INTERNATIONAL JOURNAL OF
ENERGY AND ENVIRONMENT
ISSUE ON APPLIED MECHANICS RESEARCH
Volume 8, Issue 4, 2017 pp.299-306
Journal homepage: www.IJEE.IEEFoundation.org

The effect of wet shot peening on thermal fatigue properties of 2017-t4 aluminum alloy

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Received 2 Aug. 2016; Received in revised form 31 Aug. 2016; Accepted 31 Aug. 2016; Available online 1 July 2017

Abstract
In this work, constant and increasing temperature fatigue interaction effect on fatigue behavior of 2017-T4 aluminum alloy was investigated and the effect of wet shot peening on this alloy was also studied. Fatigue tests at constant load constant temperature and constant load increasing temperature were performed. The constant temperatures were RT (25℃) and 100℃. While the increasing temperatures were RT, 50℃, 100℃ and 150℃ for one test program. The constant fatigue properties of the increasing temperatures were observed the worst case compared to the others constant fatigue properties. Fatigue strength at 100℃ was reduced by 10.43 % compared to (RT) fatigue strength, while the wet shot peening (WSP) reduced the above reduction percentage from 10.43 % to 8.69 % i-e an improvement of about 2% was observed Shot peening constant fatigue constant temperature (100℃) revealed that an improvement in the fatigue properties was obtained i-e fatigue life by 1.94 % and fatigue strength by about 2 %.

Keywords: Thermal fatigue; Aluminum alloy; Shot peening; 2017-T4 Al alloy.

1. Introduction

Components are designed to operate in high-temperature environments with high thermal gradients and mechanical loads are subjected to cyclic strains which are generated both thermally and mechanically. The thermo-mechanical fatigue cycles are caused microstructural material damage to the components and in the end leading to fatigue crack nucleation and failure [1]. The shot peening operation is widely used for improve fatigue life of the components by produced a plastic deformation of the surface leading to the creation of both surface work hardening and high residual compressive stresses at or just below the surface layer [2]. The layer of compressive residual stress reduces the probability of premature failure of the metal components under conditions of cyclic loading and therefore improves the fatigue life and strength of the peened component [3]. Farhad et al. [4] studied fatigue behavior of aluminum alloy (2024 – T4) under room and elevated temperatures and observed that the fatigue strength of 2024 – T4 Aluminum alloy at elevated temperature is reduced by a factor 1.2 – 1.4 compared with dry fatigue strength. Hussain et al. [2] studied the effect of shot peening on the two aluminum alloys 5052 and 2024. Constant and cumulative fatigue tests were performed under this process for the above alloys. For 5052 aluminum alloy the cumulative fatigue life is reduced as shot peening time increase. While the cumulative fatigue life of 2024 Al alloy is improved when the shot peening time increases but above 10 min the life is decrease. Zainab [5] studied accumulation damage for 2024-T4 aluminum alloy. The tests were done at RT (25℃) and (200℃). A modified damage model was proposed to predict the fatigue life under elevated temperature which was taken the damage at different load into account. The proposed model results were compared with the experimental results and compared with fatigue damage model (Miners rule). The comparison showed that the proposed model gave reasonable factor of safety while Miner model sometimes presents a factor of safety close to unity. AL-alkawi et al. [6] investigated dry and wet shot peening at 10 min and studied the effect on fatigue behaviour of 7075-T6 aluminum alloy using tension-compression fatigue tests. The mechanical properties (σu and σy) were increased due to wet peening by (2.42%, 4.1% and 3.23%, 5.66%) respectively. The oil film gave an improvement in fatigue strength by 0.52% relative to dry fatigue. This improvement may be due to increasing the surface hardness in which raising the compressive residual stress at surface and subsurface of 7075-T6. Guo et al. [7] studied the behavior of Ti−6Al−4V alloy under the effect of wet shot peening with ceramic beads. A tensile−tensile fatigue test was performed. The results showed that the surface roughness after wet shot peening is lower than dry shot peening and the fatigue strength increases by 12.4% because of the wet shot peening process. The aim of present work is study the effect of wet shot peening on thermal fatigue properties of 2017 T4 aluminum alloy. In this study water is used instead of oil as moisturizer before shot peening process.

2. Experimental work

2.1 Material

The material studied in the current work was 2017-T4 aluminum alloy. This alloy was the first developed in the Al-Cu-Mg series, that used in chiefly for rivets in components for general engineering purposes, structural applications in transportation and construction, machine products, screw, and fittings. This alloy has general characteristics as (Age-hardenable wrought aluminum alloy with medium strength and ductility, good machinability, good formability, and fair resistance to atmospheric corrosion [8]. The physical and thermal properties of the 2017-T4 aluminum alloy are 2.80 g/cm^3 density, 513-641 ℃ melting point, thermal conductivity is 134 W/m.℃ at 25℃ with T4 Temper and thermal expansion of 23.6 x10^{-6} µm/m.C at 20-100℃ [8].

2.2 Chemical analysis

Chemical composition of tested material (2017-T4 aluminum alloy) was performed in the (State Company for Inspection and Engineering Rehabilitation in Iraq) (SCIER). The results are compared with American Standard Test Method (ASTM B-211), and listed in the Table 1.

Table 1. Chemical Composition of 2017-T4 aluminum alloy in wt %.

Material 2017 T4 AA	Chemical Composition							
	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Standard ASTM B-211[8]	0.2-0.8	Max. 0.7	3.5-4.5	0.4-1	0.4-0.8	Max. 0.1	Max. 0.25	Max. 0.15	Balance
Actual	0.21	0.61	4.1	0.62	0.7	0.04	0.25	0.1	Balance

0.05 other (each), 0.15 other (total).

2.3 Tensile test

Tensile test was carried out by (Tinius Olsen, H100KU Model), at Al-Mustansiriya university. The specimens were manufactured according to (ASTM 370). The shape and dimensions of tensile specimen is shown in Figure 1. Three specimens were tested with 1 mm / min load rating and the average of three reading is presented.

The maximum capacity of the tensile test rig is (100 KN) and this rig can be operated at speeds ranging from (0.01 - 500) mm /min which assimilates a wide range of materials and samples. The tensile test rig is shown in Figure 2.

The experimental mechanical properties results in comparison with standard are presented in Table 2.

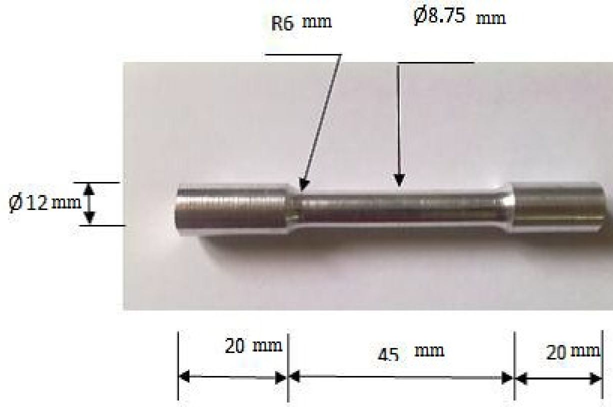

Figure 1. Shape and dimensions of tensile specimen according to standard specification (ASTM A370) [8, 9].

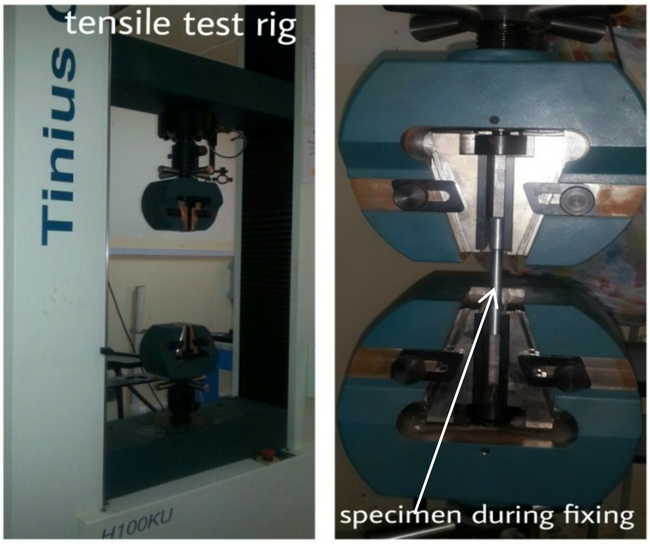

Figure 2. Static test rig (Tinius Olsen).

Table 2. The mechanical properties of 2017-T4 aluminum alloy (average of three specimens readings).

Property	Yield stress (σ_y) (MPa)	Tensile strength (σ_u) (MPa)	Elongation In50mm(2in)[(a)],(%)	Modulus of elasticity (E) (GPa)
Standard ASTM B-211 [8]	275	274	22	72.4
Experimental	265	425	21	72

2.4 Fatigue test

Fatigue test was performed by using fatigue test machine of type (PUNN rotating bending). The fatigue test specimens prepared according to the (DIN 50113) standard specification. The standard specimen and testing apparatus are illustrated in Figures 3 and 4 respectively. This test was carried out in University of Technology /Electromechanical Engineering Department.

2.5 Thermal device

Fatigue at elevated temperature required a thermal device for heating the environment of the specimens to a known elevated temperature. An electric furnace is manufactured with suitable dimensions of (100×120×140) mm. The furnace can be attached to the testing machine with a digital thermal control unit board. The walls of the furnace are made of two layers of steel plate with 3mm thickness for each layer. An electrical heater of (2000W) is fastened inside the furnace with a K-type thermocouple for the sake of control to heating temperature inside the furnace [11]. The furnace and digital thermal control unit board are illustrated in Figure 5.

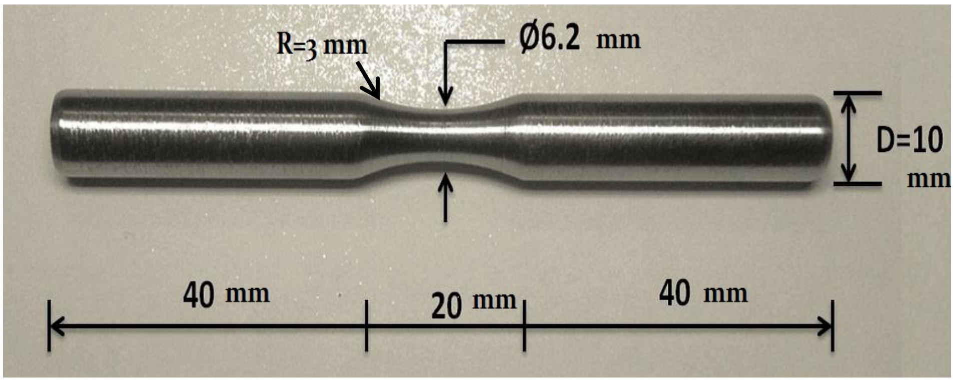

Figure 3. Fatigue test specimen according to the ASTM81-8 standard specification [10].

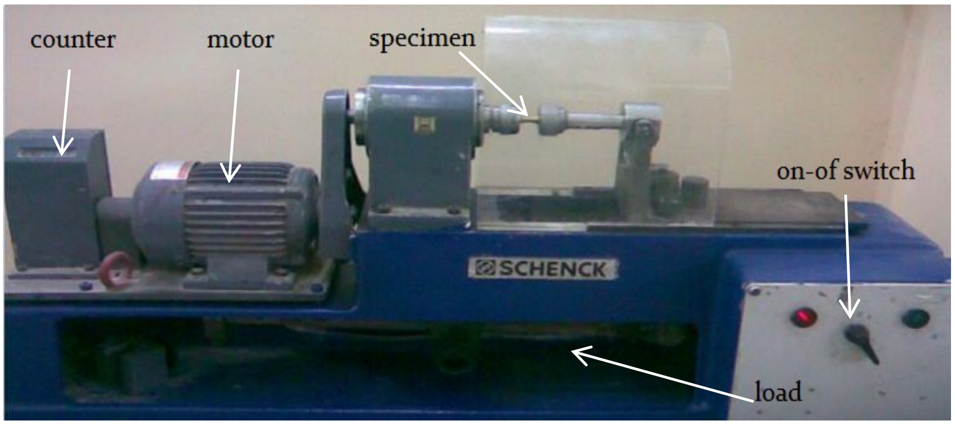

Figure 4. Fatigue testing apparatus.

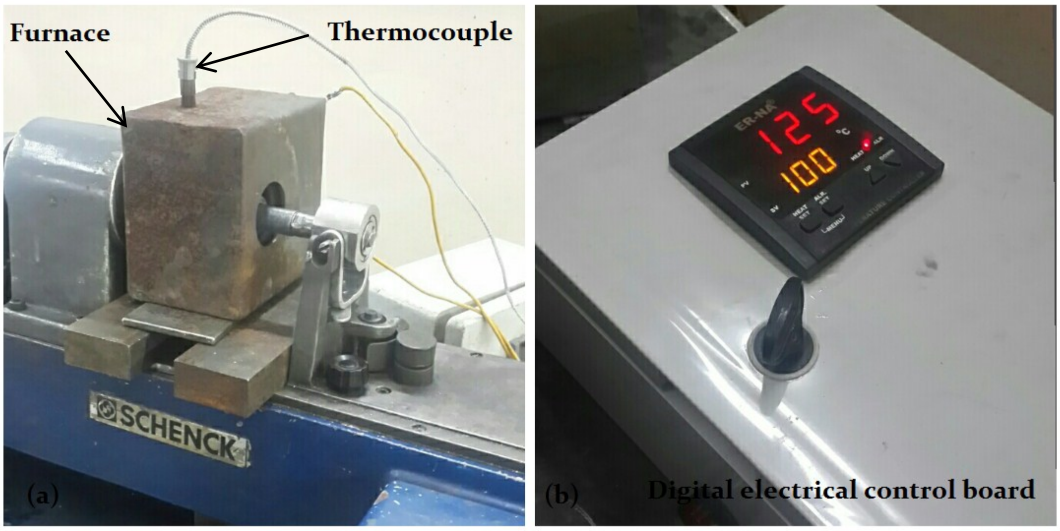

Figure 5. Thermal device (Furnace) (left), Digital electrical control board (Right).

2.6 Shot peening test

The shot peening process was performed at (Institute of Technology/mechanical department) in a special testing machine (Shot Tumblast Control Panel Model STB-OB) at room temperature (25℃). This machine is presented in Figure 6. The material of balls that used to shot the specimens made of cast steel with average ball size diameter (1mm) and ball velocity nearly (40 m/s). The distance between the nozzle and specimens surface is 10 cm. The Rockwell hardness of the ball was 48-50 HRD [9]. Water used as moisturizer for the specimens prior to start the shot. Figure 7 shows the specimens before and after wet shot peening operation.

Figure 6. Shot peening rig.

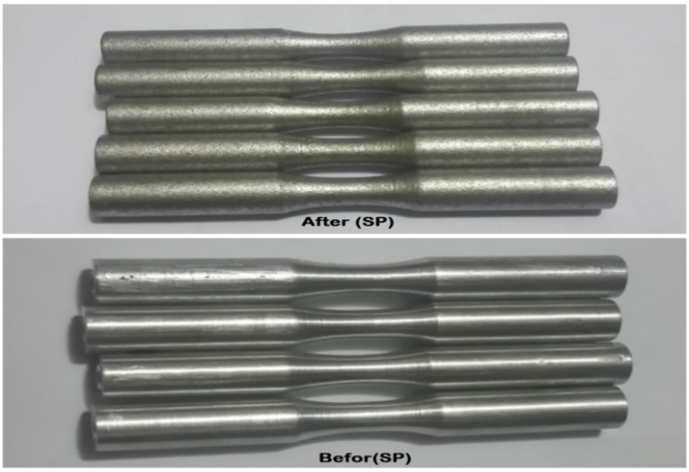

Figure 7. Specimens before and after SP.

3. Experimental work plan

Fatigue test was performed for four cases to obtain the S-N curves data and compared between them. The cases are

3.1 Constant amplitude load at RT (25℃)

Fatigue test was performed at room temperature and the load remained constant until the failure of the specimens occurred. Here the failure was defined as the fatigue specimen becomes into two pieces. When specimen failed the fatigue testing is automatically stopped. 12 specimens were tested using four stress levels 350,275,200 and 175 MPa in order to cover the high cycle fatigue region. Three tests were performed at each of these stress levels and the number of cycles until failure of the specimens were recorded by a mechanical counter which is coupled directly to the drive shaft of the d.c. motor records the number of stress cycles.

3.2 Constant amplitude load at constant temp. (100℃)

The fatigue test at constant amplitude load and constant elevated temperature (100℃) was achieved using 12 specimens tested at the same stress level mentioned above. The test specimen environments heated till the digital electrical control circuit reached the temperature 100℃, then the fatigue to machine starts to operate. In order to examine the temperature of specimen surface, a thermocouple was holded to the furnace and it can be measure the temperature at specimen surface.

3.3 Constant amplitude load at variable temp. 50℃, 100℃,150℃
12 specimens were tested under variable temperature and constant applied stress, the diagram shown in Figure 8 outlines the details of the test.

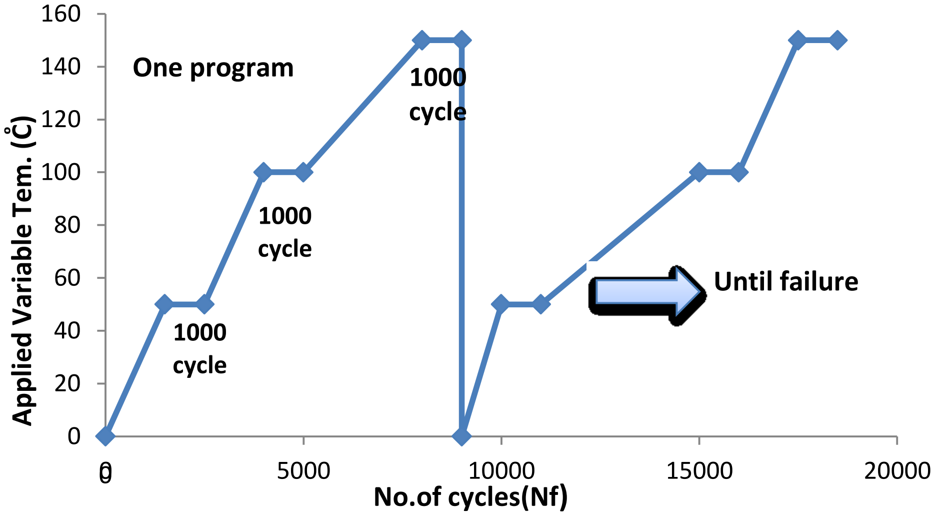

Figure 8. Variable temperature constant stress amplitude fatigue test diagram.

3.4 Constant amplitude load at 100℃ with prior 25 min. wet shot peening
12 specimens were performed at constant temp 100℃ but, the specimens of this group treated to prior shot peening at 25 minute. The selection of 25 min. is coming from previous test by Ref. [12] who concluded that the 25 min. shot peening is the optimum time for improving the mechanical and fatigue properties.

4. Results and discussion
The experimental work plan results can be described in Table 3 that is showed fatigue cycles to failure of 2017-T4 aluminum alloy for different cases of constant fatigue life.
The experimental data of the S-N curves in Table 3 are now plotted in the Figure 9.

Table 3. S-N curves data for different cases of constant fatigue life.

Specimens No.	Applied Stress(MPa)	Cycles to Failure N_f	Average Cycles $N_{av.}$
		Dry Fatigue	
1,2,3	350	2000,9000,5000	5333
4,5,6	275	97000,49000,20000	55333
7,8,9	200	460000,193000,268000	307000
10,11,12	175	388000,791000,90000	423000
		Constant Thermal Fatigue at Temp. (100℃)	
13,14,15	350	1000,4000,4000	2000
16,17,18	275	38000,13000,12000	21000
19,20,21	200	174000,115000,66000	118333
22,23,24	175	126000,59000,421000	202000
		Variable Thermal Fatigue at Temp. (50℃,100℃,150℃)	
25,26,27	350	2000,3200,2600	2600
28,29,30	275	12600,15000,18000	15200
31,32,33	200	34500,36000,29000	33166
34,35,36	175	62000,76000,68000	68666
		Thermal Fatigue at (100 Ċ) with prior 25 min. Wet Shot Peening	
37,38,39	350	2000,6000,2500	3500
40,41,42	275	22000,28000,31000	27000
43,44,45	200	160000,175000,136000	157000
46,47,48	175	230000,290000,410000	310000

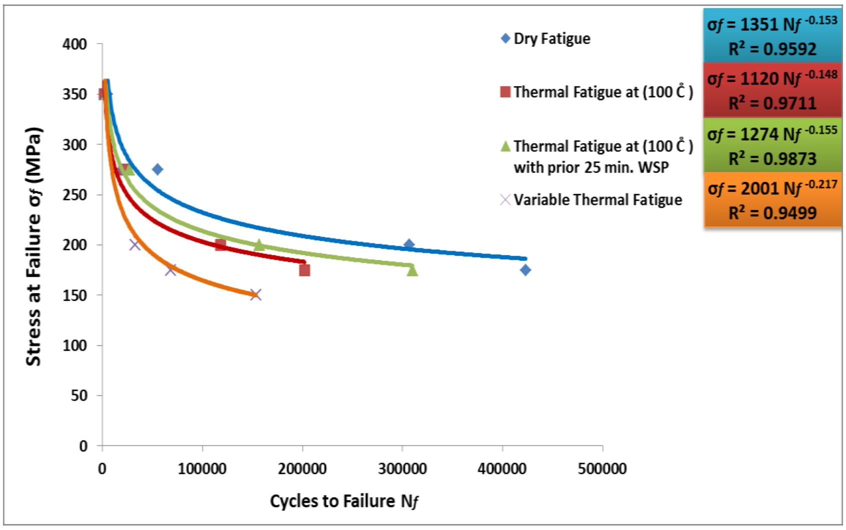

Figure 9. Comparison between four cases of fatigue testing.

Figure 9 shows the S-N curves for dry and thermal fatigue conditions. The endurance fatigue limits (fatigue strength) at 10^7 were conducted for all conditions mentioned in above figure, that were (115, 103, 105, 61) MPa respectively. Fatigue strength of variable thermal fatigue condition show a significant large reduction related to fatigue strength of dry fatigue; also improvement was observed in fatigue strength of thermal fatigue at 100℃ with prior 25 min wet shot peening (WSP) condition related to same condition but, without (WSP) process. In the figure above it is shown that the fatigue strength decreases with increasing and changing temperature compared to dry fatigue. Farhad et al. [4] studied fatigue behavior of aluminum alloy (2024-T4) under room and elevated temperatures (180℃), in this research the fatigue strength of 2024 – T4 Aluminum alloy at elevated temperature is decrease by factor (1.2-1.4) related to dry fatigue strength. Costa and Silva [13] researched the fatigue strength of nodular cast iron at temperatures (20,150,300,450)˚C. The experimental results were showed; no change in fatigue strength for specimen tested at 20 and 150˚C, whereas the fatigue strength increases for specimens were tested at 300˚C, and then reduces when tested at 450 ˚C. This research was showed the opposite tendency of fatigue limit and tensile strength with temperature.

5. Conclusions

Fatigue behaviour of 2017-T4 aluminum alloy at different temperatures was studied. The main conclusions derived from this research are:

1. Fatigue life of 2017-T4 aluminum alloy was reduced with increasing of temperature.
2. The worst case of fatigue life was observed at increasing temperature condition.
3. Fatigue strength at 100℃ reduced by 10.43 % compared to (RT) case.
4. Fatigue strength at 100℃ was enhanced due to 25 minutes (WSP) by 2 % in comparison with fatigue strength at 100℃.
5. Fatigue strength of increasing temperature case revealed lower strength compared to the constant temperature condition, and the reduction in fatigue strength due to increasing temperature was 46.95 % compared to (RT) condition.
6. Shot peening at 25 minutes improved the fatigue life significantly by factor of (1.94 %).

References

[1] Wyman Z. Z., Neil S. S. Thermo-mechanical fatigue life prediction a critical review, defence science and technology organization, Vol. 14, PP.25 1998.

[2] Hussain J.M. AL-alkawi, Qusay K. M., Waleed S.A. The Effect of Shot Peening and Residual Stresses on Cumulative Fatigue Damage, Eng. & Tech. Journal, Vol.28, PP. 5055-5072, 2010.

[3] Hong Y. M. Experimental study of shot peening and stress peen forming, Journal of Materials Processing and Technology, Vol. 210, PP. 2089-2102, 2010.

[4] Farhad B. B., Ahmed M. S., Khaleed H., Zaidi M., Zainal A.A., Nur A. B. & Zahurin S. Fatigue Behaviour of Aluminum Alloy at Elevated Temperature, Modren Applied Science, Vol.3, PP.52-61, 2009.

[5] Zainab K. H. Fatigue Life Prediction at Elevated Temperature under Low – High and High – Low Loading Based on Mechanical Properties Damage Model, Engineering and Technology Journal, Vol. 30, PP. 1886-1896, 2012.
[6] Hussain J.M. AL-alkawi, Talal A., Safaa H. A., Basil A. S., Ali Y.K. The Effects of Dry and Wet Shot Peening on the Mechanical and Fatigue Properties of 7075-T6 Aluminum Alloy, International J. of Engineering research and industrial applications, Vol. 4, pp. 343-356, 2012.
[7] Guo-qing C., Yan J., Tang-yong T., Xin-hua Z., Zhi-qiang L., Wen-long Z. Effect of Wet Shot Peening on Ti−6Al−4V Alloy Treated by Ceramic Beads, Trans. Nonferrous Met. Soc. Vol. 24, PP.690-696, 2014.
[8] Ohio ASM Metal Handbook, Properties and Selection: Nonferrous Alloys and Special-Purpose Materials, ASM International, Vol. 2, PP.259-261, 1993.
[9] Hussain J. M. AL-alkawi, Shakir S. H., Salah F. A. Experimental Study of the Effect of Shot Peening on Elevated Temperature Fatigue Behavior of 7075-T651 Al. alloy, Eng. & Tech. Journal, Vol.31, PP. 416-433, 2013.
[10] Hasan H. J. Deflection and Noises Measurement Using Sensor Device Under Dynamic Loading, MSc. Thesis, University of Technology Electromechanical Engineering Department, 2013.
[11] Thabat M. A. Effect of Carbon Content Percentage of Steel Alloys on Cumulative Hot Creep-Fatigue Interaction, MSc thesis, Al-Mustansirya University, Materials Engineering Dept., 2012.
[12] Ali Y. Kh. The effect of Shot Peening Process on the Fatigue Life of 2024-T4 Aluminum Alloy, MSc. Thesis, Omdurman Islamic University, Mechanical Engineering Department, 2011.
[13] Costa N., Silva F. S. On anew temperature factor to predict the fatigue limit at different temperatures, International Journal of Fatigue Vol. 33, PP. 624-631, 2011.