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Experimental Determination the Effect of Surface roughness and temperature on the cumulative fatigue life of shot peened 7075-T651 Al-alloy

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ABSTRACT

In this work, an experimental study to obtain the fatigue endurance limit for an aluminum alloy7075-T651 were carried out at stress ratio R=-1 and rotary bending tests. The fatigue tests were performed at RT and 250 °C in order to establish the S–N curve equations. The fatigue endurance limits for the alloy at different temperature conditions were calculated at 10^7 cycles from the empirical S-N curve equations. It was found that the fatigue endurance limit decrease with increasing the temperature. Also The effect of shot peening on the rotating bending fatigue behavior of 7075-T651 was studied. The fatigue strength of specimens tested at250°C at 10^7cycles is reduced about 12%. The fatigue strength of specimens tested at250°C prior to (10 min.) SP at 10^7cycles is increased by 7.2%. The roughness of the samples increases after shot peening which leads to the deterioration of the fatigue strength, because the surface of the samples become prone to nucleation of cracks.

Introduction

Shot peening is a cold working process in which the surface of a part is bombarded with small spherical media called shots. Every shot striking the material acts a tiny peening hammer, importing to the surface a small indentation or dimple. Shot peening has develop an even layer of metal that it is a state of residual compressive stress.

Fuchs [1] has reported that the values of the compressive stresses are at least as high as 50% of the ultimate strength of the material. The fatigue limits of specimens containing an artificial small hole were increased by shot peening and stress shot peening (SSP) was more effective in improving fatigue limit.

The fatigue limit of spring steel specimens containing a surface defect increased 22%-51% for shot peened and 72%-100% increased for stress shot peened [2].

Moreover, it is known that shot peening is one of the most common surface treatment to improve the fatigue strength of the metallic products. Furthermore shot peening can work harden and change the dislocation density just near the surface layer .Although shot peening treatment increase the surface roughness of the samples and seems to deteriorate the fatigue strength by increasing the density of crack nucleation sites , but the beneficial effects of compressive residual stresses and work hardened layer are superior [3,4,5] .

This study aims to investigate the effect of shot peening process on the fatigue behavior at elevated temperature of 7075-T651 aluminum alloy considering the surface roughness.

Advantages and disadvantages of shot peening [6]

Advantage

- Decrease of tensile stresses in the surface and compensation for deformations without thermal treatment.
- Widely applicable, easy to control.

Disadvantages

- Thin work pieces are susceptible to deformation

Mechanical after treatment should be avoided except in case of aluminum and magnesium alloys. These can be shot peened to a large depth, so that about 0.1 mm is available for machining afterwards.

Shot peening is a method of introducing compressive strain in a surface with the aim of:

a) Increasing the fatigue strength of a material.

b) Decreasing the tension in the surface.

c) Getting rid of deformations, or aiming at the creation of deformations.

d) Decreasing the susceptibility of stainless steel and aluminum alloys to electromechanical corrosion [6].

Applications

The most important application is prevention of fatigue. Well known applications are peening of crankshafts, gears, turbine blades and fans.

Shot peening is especially effective in:

a) Decreasing residual stresses as a result of mechanical treatment.

b) Preventing concentrations of tensile stress in notches, sharp angles, forging pits and other surface defects.

c) Preventing negative effects on the strength in the heat treated zone of welds and in decarburized surface after heat treatment.

Finally, peening can be used in the prevention of stress cracking corrosion in aluminum and magnesium alloys, brass and stainless steel.

Experimental work

Material

Zinc-based aluminums alloy 7075 is utilized throughout aircraft and aerospace structures where a combination of high strength with moderate toughness and corrosion resistance is required. According to this application, mechanical behavior of this material has been the subject of intensive research for many years.. This alloy has good mechanical properties such as mechanical strength, light in weight and high in corrosion strength [7]. The character (T) represents thermally treated to produce stable tempers other than as fabricated alloy. The digits represent how the alloy has been fabricated and it always followed by the symbol (T) [8].

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Chemical composition

Chemical composition of the alloy was done at the specialized institute using x-rays method. The results, which are compared to the American standards, are tabulated in table (1).

Table 1. Experimental and standard chemical composition of 7075-T651 Al-alloy, wt%

Material	Zn	Mg	Cu	Fe	Cr	other	Al
7075-T651 experimental	5.7	2.4	1.8	0.15	0.04	0.55	Rem.
7075-T651 standard	5.7	2.4	1.5	0.25	0.5 max.	-	Rem.

Mechanical properties

Tensile tests were carried out at RT(room temperature, 30°C) .The tensile tests have done using (instron 225 testing machine) that has a maximum capacity of 150KN. And the mechanical properties of the alloy used can be illustrated in table (2).

Table 2. Mechanical properties of 7075-T651 Al alloy

Property	σ_u(MPa)	σ_y(MPa)	E(GPa)	Ductility %	Hardness (HB)
RT	540	484	75	18	122
Standard RT	545	481	73	20	120

Fatigue testing machine

Rotating bending fatigue tests were conducted at Room Temperature (25°C)and 250°C under stress ratio R=-1. This machine was used for creep, fatigue and fatigue-creep interaction tests. The test rig has a property of automatic cut-off when specimen fails. Fig. (2) a. Shows the fatigue-creep testing machine, which used in the ordinary tests at RT (25°C). While Fig. (2) b. shows the fatigue-creep testing machine, with designed furnace for testing specimens at 250°C.

Fatigue specimen

Fig. 2 a. The fatigue-creep testing machine

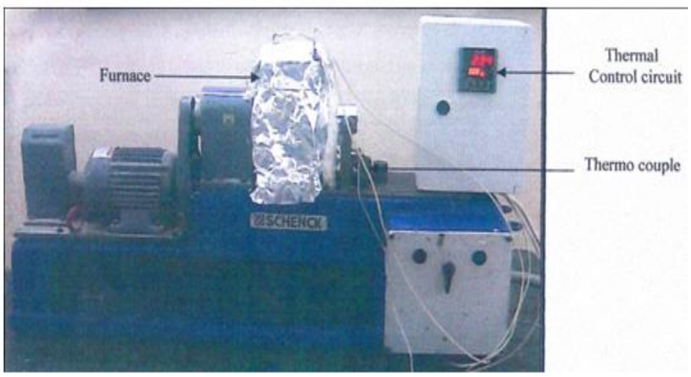


Fig. 2 b. the fatigue-creep testing machine with furnace

Fatigue-creep interaction specimen

Fig.(2)c. shows the shape and dimensions of fatigue-creep specimen. The manufactured specimens were classified into three groups as given in table (3).

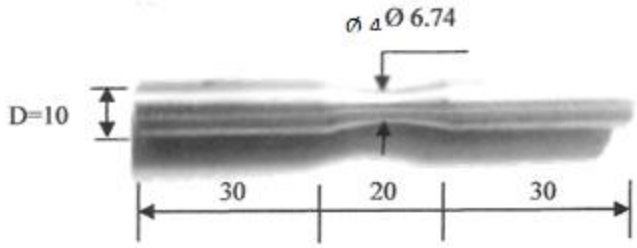


Fig. 2c. The shape and dimensions of fatigue-creep specimen (All dimensions in mm)

Table 3. The plan of the experimental work

S-N curve fatigue tests at RT	12 specimens
S-N curve fatigue at 250 °C	12 specimens
S-N curve fatigue at 250 °C prior to SP(shot peening)	12 specimens
Cumulative fatigue at 250 °C for unpeened specimens	4 specimens
Cumulative fatigue at 250 °C for peened specimens	4 specimens

Experimental results and discussion

Roughness results

The results of the surface roughness are given in Table (3) where it is measured in the direction; this direction is the initiation of propagation transverse of cracks in the minimum diameter of specimen.

Table 3: surface roughness results of 44 specimens

Specimen No.	Ra (µm)	Rt (µm)	Specimen No.	Ra (µm)	Rt (µm)	Specimen No.	Ra (µm)	Rt (µm)
1	0.4	1.1	16	0.66	2.3	31	0.92	2
2	0.3	1.3	17	0.7	2.15	32	0.71	2.1
3	0.25	1.25	18	0.55	1.7	33	0.62	3.1
4	0.2	1.2	19	0.48	1.27	34	0.91	1.9
5	0.11	1.7	20	0.38	1.8	35	0.87	2.11
6	0.17	1.4	21	0.41	1.4	36	0.72	2.3
7	0.32	1.72	22	0.76	1.7	37	0.58	1.8
8	0.41	1.61	23	0.66	2.1	38	0.49	1.9
9	0.5	1.41	24	0.52	1.9	39	0.82	2.1
10	0.6	2	25	0.61	1.7	40	0.92	3.1
11	0.47	1.9	26	0.42	1.6	41	0.25	1.2
12	0.7	1.72	27	0.61	2.2	42	0.39	1.5
13	0.62	1.52	28	0.42	1.82	43	0.35	1.7
14	0.58	1.61	29	0.63	1.9	44	0.57	1.2
15	0.71	2.1	30	0.8	2.7			

The above data are the average of five readings

S-N curve data for 7075-T651 Al-alloy without shot peening is illustrated in table (4)

Table 4. S-N curve fatigue test results at room temperature (RT)

Specimen No.	**N_f (cycles)**	**Applied bending stress σ_b(MPa)**	**Average N_f (cycles)**
1,2,3	14600, 11800, 9000	350	11800
4,5,6	33800, 39000, 28000	300	33600
7,8,9	141000, 122700, 188000	250	150560
10,11,12	557000, 680000, 611800	200	616200

The fatigue S-N curve of the Al alloy under RT and elevated temperature, 250°C can be analyzed based on Basquin equation form as follows:

$$\sigma_f = AN_f^{\alpha} \quad \ldots\ldots (6)$$

where σ_f is the applied stress at failure

N_f is the number of cycles at failure due to the applied stress σ_f

A and α are material constants that can be evaluated by linearizing the curve by re-writing equation (6) in logarithmic form as following:

$$\alpha = \frac{h\sum_{i=1}^{h}\log\sigma_f \log N_f - \sum_{i=1}^{h}\log\sigma_f \sum_{i}^{h}\log N_f}{h\sum_{i=1}^{h}(\log N_f)^2 - [\sum_{i=1}^{h}\log N_f]^2} \quad \text{...... (7)}$$

and

$$\log A = \frac{\sum_{i}^{h}\log\sigma_f - \alpha \sum_{i=1}^{h}\log N_f}{h} \quad \text{...... (8)}$$

where(i)is the number of readings or (i= 1,2,3 ….. h)
and (h) is the total number of readings
The S-N curve of the fatigue behavior at RT is illustrated in fig. (3)

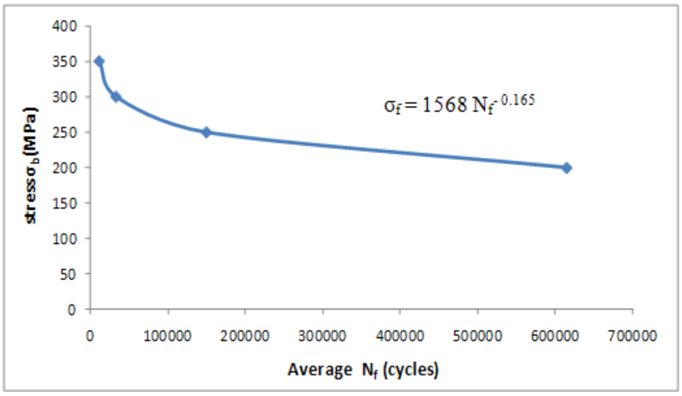


Fig. 3. Shows the S-N curve behavior for the above data which gives the fatigue strength at 10^7 cycle is (110)MPa.

The S-N curve data of the above alloy at the same stresses but tested under 250°C is given in table (5).

Table 5. Basic S-N curve data at 250°C

Specimen No	N_f (cycles)	Applied bending stress σ_b(MPa)	Average N_f (cycles)
13, 14, 15	6500, 5000, 4800	350	5400
16, 17, 18	17800, 15600, 12800	300	15400
19, 20, 21	54900, 66800, 69000	250	63560
22, 23, 24	210000, 187000, 224600	200	207200

The fatigue behavior of 7074-T651 at 250°C is shown in fig (4)

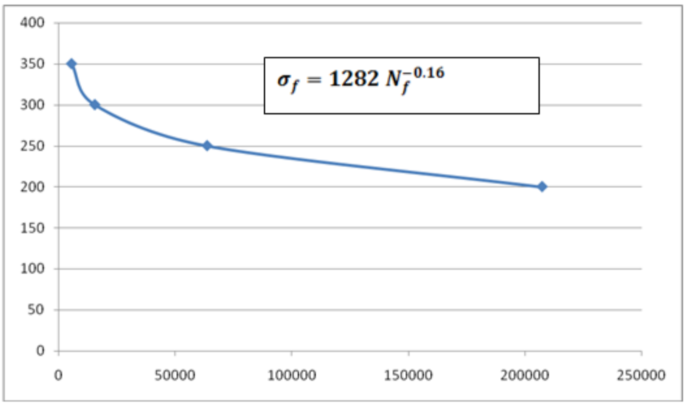


Fig. 4. shows the endurance fatigue limit at 10^7 cycle is (97)MPa.

The fatigue life of Specimens tested at 250°C prior to shot peening (SP) at 10 min is given in table (6).

Table 6. Basic S-N curve data at 250°C prior to shot peening

Specimen No	N_f (cycles)	Applied bending stress σ_b(MPa)	Average N_f (cycles)
25, 26, 27	4800, 5000, 4200	350	4660
28, 29, 30	13800, 14600, 12900	300	13760
31, 32, 33	42800, 40800, 38600	250	40730
34, 35, 36	155600, 182000, 160000	200	165800

The behavior of fatigue at constant stresses at 250°C prior to shot peening (SP) at 10 min can be seen in fig (5).

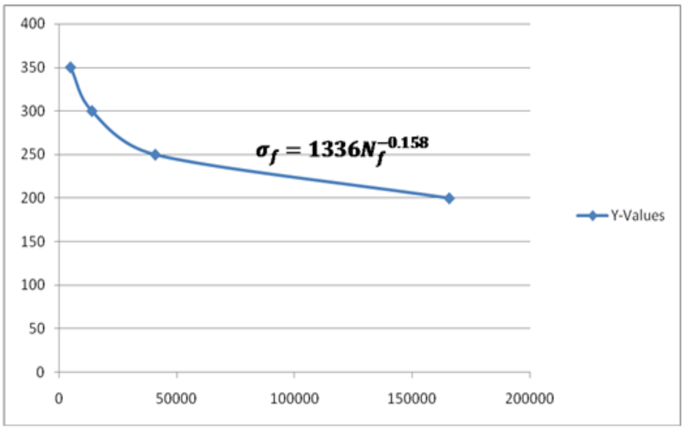


Fig. 5 The endurance fatigue limit is calculated from above equation to be (104)MPa.

The fatigue behavior of 7074-T651 at different conditions is shown in fig (6).

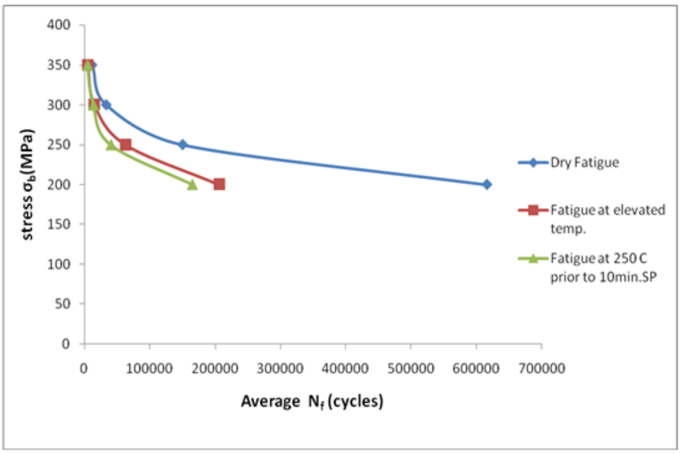


Fig. 6. S-N curves at RT and at 250°C prior to 10 min, to shot peening (SP)

Table (7) gives the S-N curves equations at different conditions of testing, with the fatigue endurance limit.

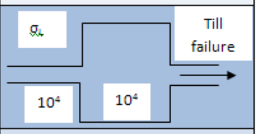
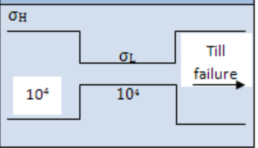
Table 7. S-N curve equations and fatigue endurance limit at different conditions of testing

Testing conditions	S-N curve equation	$\sigma_{E.L}$(MPa) at 10^7 cycles
Fatigue at (RT)	$\sigma_f = 1586\, N_f^{-0.165}$	110
Fatigue at 250°C	$\sigma_f = 1282\, N_f^{-0.16}$	97
Fatigue at 250°C prior to 10 min. SP	$\sigma_f = 1336 N_f^{-0.158}$	104

Cumulative fatigue damage results

The experimental results of variable fatigue damage at low-high and high-low for fatigue at elevated temperature (at 250°C) and at 250°C prior to shot peening are tabled in table (8)

Table 8. Cumulative fatigue life at different conditions of testing

Specimen No	Loading Sequase (MPa)	N_f (cycles)	Testing condition	Loading program
37 **38** **39** **40**	225-325 225-325 325-225 325-225	31800 28600 11600 14800	Fatigue at 250°C	
41 **42** **43** **44**	225-325 225-325 325-225 325-225	52000 44600 21000 19800	Fatigue at 250°C prior to 10 min. (SP)	

Discussion

When the creep and fatigue operate simultaneously, therefore, it is necessary to consider not only the individual effects, but also effect of their interaction, to obtain more accurate prediction of component life [9].

In addition, as the temperature increases, the interaction between the processes of creep and fatigue can lead to significant reduction in product life and fatigue strength.

The fatigue life reduction due to the high temperature is quite obvious from Fig. (6). for a given fatigue stress, the higher the temperature, the shorter the lifetime, and fatigue strength.

From a general point of view, creep-fatigue tests were found to be more deleterious than fatigue tests [10].

To improve the fatigue life of metallic components, especially in aerospace industry, SP is widely used. The (SP) process is considerably complex. Moreover, it is known that SP is one of the most common surface treatments to improve the fatigue strength of the metallic products. Shot peening creates compressive residual stress. This compressive residual stress can reduce the tensile stress. Although (SP) treatment increases the surface roughness of the samples and seems to deteriorate the fatigue strength by increasing the density of crack nucleation sites. But the beneficial effects of compressive residual stresses and work hardened layer are superior [5].

According to the results, the fatigue strength of 7075-T651 Al-alloy at 10^7cycles is about (110) MPa which decrease after testing at 250°C to about (97) MPa. This is because of fatigue damage increase with temperature.

The effect of (SP) on the endurance fatigue limit can be illustrated by the fig. (7).

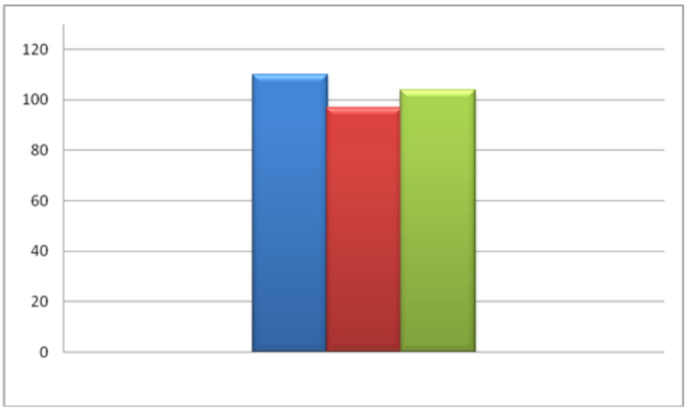


Fig 7. Endurance Fatigue limit at different test conditions

The roughness of the samples increases after shot peening which leads to the deterioration of the fatigue strength, because the surface of the samples become prone to nucleation of cracks. However results show that the work hardening and compressive residual stress are overwhelming and finally the fatigue strength and life improve. The roughness measurements of the specimens tested under cumulative creep-fatigue tests are given in table (9).

Table 9. Shows the roughness of samples after SP

Specimen No.	Unpeened		Peened	
	Ra(µm)	RT(µm)	Ra(µm)	RT(µm)
41	0.25	1.2	1.4	2.5
42	0.39	1.5	1.7	2.7
43	0.35	1.7	1.25	2.2
44	0.57	1.2	1.9	2.8

It must be mentioned that SP operation would not be much effective in enhancement of fatigue strength for higher stresses [10]. At higher stresses, the difference in the fatigue strength before and after shot peening is less than that of lower stress. This is because of stress relaxation that occurs at high stresses [10]. Table (10) shows a comparison between the cumulative fatigue-creep interaction life for both cases (a) without SP and (b) with SP

Table 10 Shows the cumulative fatigue-creep interaction life for both cases (a) without SP and (b) with SP

Specimen No.	N_f 250°C	N_f 250°C+SP	LIF *
41	31800	52000	1.635
42	28600	44600	1.559
43	11600	21000	1.81
44	14800	19800	1.337

*LIF is life improvement factor = (N_f 250°C+SP/N_f 250°C)

Conclusions

It can be concluded that:

1. Shot peening was intentionally employed to improve fatigue strength & fatigue life of materials.

2. The fatigue strength of specimens tested at250°C at 10^7cycles is reduced about 12%.

3. The fatigue strength of specimens tested at250°C prior to (10 min.) SP at 10^7cycles is increased by 7.2%.

References

[1] Fuchs, H.O., "Shot peening mechanical engineers handbook", pp. 941-951, John Wiley and sons, Inc 1986.

[2] Koji T., Kotoj A., Toshihiko A., Takamass M.," Improving of fatigue limit by shot peening for spring steel specimens containing an artificial surface defect".(japan Yokohama national university),(2011)

[3] Avinshon B. ,Yazdari S. ,Jalali V. "The influence of depth of cut on the machinability of an alloyed austempered ductile iron ." Material Science and Engineering A ,523,pp 93-98 (2009).

[4]Ji. S.,Roberts K., Fan Z. "The effect of shot peening on fatigue performance of ductile iron castings." Material Science and Engineering Technology ,18 (2) ,pp1 93-197 , (2002).

[5]Amir S. B. , Sasan Y. , Behzad A., "Effect of shot peening process on fatigue behavior of an alloyed austempered ductile iron." China Foundry vol.8 ,No. 3, 325-330, (2011).

[6] Surface Treatment file//G: surface technology. htm(2011) JSSE conference www.smihq.org/public/publication/past_articles/springs_April_.

[7] **R.H. Oskouei**a **and R.N. Ibrahim** "The effect of typical flight temperatures on the fatigue behaviour of Al 7075-T6 clamped plates "Materials Science and Engineering: A Volume 528 Pages 1527-1533 (2011).

[8] R.H. Oskouei and T.N. Chakherlou, Aerospace Science and Technology **13** ,pp. 325–330. (2009),

[9] Kim T.W., Kang D.H., Yoem J.T., Park N.K., "Continuum damage mechanics-based creep-fatigue increased life prediction of nickel-based superalloy at high temperature", scripta Materials, 57, 1149-1152(2007).

[10]Harold Luong ,Michael R.Hill "The effects of laser peening and shot peening on high cycle fatigue in 7050-T7451 aluminum alloy" material science and engineering A527,699-707(2010).

[11] R.H. Oskouei, R.N. Ibrahim., " The effect of clamping compressive stresses on the fatigue life of Al 7075-T6 bolted plates at different temperatures "Materials and Design, 34 (2012) 90–97