.

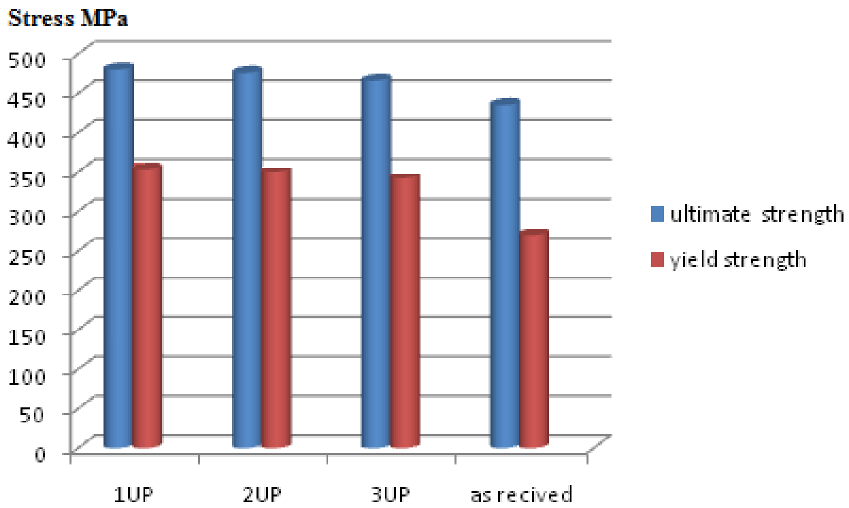

Figure 6. Comparison of four conditions tensile properties.

It is clear that the 1UP tensile properties are slightly better than the 2UP and 3UP. The reasons may be coming from the followings.

1. The roughness of 2UP is higher than the roughness of 1UP resulting in little reducing in the σ_u and σ_y.
2. The hardness of 2UP relatively less than 1UP which leads to slightly difference in the σ_u and σ_y of 2UP compared to the values of σ_u and σ_y 1UP. Table 4 gives the results of roughens of specimens treated by ultrasonic peening.

Table 4. The results of roughens & hardness under ultrasonic peening.

Properties	1UP	2UP	3UP	Unpeened
σ_u (MPa)	480	476	466	435
σ_y (MPa)	353	350	343	270
HB	118	116	110	107
Roughens (Ra) µm	0.82	1.27	1.97	0.64

3.2 S-N curves

The tests getting between $\sigma_f = 350$ MPa to $\sigma_f = 175$ MPa availability of data for the basic S-N curves are given in Table 5, and plotted in Figure 7.

Different methods have been used in order to improve the fatigue life and strength include optimization of geometric design, and surface treatments such as laser peening, shot peening and ultrasonic peening. Ultrasonic peening (UP) has long been widely employed as a low cost and simple method for raising the fatigue properties [15]. Effect of UP on fatigue design for a rod aluminum alloy of 2017A-T3 is given in Table 6.

All increase in UP lines resulted in an increase in fatigue strength. The fatigue limit stress was 77 MPa as received and became 124MPa at 1UP i-e 61% increase compared to the dry fatigue. This increase generates high compressive residual stress filed, but an increase in the UP lines does not necessarily increase the strength and fatigue life of aluminum alloy used. The best fatigue life prediction was occurred at 1UP and it was observed that in all cases of UP, the strength and fatigue life are greater than that of unpeened fatigue. Also it was observed that at low cycle fatigue the fatigue life predication is always less than that of as-received fatigue condition because the dominant factor which controls the crack initiation and propagation is the stress applied which is very high compared to high fatigue region. The present alloy usually used in low temperature environment. This environment improved the high cycle fatigue life as mentioned in Ref [16].

Table 5. Constant fatigue results for three conditions of ultrasonic treatment.

Applied Stress (MPa)	N_f as received average cycles	N_f 1UP average cycles	N_f 2UP average cycles	N_f 3UP average cycles
350	5200	5700	5200	5000
325	7560	7615	6888	6170
300	11260	12800	8900	7890
275	16300	45000	15000	13000
250	27900	50387	35140	26950
225	47100	111200	77500	59200
210	66500	186790	130300	99200
205	75017	223800	156200	118880
200	101700	285500	234000	162000
185	125078	484200	338013	256190
175	164950	520000	484000	372000

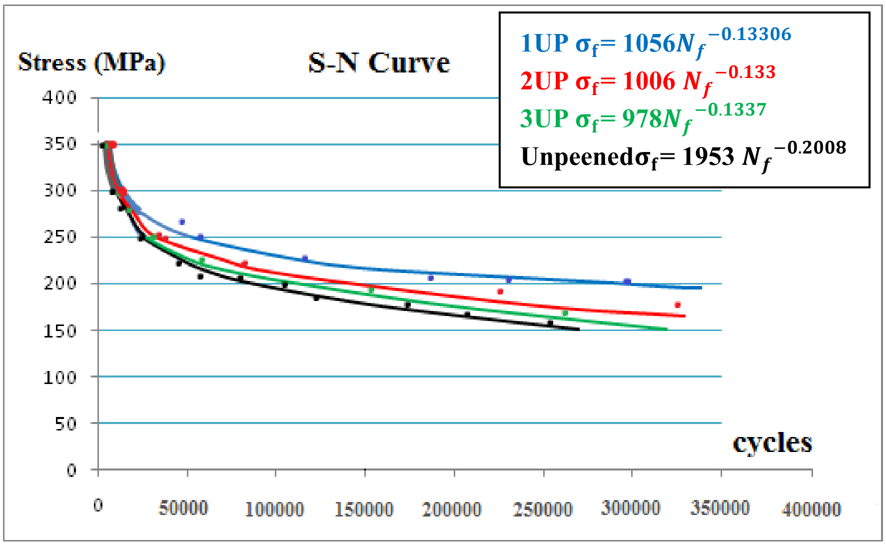

Figure 7. Four cases of fatigue test result with and without UP.

Table 6. UP treatment effect on fatigue design.

Condition	S-N curve equation	Endurance Fatigue limit at 107 (MPa) cycle	Increase In End. fatigue limit	Fatigue life predictions		
				Exp.σ_u 455 (MPa)	Exp.σ_y 270 (MPa)	σ_{EL} 77 (MPa)
As received	σ_f= 1953 $N_f^{-0.2008}$	77	------	1415	19033	107
1UP	σ_f = 1056$N_f^{-0.13306}$	124	61%	560	28257	351,444,334
2UP	σ_f = 1006 $N_f^{-0.133}$	118	53%	390	19724	245,976,913
3UP	σ_f = 978 $N_f^{-0.1337}$	113	47%	306	15156	180,169,038

4. Conclusions

Effect of three type ultrasonic peening i-e one line, two lines and three lines surface modification on mechanical and fatigue properties of 2017A-T3 aluminum alloy were investigated and compared. The main remarks arising from this work are listed below.

1. All ultrasonic peening showed an increase in mechanical and fatigue properties compared to unpeend results.
2. The best type of ultrasonic peening is the one line which gave an improvement by10.3% for σ_u and 30.7% for σ_y.

3. The increase percentage in mechanical properties reduce gradually as the number of peening line increase.
4. The fatigue strength was improved under ultrasonic peening i-e an increase of 61% for 1UP, 53% for 2UP and 47% for 3UP.
5. The experimental results observed that the best endurance fatigue limit is occurred for 1UP treatment i-e 61% improvement compared to the unpeened endurance fatigue limit.

References

[1] Amir Abdullah, Massoud Malaki "Strength enhancement of the welded structures by ultrasonic peening" Department of Mechanical Engineering, Amirkabir University of Technology, No. 424, Hafez Ave., P.O. Box: 15875-4413, Tehran, Iran, (2012).

[2] Yanjun Fana, Xiaohui Zhaoa",Research on fatigue behavior of the flash welded joint enhanced by ultrasonic peening treatment "Key Laboratory of Automobile Materials, School of Materials Science and Engineering, Jilin University, Changchun 130025, China, (2016).

[3] Yanyan Feng, Shengsun Hu, Dongpo Wang,," Formation of short crack and its effect on fatigue properties of ultrasonic peening treatment S355 steel" Tianjin Key Laboratory of Advanced Joining Technology, School of Materials Science and Engineering, Tianjin University, Tianjin 300072, People's Republicof China, (2015).

[4] B.N. Mordyuka, G.I. Prokopenkoa," Improved fatigue behavior of low-carbon steel 20GL by applying ultrasonic impact treatment combined with the electric discharge surface alloying" Kurdyumov Institute for Metal Physics, NAS of Ukraine, 36 Academician Vernadskyblvd., UA-03142, Kyiv, Ukraine, (2016).

[5] M.A. Vasylyev, S.P. Chenakin, "Ultrasonic impact treatment induced oxidation of Ti6Al4V alloy" Institute of Metal Physics, Nat. Acad. Sci. of Ukraine, Akad. Vernadsky Blvd. 36, 03680 Kiev, Ukraine, (2015).

[6] Thomas Rousseau, Thierry Hoc, Philippe Gilles, Cécile Nouguier-Lehon," Effect of bead quantity in ultrasonic shot peening: Surface analysis and numerical simulations" Université de Lyon, EcoleCentrale de Lyon, Laboratoire de Tribologie et Dynamique des Systèmes, Journal of Materials Processing Technology Volume 225, November 2015, Pages 413-420, (2015).

[7] J. Marteaua,, M. Bigerelle,"Relation between surface hardening and roughness induced by ultrasonic shot peening" Laboratoire Roberval, UMR 7334, Université de Technologie de Compiègne, Centre de Recherches de Royallieu, CS 60319, 60203 Compiègne Cedex, France, Tribology International Volume 83, March 2015, Pages 105-113, (2014).

[8] http://www.makeitfrom.com/material-properties/2017A-AlCu4MgSiA-3.1325- H14-Aluminum copyright, 2009, last update on 06.08. (2016).

[9] Kardas D., Kluger K., Lagoda T. ,Ogonowski P. "Fatigue life of 2017 aluminum alloy under proportional constant-amplitude bending with torsion in the energy approach" Material science vo.44,No.4 (2004).

[10] Kacem S. , Lakhdar T. , Georges C. "Numerical simulation of the anisotropic behavior of 2017 aluminum alloy"Computational Materials science 65, 48-57(2012).

[11] Hangzhou Create Ultrasonic Technology Co. Ltd "Ultrasonic Generator, Ultrasonic prestressing force impact treatment system" Operation Instruction. WW. hzcreate. en. alibaba. Com (2013).

[12] Meurling F, Melander A, Linder J, Larsson M,"The influence of mechanical and laser cutting on fatigue strength of carbon and stainless sheet metals" Sc and J Metall, 30, 309-319 (2001).

[13] Maronne E, Galtier A, Brisebard B, Velieaud P, Wassef M, Robert JL, "Cutting effect on fatigue steel sheet properties" Proceeding of the international conf. on mech. Design and production, Cairo (2004).

[14] A.May, L. Taleb, M.A.B elouchrani,"Analysis of the cyclic behavior and fatigue damage of extruded AA2017 aluminum alloy" Material science and engineering A571,123,136 (2013).

[15] M L Aggarwal, R A Khan& V P Agrawal."Influence of shot peening intensity on fatigue design reliability of 65Si7 spring steel "Indian Journal of Eng. and material sciences Vol. 12, pp, 515-521 (2005).

[16] Duaa A. K. Q, "Fatigue of aluminum alloy under low temperature using electrical control circuit" A thesis submitted to the electromechanical engineering Department University of Technology, (2016).