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Investigation of fatigue life by shot peening for 7075-T651 Aluminum alloy

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ABSTRACT

Shot-peening is a cold-working process primarily used to improve the fatigue life and strength of metallic structural components. In this work, the shot-peening time (SPT) effect on fatigue life of 7075-T651 Al-alloy was investigating at room temperature stress ratio R=-1 and reversed bending. An increase in shot-peening time (SPT) resulted in an increase in fatigue life improvement percentage (FLI %). For 5 SPT, reducing the applied stress, increasing (FLI%) while at 10 and 15 SPT reducing the applied stress reducing the (FLI%).

Introduction

It is well recognized that surface modification technologies provide a means for enhancing the fatigue life of engineering components.

Shot peening is one such surface treatment process for fatigue life enhancement. Requirements to improve the fatigue life and fatigue strength of components are increasing year by year from the viewpoint of environmental and energy conservation issues. There are mainly two popular ways to increase fatigue life (a) increase the hardness of materials, and (b) introduce compressive residual stress in components. [1].Shot peening coverage of at least 100% is thought to be necessary to achieve uniform surface compression and hence improved fatigue performance in metals .E.R . de los Rios et al [2] studied the effect of shot peening on the fatigue resistance of 7075-T651aluminum alloy using four point bending fatigue testing. The results show that the fatigue lives for peened specimens are longer than those for unpeened specimens over a wide range of applied stress. The hardness and residual compressive stresses were also increase by peening. Fatigue life improvement due to shot peening is caused by the dual effect provided by prolonging crack arrest and reducing the crack growth with both mechanisms being affected by the residual stress relaxation profile [3]. Alalkawi and [4] investigated the fatigue damage accumulation behavior of 7075-T651 Al. alloy under the effect of varying the time of shot peening. The time of shot peening was in the range of 2-20 min. and the number of cycles to failure increases as the shot peeing time increases up to about 6-8 min. after that the number of cycles decrease. Stainless steel 316L has low resistance to fatigue and wear. For this purpose specimens, were shot peened for (5, 10, 15, 20 and 25 min). the shot peening treatment increase the surface hardness and fatigue resistance, but decreases the break-down potential of the passive layer and increase the corrosion current density up to (10min). which shows a reduction in resistance to pitting corrosion. [10]. Development of crack growth after shot peening was measured and compared with crack growth in specimen without shot peening. The crack will be reliably arrested. [11]. The study demonstrates that fatigue life extension by shot peening can be attributed to beneficial compressive residual stress in the surface layer that the principle of superposition is applicable to fracture mechanis. [12]. Fine particle shot peening (FPSP) is a new technology using smaller media with higher blowing velocity compared with (SP). (FPSP) created fine uniform dimples and high compressive residual stress at very near surface. (FPSP) enhances fatigue life of Al alloy compared with (SP) because of the high compressive residual stress at very near surface with low roughness.[13].

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.[14] .[15]

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 .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 this symbol [4].

The material used in this present investigation is aluminum alloy 7075-T651, in plate form with 2mm. thickness.

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).

Fatigue specimens

Flat specimens were prepared according to DIN 50133 from a raw material consisting of sheets of dimensions 500*500mm. first, small rectangular sheets were cut to dimensions of a

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fatigue specimen and to avoid mistake, the desire profiles were machined to obtain the necessary holes. For this reason, four holes per specimen were done using fixed drill. The specimen is shown in fig. (1). For all tests, crack initiation and fracture occurred at the midpoint of the specimen.

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.

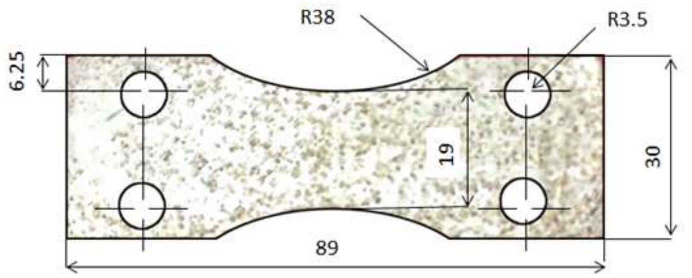

Fig 1. Reserved bending specimen geometry, dimension in mm. (after shot peening)

Mechanical properties

Tensile tests were carried out at RT(room temperature, 30^{o}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

Specimens Roughness

The surface of the specimens were carefully polished to remove scratches and the surface roughness was measured by a profilometer. The average roughness (Ra) and maximum roughness (Rt) were recorded an average of 5 readings and they found to be (0.7 – 1.3)µm. and (1.2 – 2.2)µm. respectively.

Shot peening and fatigue test

Fatigue specimens were machined accurately according to DIN 50113 standard. Shot peening treatment was carried out on (STB-OB) shot peening machine. A group of specimens were shooting in different time by cast steel ball with diameter 1mm, having Rockwell hardness of 50 HRC. The peening pressure 12 bars and the number of balls was kept constant at the whole operation time. The ball velocity of nearly 40 m/sec. Fig.(2) shows shot peening device.

Fig 2. Shot Peening Device

Fig 3. Fatigue Test Device

Result and Discussion

The fatigue test is carried out to obtain the S-N curve for both peened and unpeened specimens in different time (5,10 and 15min.), under reverse bending fatigue at constant amplitude and stress ratio (R=-1) at room temperature. Table (3) illustrates the fatigue experimental results at different SPT (0, 5, 10 and 15 min.), while Fig. (4) represent the unpeened and peened S-N curves for the metal used.

Table 3. S-N curve constant with S.P for 7075-T651AL

SPT(min.)	A	α	S-N curve equation	σ EL(MPa)
Zero	1012	-0.1217	σ_f=1012*Nf $^{-0.1217}$	142
5	1005	-0.1202	σ_f=1005*Nf $^{-0.1202}$	144
10	1132	-0.126	σ_f=1132*Nf $^{-0.126}$	148
15	1206	-0.1296	σ_f=1206*Nf $^{-0.1296}$	149

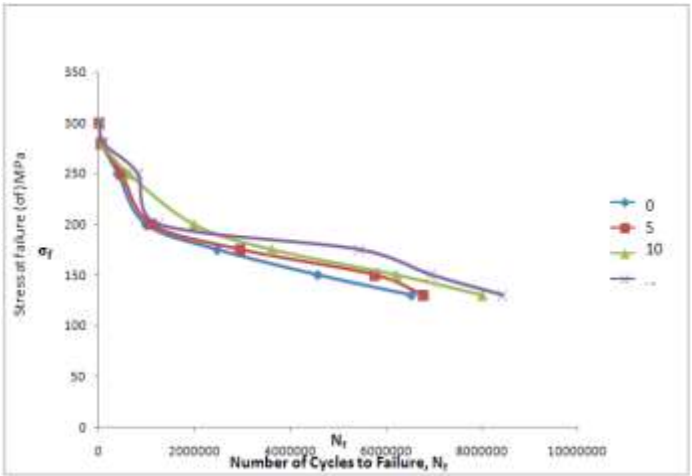

Fig 4. Comparison between S-N Curves for unpeened and peened in different time (5,10,15 min)

Figure (4) shows that the shot peening process is considered as an excellent approach for the improvement of the fatigue life of metal parts. This increase in fatigue life is a result of the creation of compressive stresses in metal surface after peening. In reverse bending, peening reduces the peak tensile stresses in the metal part and moves away from the surface [6]. The time required for the peening depending on:- a. Element intensity. b. The coverage rate. c. Surface roughness.

Also by increasing the peening time, more compressive stresses at the surface are developed. However, increasing time further promotes sub-surface crack initiation especially in the aluminum alloys. Therefore, the development of sub-surface crack will influence the effectiveness of shot peening enhancement [7]. Thus, the time of peening must be chosen carefully to avoid the contrast result of high shot time.

Fatigue life against shot peening of specimens made of aluminum alloys was experimentally investigated The benefits of shot peening in terms of fatigue life are dependent on the SPT. The higher the SPT is the lower the benefit is for time $0 < t < 15$ min. The fatigue life improvement factor (LIF) is limited up to 15 SPT and equals to 3.185 .

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Fatigue life improvement

There are several factors responsible for the improvement in fatigue life such as, compressive residual stress, increase the hardness of surface and the surface roughness. These factors reduce the possibility of a propagation fatigue crack. Table (4) shows the improvement in fatigue life cycles in different time of peening based on the equations in table (3).

Table 4. The improvement in fatigue life cycles at different time of shot peening

ZeroN_f	5minN_f	10minN_f	15minN_f	Applied Stress (MPa)
21829	23340	37773	45945	300
38480	41435	65311	78241	280
97645	106375	160548	187588	250
610876	680893	943482	1049462	200
1830075	2067954	2722621	2940598	175
6494800	7455942	9253603	9660517	150

As shown in table (4), there is significant improvement in fatigue life with the increase in the time peening due to increase the Element intensity, and the magnitude of the layer of compressive residual stress is increased. Also by increasing the time period, the number of deformed grains will increase so the defected grains will be more homogenously detected and that will arrest crack propagation due to crystal dislocations.

The improvement in fatigue life percentage can be summarized in table (5).

Table 5. Improvement percentage in fatigue life under shot peening (5,10and 15min)

Applied stress (MPa)	Fatigue life improvement % (FLI%)		
	5min.	10min.	15min.
300	6.9	73	101
280	7.67	69.3	103
250	8.94	64.42	92.1
200	11.46	54.4	71.79
175	12.99	48.77	60.68
150	14.79	42.47	48.74
Average FLI %	10.45	58.8	79.55

More recent test have shown a relationship between mean life improvement factor (LIF) and maximum applied stress as in the equation below [9].

$LIF = 6*10^{15} (\sigma)^{-5.8749}$ -------------------------------------(1)

Equation (1) shows a rapidly increasing LIF with lower stress, but detailed results showed the lower bound LIF value increases a lot more slowly. At the stresses (400-420MPa) examined in many of the research programs a LIF ≈ 1.5 is conservation and appropriate.

For the present work the fatigue life improvement percentage FLI% against the applied stress is shown in figure (5) for different shot peening time, and the best fitting equation is an follows :-

$FLI\% = 16975\ \sigma^{-1.379}$ --------------- 5(SPT) ----------- (2)

$FLI\% = 0.787\ \sigma^{0.797}$ --------------- 10(SPT) ---------- (3)

$FLI\% = 0.1197\sigma^{1.199}$ --------------- 15(SPT) ---------- (4)

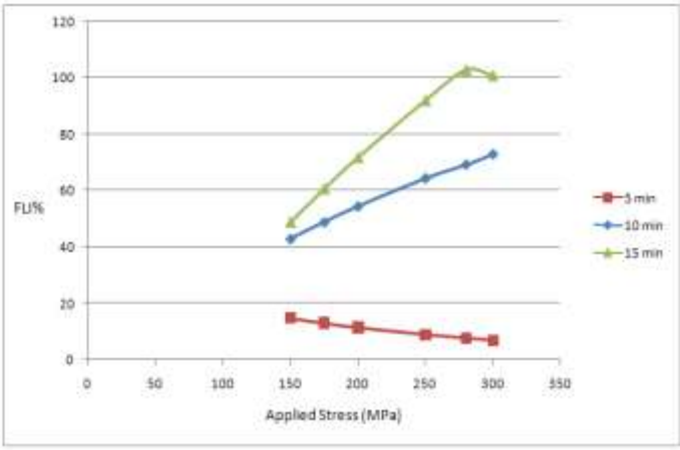

Fig 5. Fatigue life improvement percentage (FLI%) against the applied stress for different SPT.

The benefits of shot peening in terms of fatigue life extension are dependent on the applied stress the higher the applied stress the lower the benefit. For the test stresses described here the fatigue improvement life percentage (FLI %) is increased when the applied stress decreased.

Figure (6) represents the curve for the fatigue life improvement % and the applied stress, shows that the time of shot peening is in the range (5,10 and 15min.). The number of cycles to failure increase as the shot peening time increase up to about (10min). After that the rate of the number of cycles decrease.

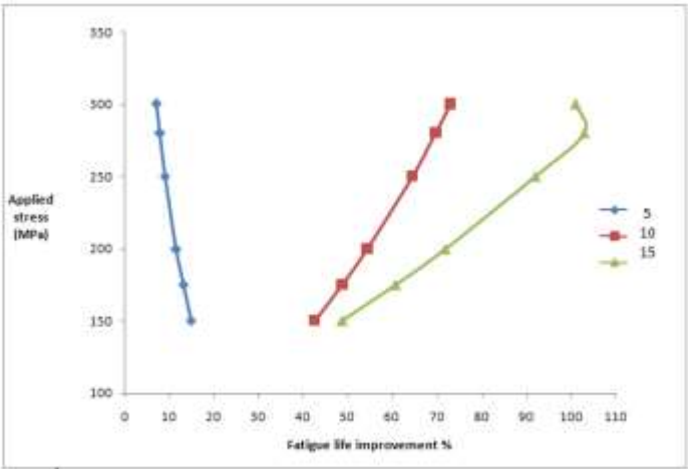

Figure 6. Fatigue life improvement in different time (5,10,15min)

Conclusions

In this investigation, the effect of shot peening on fatigue life was studied on Al 7075-T651and the following remarks were concluded:

1. An increase in shot peening time (SPT) resulted in an increase in fatigue life improvement percentage (FLI%).
2. At shot peening (5SPT) the fatigue life was increased and a significant improvement was observed at low stresses. Reducing the applied stress, increasing the FLI%
3. At shot peening (10 and 15 SPT)the fatigue life was improved clearly at high stresses . Reducing the applied stress, reducing the FLI%.
4. It is very complex to obtain the best shot peening time (SPT) condition to increase the fatigue life and strength, because it depends on several factors

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