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Mechanical Properties and Fatigue life Evaluation under high temperature and shot peening application using AA7001

Huda S. Mahdi [1,] Hussain J. M. Alalkawi [2*] and Saad T. Faris[3]

[1] Diyala University , Dep. Of Mechanical Engineering , Diyala, Iraq
Dr.saadtheeyab@engineering.uodiyala.edu.iq

[2] Bilad Al-rafidain University College, Aeronautical Techniques Engineering Dep.
Dr.algawi@bauc14.edu.iq

[3] Diyala University , Dep. Of Mechanical Engineering , Diyala, Iraq eng_grad_mech014@uodiyala.edu.iq

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ABSTRACT

In some applications, AA7001 may be subjected to high temperature and fatigue. This interaction leads to varying the mechanical and fatigue properties of the above alloy. This work deals with the effects of tensile properties and constant fatigue amplitude performance. Aluminum alloys have low specific strength, are simple to produce, and are lightweight, which has made them popular in the construction, automotive, marine, and aviation industries. The history of stress and temperature applied to the component has a significant impact on the time-dependent process of creep and strain damage. The purpose of this research is to investigate the behavior of AA7001-T6 when two phenomena, high temperatures creep and fatigue, are combined. When compared to the fatigue life interaction employing shot peening thereby, the fatigue lifetimes were increased in this interaction. The influence of shot peening on the mechanical and fatigue characteristics of AA7001-T6 was investigated utilizing four different temperatures, including RT, SP+RT, 330°C, and SP+330°C. it has been observed The application of 330°C to the tensile process lowered the ultimate tensile strength of UTS and YS by 21.9 % and 22.3 %, respectively. Shot peening improved the aforesaid percentage, lowering it to 19.2 % and 19.7%, respectively. At a stress level of 400MPa, fatigue life was lowered by 18.18 % owing to an increased temperature of 330°C, and this percentage was reduced to 10.16 % due to creating the compressive residual stresses (CRS) (SP). At (RT), the fatigue strength (endurance fatigue limit) was 229 MPa, but after Shot Peening, it improved to 237 MPa. At 330°C, shot peening increased the improved fatigue limit from 217MPa to 229MPa, resulting in a 5.24 % improvement.

Keywords: AA7001-T6, Fatigue at high temperatures, Mechanical properties, Shot Peening treatment.

1. INTRODUCTION

Fatigue is an extremely common failure mode and deserves considerable titration because it can inflict damage on a material at a stress level that is less than the yield stress. Fatigue has been attributed to playing a role in approximately 90 % of all material structure failures [1]. At high temperatures, fatigue can act simultaneously to produce harmful effects on a material i-e cyclic strain and creep strains that can seriously compromise the material's expected lifetime, If the material experiences cyclic fatigue and undergoes high temperature (creep), its fatigue life can be greatly reduced [2]. AA7001 is a precipitation-hardened zinc alloy. It has high mechanical and corrosion resistance, as well as long service life. As a result of external and internal challenges, a variety of complications develop during machine service. Defects produce initiation cracks; they grow over time until they reach a certain length, at which point they collapse catastrophically [3]. You can avoid such problems and save money on the cost of

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eng_grad_mech014@uodiyala.edu.iq

replacing or servicing damaged parts, which can soon mount up. Shot peening (SP) and ultrasonic impact peening (UIP) are low-cost, easy-to-apply, and standard surface treatments for improving mechanical and fatigue characteristics (UIP). Ultrasonic impact peening (UIP) and shot peening are two methods for improving a material's fatigue strength (SP). The number of cycles it takes for a fatigue life to fail at a given load is known as "fatigue life." When materials in structures are exposed to dynamic and changeable forces, the most common failure scenario occurs[4] .Shot peening is a method of blasting a treated surface with small, spherically shaped metal or ceramic glass particles propelled by a rapid impeller through compressed air, water, or air. Localized plastic deformation occurs as a result of the collision, resulting in surface perfection weakness, increased surface hardness, and considerable residual compressive surface stress. [5].SP is a cold-working technique that dates back to the late 1920s. Material land (CRS) district plastic deformation near the impact zone results from a considerable contact between the shot (glass made up of ceramic-metallic circles) and the substrate (the handled portion)[6].The following changes in metallic composition improved fatigue characteristics significantly, prolonging the engineering component's service life[7].The SP method was shown to generate more considerable levels of CRS in pre-stressed metallic content[8, 9, 10].

2. MATERIAL AND METHODS

2.1 Materials selection

Because of their high specification dependability, excellent corrosion resistance, and low cost, aluminum alloys are frequently utilized in structural applications in the aircraft, automobile, and construction sectors. Aluminum is the primary material in this piece. The AA7001 has the highest strength of all working aluminum alloys [16].

2.2 Tensile test

Tensile tests were performed at (RT) and 330°C to determine the experimental mechanical parameters indicated, utilizing a (WDW-50) tensile test equipment with a 200KN capacity. The tensile specimen's form and dimensions are depicted in **Figure (1)**. (ASTM A370) was used to choose the tensile specimen.

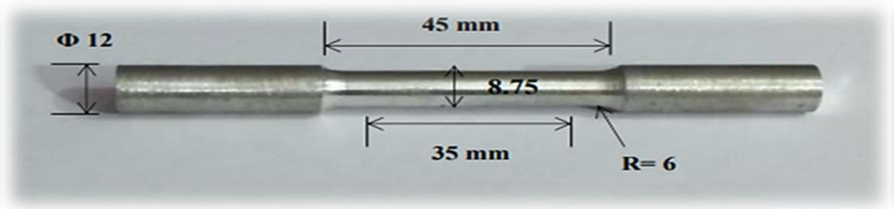

Figure 1. Tensile test specimen according to (ASTM A370), All dimensions in (mm)

The tensile test is carried out using a material tensile test rig to measure the mechanical characteristics of AA7001 at (RT) and 330°C The tensile test rig is illustrated in Figure (2).

Figure 2. High-temperature tensile test specimen loaded into the grips with proper alignments.[17]

2.3 Fatigue test

A programmed CNC lathing machine was used to create the sample. According to the cylinder fatigue study's fundamental specifications (DIN 50113), Figure (3) shows the fatigue test sample

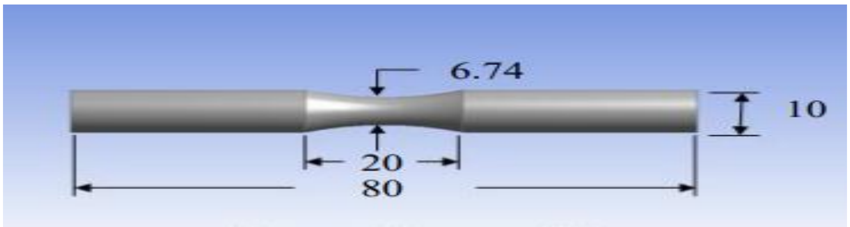

Figure 3. Fatigue test specimen, All dimensions in (mm) according to (DIN 50113) standard specification.

Fatigue–testing machine of type PUNN rotating bending is used to execute all fatigue tests with constant and variable loading, as shown in Figure(4)**.** The applied stress (σ_f) at failure is calculated from applying

the equation, $\sigma_f(\mathrm{MPa}) = \frac{32\times125.7\ \mathrm{P(N)}}{\pi d^3}$ (1)

Where The arm of the force (P) is equal to (125.7) mm, (P) is applied force (in Newton), and (d) is the minimum diameter of the sample in (mm).

Figure 4. Complet fatigue elevated temperature test machine (Furnace attached to fatigue machine with the control board).

2.4 Shot Peening test machine

The shot peening technique was carried out at room temperature on specific testing equipment (Shot Tumblast Control Panel Model) (STB-OB). at the Institute of Technology. This machine is seen in Figure (5). Cast steel balls with an average diameter of (1) mm and a ball velocity of about (40) m/s were employed to shoot the specimens. The nozzle and the specimen's surface are separated by a distance of (10) cm. The ball had a (48–50) HRD Rockwell hardness. The specimens were moisturized with water before the photograph was taken.

a- General (SP) machine

b- (SP) treatment with samples inside the container rotation

Figure 5. The shot peening device.

The specimens before and after the shot peening technique are shown in Figure (6). Table (1) gives the main parameters of the (SP) device.

Figure 6. Specimens before and after shot peening.

Table 1. shot peening process parameters

Peening pressure	**12 bar**
No. of balls for each operation (run)	**50**
Speed	**40 mm/min**
Distance from jet to the specimen (cm)	**15cm**
Average ball size	**0.6mm**
Goverage	**100%**

3. RESULTS AND DISCUSSION

3.1 The chemical and mechanical properties

Table (2) shows the experimental chemical composition of AA7001 in comparison with the standard [18].

Table 2. Chemical composition of AA7001 in wt%

Elements wt %.	Zn	Si	Fe	Cu	Mn	Mg	Cr
Standard [18]	6.8 - 8	0.35	0.4	1.6-2.6	0.2	2.6-3.4	0.18-0.35
Experimental	6.1	0.33	0.4	1.85	0.18	3.1	0.27

The experimental mechanical properties(UTS, ultimate tensile strength), YS(yield stress), E(modulus of elasticity), and ductility .are presented in table (3). The tensile tests were done at four cases (RT) room temperature, SP before testing at (RT), elevated temperature (330°C) only, and finally (SP) before tensile test.

Table (3). Mechanical properties of AA7001

Condition	UTS(MPa)	YS (MPa)	E(GPa)	Ductility
Standard(RT) [19]	676	627	(69-73)	9
Exp(RT)	683	644	71	9
Exp(SP+RT)	702	672	71	9
Exp(330°C)	533	500	60	12.7
Exp(SP+330°C)	551	517	62	11.5

The variation in UTS and YS due to elevated temperature and SP treatment can be seen in figure(7).

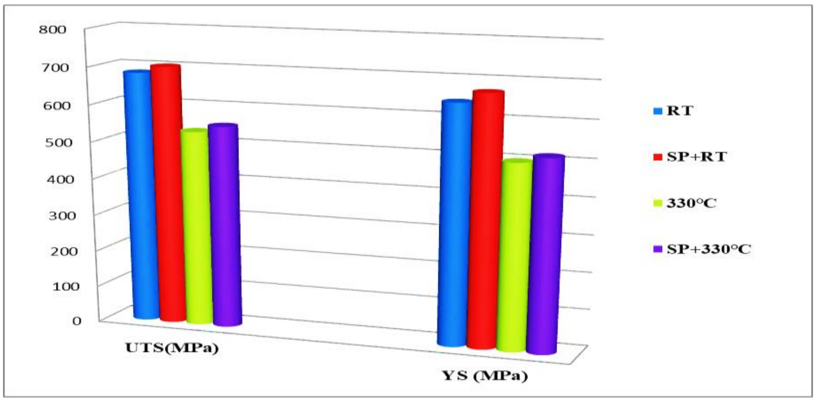

Figure 7. Duration of UTS and YS under high temperature and (SP) treatment

At elevated temperature, if the material experiences tensile load while undergoing creep. The mechanical properties like UTS and YS can be significantly reduced. The combined effect of tension and creep reduces the strength of the material and increases ductility. The UTS and YS reduced from 683 to 533 and 644 to 500 MPa when the temperature rises from 25℃ to 330℃ respectively. The reduction in strength due to applying high temperature (330℃) was recorded to be 21.9% and 28.8% for UTS and YS respectively. While ductility increased from 9 to 12.7. Applying temperature to aluminum alloy when examined under tensile test was found to increase the work hardening, (n) in the equation $\boldsymbol{\sigma = k\epsilon^n}$ from 0.23 to about 0.29 (above 200℃). This leads to reducing the value of (σ)[20]. Shot Peening (SP) is a cold working process in which the surface of a part is bombarded with small spherical media called shots. A hemisphere of cold-worked material is highly stressed in compression to prevent cracks to initiate and propagate. Benefits obtained by (SP) are the result of the effect of the compressive residual stress (CRS)and the cold working induced. CRS is beneficial in increasing the strength of material and resistance to fatigue failure, corrosion fatigue, and creep-fatigue interaction[21].

For the majority of materials, the yield strength decreases with increasing temperature. In metals, this decrease in yield strength is due to the thermal activation of dislocation motion, resulting in deformation at higher temperatures.

3.2 Experimental fatigue results

The test series of the experimental work is divided into four series (RT, SP+RT, 330℃, and SP+330℃) using 36 specimens, for each series nine specimens were tested, to estimate the basic S-N arrives for rotating bending for rotating loading. The roughness was found to be equal to Ra = 1.5µm, and this is an average value for all shot-peened specimens. The complete experimental fatigue results for the above series can be illustrated in the table (4).

Table 4. preliminary data of AA7001 with 10 mm. shot peening and without peening.

Condition	Spec. No	Applied Stress (MPa)	Nf cycles	Spec. No	Applied Stress (MPa)	Nf cycles	Spec. No	Applied Stress (MPa)	Nf cycles
Lab-air RT(25℃)	1 2 3	516 (0.75UTS)	18600 22500 24600	4 5 6	447 (0.65UTS)	74800 82800 66000	7 8 9	378.5 (0.55UTS)	190800 225800 244000
(SP+RT)	10 11 12	516 (0.75UTS)	22600 30700 34000	13 14 15	447 (0.65UTS)	102800 110200 98800	16 17 18	378.5 (0.55UTS)	266000 286600 305000
330℃	19 20 21	516 (0.75UTS)	5500 4200 6000	22 23 24	447 (0.65UTS)	21800 19900 24500	25 26 27	378.5 (0.55UTS)	82800 77000 65800
(SP+330 ℃)	28 29 30	516 (0.75UTS)	6200 7000 5200	31 32 33	447 (0.65UTS)	28200 30000 31600	34 35 36	378.5 (0.55UTS)	106000 94600 88800

The deduced S-N curve relations for AA7001 rod samples for the above series can be tabulated in the table (5)

Table 5. S-Ncurve equations for the four series above.

Condition	S-N curve equation	R^2	σ_f.L (MPa) Endurance fatigue limit at 10^7cycles
Lab-air RT(25℃)	$\sigma_f = 1980\ N_f^{-0.133895}$	0.9939	229
(SP+RT)	$\sigma_f = 2077\ N_f^{-0.13466}$	0.9883	237
330℃	$\sigma_f = 1401\ N_f^{-0.1158}$	0.9921	217
(SP+330℃)	$\sigma_f = 1375\ N_f^{-0.1113}$	0.9832	229

Table (5) shows the S-N curve equation based on the Basque formula of the general form
$\sigma_f = A\, N_f^{\alpha}$

Where **N_f**: fatigue life at failure (cycle)
σ_f: applied stress at fatigue (Mpa)

A and **α** are material constants that can be obtained by linearizing the curve using the logarithmic form of equation $\sigma_f = A\, N_f^{\alpha}$

$$\alpha = \frac{h \sum_{i=1}^{h} \log \sigma fi \ \ log\, Nfi - \sum_{i=1}^{h} \log \sigma fi \ \ \sum_{i=1}^{h} logNfi}{h \sum_{i=1}^{h} (logNfi)^2 - [\sum_{i=1}^{h} logNfi]^2} \tag{2}$$

And

$$\text{Log A} = \frac{\sum_{i=1}^{h} \log \sigma fi - \alpha \sum_{i=1}^{h} log\, Nfi}{h} \tag{3}$$

Where **h:** is No.of stress levels applied

The behavior of AA7001 at four conditions of testing can be presented in figure (8).

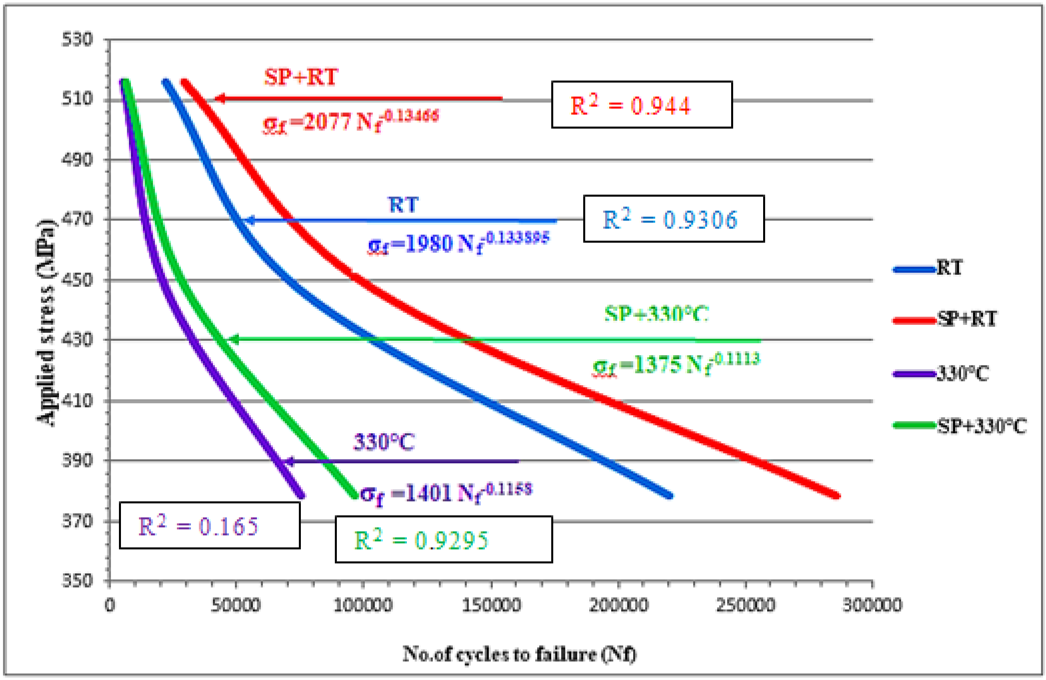

Figure 8. shows the S-N curves for fatigue at four cases of testing showing a correlation factor R^2 close to unity

Aluminum alloys are sensitive to high temperatures ranging between 200 and 250 °C(392and 482 °F)and might lose some of their strength [22].
Fatigue at high temperatures has become progressively more prevalent in automobiles, compressors, turbines, pumps, and aircraft. Aluminum alloys 7001 is a heat treatable, high strength, structural aluminum alloy .It was formely known as Aluminum HZM-100[23]

3.3 Shot peening effects

Shot peening has enhanced the fatigue property of AA7001. The importance is due to compressive residual stresses (CRS) generated on the surface of the specimen. The (CRS) due to (SP) process arises the S-N curve level, The results are similar to that found.The fatigue life were enhanced by 54%

for SP by Marwa et al [24]. Elevated temperature-fatigue interaction is one of the most significant features of many machines. The fatigue life was reduced due to high-temperature application, for the present work 330℃ temperature environment was applied and the result showed that at stress σf = 400 MPa, for example, the fatigue life was reduced from 36970 cycle at (RT) to 30246 cycle at 330℃, exhibiting 18.18% reduction. while this percentage improved to 10.16% due to the application of shot peening. Also, the fatigue strength (Endurance fatigue limit stress at 10^7 cycles) is found to 229MPa at (RT), and this value raises to 237MPa due to (SP) resulting in a 3.37% strength improvement. At 330℃, the fatigue strength was recorded to be 217MPa but when using (SP) this value improved to 229MPa showing an improvement percentage of 5.24%. The (SP) induces compressive residual stress (CRS) which reduces the tensile mean stress due to the applied loads and production whereby it raises fatigue strength and life. These conclusions are in good agreement with what is found [25][26].

4. CONCLUSION

The effect of shot peening (SP) on mechanical and fatigue properties of AA7001 has been studied using four cases of testing i-e (RT), (SP+RT), (330℃), and (SP+330℃). The major conclusions drawn from the present work can be summarized below :

1. The ultimate tensile strength (UTS)and (YS) were reduced by 21.9% and 22.3% respectively due to the application of 330℃ to the tensile process.
2. Shot peening improved the above percentage resulting in reducing the above percentage to 19.2% and 19.7% respectively
3. Fatigue life reduction due to elevated temperature (330℃) was recorded to be 18.18% at stress level 400MPa, and this percentage was reduced to 10.16% due to generating the compressive residual stress (CRS) created by (SP).
4. The fatigue strength (Endurance fatigue limit) was observed to be 229MPa at (RT) and it improved to be 237MPa due to (SP).
5. Shot peening treatment enhanced the enhanced fatigue limit from 217MPa to 229MPa at 330℃ resulting in a 5.24% improvement percentage.

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