Improvement of Fatigue Property in High Strength Aluminum Alloy by Shot Peening

Hussain J.Al-Alkawi¹, Tag Elsir Hassan², Basil Ahmed Selman, Ali Yousif Khenyab³, Mohammed j.Kadhim⁴

Abstract

Shot peening process has both the beneficial and detrimental effects; therefore, it is difficult and time-consuming task to determine the optimized process parameters based on the fatigue life. In this study the fatigue of 7001-T6 high strength aluminum alloy has been investigated before and after a shot peening is beneficial for a treatment to investigate where a shot peening is beneficial for a component with this combination. The effect of 12 min. shot peening on the fatigue behavior of the material used gave an increase in the fatigue life of up to 2.49 times depending on the applied stress, and a 28.34% increase in the endurance limit of the material. Cumulative fatigue damage was conducted under low-high and high-low stress amplitude. The fatigue life prolonging factor (FLPF) was calculated for different stress amplitudes and it was found that this parameter is an indicator for prolonging the fatigue life.

Keywords: shot peening, fatigue, high strength, aluminum alloy, residual stress.

مستخلص

تأثيرات عمليات القذف بالكريات المعدنية لها فوائد ومضار ومن الصعوبة ضياع الوقت لاستخراج العوامل المثالية معتمداً على عمر الكلال. في هذه الدراسة تم بحث الكلال لسبيكة الالمنيوم 7001-T6 عالية المقاومة قبل وبعد المعاملة بالقذف بالكريات لمعرفة تحسين خواص الكلال للمادة. تأثير القذف بـ 12 دقيقة على سلوك الكلال

¹ Professor , University of Technology-Electromechanical Eng. Dept. Iraq

² Omdurman Islamic University-Faculty of Engineering Sciences-Mechanical Eng. Dept. Sudan

³ Msc. Student- Omdurman Islamic University-Faculty of Engineering Sciences-Mechanical Eng. Dept. Sudan

⁴ Assistant Lecturer-University of Mustansiriyah-College of Engineering-Materials Eng Dept. Iraq

للمادة المستخدمة ففي هذا البحث اعطت زيادة في عمر الكلال لحد 2.49 مرة معتمدة على الاجهاد المسلط وزيادة حد الكلال بنسبة 28.43 لهذه المادة. كلال الضرر المتراكم تم انجازه تحت تحميل واطيء-عالي وعالي-واطيع للاجهادات المسلطة. عامل اظالة عمر الكلال (FLPF) تم حسابه لسعة اجهادات مختلفة ووجد ان هذا العامل هو مؤشر لاطالة عمر الكلال.

1. Introduction

Shot peening is a cold working process widely used to improve the fatigue life of metallic components[1]. Several shot peening parameters ,such as shot size , type, velocity, incidence angle, material properties of the target components ..etc have a great influence on the effectiveness of the treatment. Shot peening has both the beneficial and detrimental effects, therefore, it is a difficult and time –consuming task to determine the optimized process parameters based on the fatigue life prolonging factor under the same stress/strain condition and/or fatigue strength improvement percentage under the given fatigue life ,usually for the 1×10^7 cycle [2]. The effect of shot peening on fatigue life extension for 7475-T7351 Al. alloy, reduce small crack growth rates. This beneficial effect is attributed to the compressive residual stresses induced by shot peening in the surface layer [3]. The compressive residual stress field (CRSF) introduced by shot peening was studied comprehensively. The 40 cr steel which is widely applied in industry materials was used and shot peened under different conditions. The maximum of (CRSF) for given material is almost the same even under different shot peening technique, and the surface residual stress value are dependent on both the mechanical properties of target materials and peening parameters[4]. The high cycle fatigue performance of 7075-T7451 aluminum alloy was investigated for untreated, laser peened, and

shot peened conditions under four-point bending at a stress ratio of $R=0.1$. Results show that laser peening induces a layer of compressive residual stress more than three times deeper than for shot peening and both treatments significantly increase fatigue performance [5]. The fatigue life of sand – cast A8 magnesium alloy has been investigated before and after a shot peening treatment to investigate whether shot peening is beneficial for a component this combination of relatively low strength and relatively poor initial surface finish. The results show that the fatigue life is significantly improved by the shot peening process [6].

The fatigue strength increased with peening time until 1000 sec. above which it remained constant. Shot peening created a nanocrystalline surface layer which improves the fatigue strength of compressive coil springs made from oil tempered wire [7]. The depth of compression can be increased by higher intensity peening ,realized by increasing the duration of shot bombardment ,peening with larger or higher velocity shot, or both however increased shot peening intensity increase roughness and the level of cold work at the surface, both of which reduce fatigue performance[8]. Post-peen polishing can improve surface quality, but material removed by polishing decreases the benefits of shot peening because the layer of compressive stress is typically shallow ,Hence ,successful fatigue enhancement from shot peening is a compromise between beneficial compressive residual stresses and detrimental effect on surface quality[9]. The objective here is to explore the effect of shot peening on the performance of 7001-T6 aluminum alloy, a material used in fatigue –critical aircraft components. The 7001-T6 alloy is

commonly selected for aircraft application because of its high strength, high resistance to stress corrosion cracking and good fracture toughness [10].

2. Material

Wrought aluminum alloy 7001-T6 was used in this study due to its one of the most versatile, economic and attractive metallic materials. The AA 7001-T6, low-specific weight and high strength to weight ratio and also high electrical and thermal conductance. This alloy is widely used in industry.

Chemical composition of this alloy used in this study is given in table (1) and the mechanical properties are listed in table (2).

Table (1): The Chemical Composition of Aluminum (7001-T6 AL) Alloy, wt%

Elements	Cu	Mg	Zn	Mn	Si	Rem.
Standard aluminum alloy (7001-T6)	1.6-2.6	2.6-3.4	6.8-8.0	0.2	0.35	Al
experimental	2.01	2.8	6.95	0.206	0.34	Al

Table (2): The Mechanical Properties of Aluminum (7001-T6 AL) Alloy

Property	Tensile strength	Yield strength	Ductility percent	Endurance limit	Modulus of elasticity
	(KSi) (MPa)	(KSi) (MPa)		(MPa)	(Gpa)
standard	98676	91 627	9	152	73
experimental	94 649	88 606	10	111	70

3. Experimental procedure

Figure (1) shows the configuration and dimensions of fatigue specimens were machined from 2.1mm thick rolled plates with length direction of specimens parallel to longitudinal rolling direction. The final machining is the fine grinding and the surface roughness of machined specimens is Ra (average roughness) 0.7-1.3 μm .

Figure (1): Shows the Dimensions of Fatigue Specimens

Fatigue tests were carried out on reversed-bending machine (Avery Denison LTD) with frequency of 5 HZ at room temperature and stress ratio $R=-1$. Figure (2) shows the fatigue test.

Figure (2): Reversed-Bending Fatigue Test Rig.

Three groups of specimens were used for fatigue tests. The first group was untreated as machined, tested as the referenced ones. The second group was the shot peened ones under 12 min. The third group was the cumulative fatigue tests without and with shot peening at the same time of peening. The peening operation was performed in a special test rig (Shot Tumbler Control Panel model STB-OB). This apparatus enables a defined shot peening treatment on round and flat specimens.

Figure (3): Shot Peening Test Device

The ball material was cast steel with an average ball size of diameter 1mm and a Rockwell hardness of 48-50 HRC. The number of balls at the whole operation time was kept constant for a wide range of peening pressure around 12 bars resulting in ball velocities of nearly 40m/s. More details can be found elsewhere [9]. Figure (3) shows the shot peening device.

4. Results and Discussion

Figure (4) shows the $S-N$ data for the peened and unpeened samples. It can be seen from this figure that shot peened specimens show an increase in fatigue life as compared to the unpeened specimens across the whole range of stress amplitudes, as well as an increase in the endurance fatigue limit.

Figure (4): the S-N Curve Behavior of 7001-T6 AL Alloy

The data does show some scatter and the average increase in fatigue life for shot-peened specimens is often greatest at lower stress amplitudes and diminishes at higher stress amplitudes. At higher stresses the residual stress imparted by the peening process are often quickly overcome [11] whilst at lower stresses the peening can give an order of magnitude improvement in resistance to fatigue life. These observations are in good agreement with the findings of Ref. [6] The behavior of the present alloy used can be described under constant loads by the following equations:

$$\sigma_f = 1620 N_f^{-0.134} \text{ unpeening specimens...} \quad (1)$$

$$\sigma_f = 1893 N_f^{-0.138} \text{ peening specimens} \quad (2)$$

Also figure (4) shows that the improvement in fatigue life is good over the whole stress amplitudes tested in this study. Table (3) gives the improvement factor over a wide range of applied stress.

5. Roughness Tests

The performance of controlled shot peening in terms of fatigue it is balance between its beneficial (compressive residual stress and work hardening) and detrimental effects (surface roughness). As shown in table (3). The process of shot peening produces compressive residual stress which in turns increases the surface hardness as result.

SEM examination shows that the surface roughness increases after shot peening.

Table (3): Roughness results under with and without S.P

SP T _{min}	Roughness Ra (μm) of AA 7001-T6
Zero	0.66
12	2.124

6. Microstructure of 7001-T6 Al. Alloy

The image analysis is results and scanning electron microscope (SEM) photographs taken from the surface of A.A 7001-T6 specimens after and before SP are presented in fig (5). According to this figure shot peening (12 min) increased the surface roughness due to local deformation of surface by

peening which increase the number of dimples per unit area of the surface. This behavior has been reported in other research and depends on material properties and shot peening time.

Figure: (5) SEM Image of Surface after and before S.P

7. Crack Growth

Development of crack growth after S.P was measured and with crack growth in specimens without SP. Retardation of crack growth was significant particular for cracks shorter than 2mm. For the specific stress amplitude. Evaluated results enable to estimate threshold of defects, which after the application of the shot penning will be reliably arrested fig (6) shows the fatigue fracture surface.

Figure (6) SEM Fractures Surface of AA 7001-T6

Table (4): Improvement Fatigue Life Factor (IFLF).

Stress applied (MPa)	Unpeened life (cycle)	peened life (cycle)	IFLF
186.86*	10^7	19373356	1.937
240**	1544664	3159080	2.045
300	292163	627067	2.146
400	34138	77976	2.284
500	6457	15478	2.397
600	1656	4130	2.49

*endurance fatigue limit for unpeened specimens at 10^7 cycles.

** endurance fatigue limit for peened specimens at 10^7 cycles.

The variation of IFLF is from 1.937 to 2.49 i-e the factor is a round 2.2. barry et.al[4] found that the increase in fatigue life of up to five times

depending on the applied stress amplitude for cast magnesium A8. These increases are significant, and show that the peening treatment may be highly attractive in improving the fatigue life of 7001-T6 Aluminum alloy. There is also an increase in the endurance limit at 10^7 cycles, from 186.86 MPa to 240 MPa; an increase of 28.43% in the available applied stress amplitude. Barry et.al[6] also found that an increase of 30% in the available applied stress amplitude. An increase in the surface roughness of the specimens was found after peening (1.8-2.2 μ m) at 12 min. peening but this was not found to be detrimental to the fatigue performance.

8. Cumulative Fatigue Damage under Shot Peening Treatment

Following the work of Gao [2]. To determine the effect of peening on fatigue property, the FLPF (fatigue life prolonging factor) analysis under the same stress or strain conditions is used. The FLPF is calculated as: [2]

$$FLPF = \frac{N_{modified} - specimen}{N_{baseline}} - 1 \quad (3)$$

Three specimens were taken as a group and made the average fatigue life as the fatigue of the group. For the different low-high and high-low stress amplitudes the fatigue lives of specimens and FLPF are listed in table (5).

Table (5): Low-high and high-low cumulative fatigue damage lives and FLPF under 12 min. shot peening

Unpeened specimen		peened specimen		Unpeened	peened	FLPF	Test program
Specimen No.	N_f cycle	Specimen No.	N_f cycle	N_f av.	N_f av.		
C1	1.82×10^5	C4	4×10^5	2.373×10^5	4.633×10^5	0.952
C2	2.2×10^5	C5	3.9×10^5				
C3	3.1×10^5	C6	6×10^5				
C7	1.1×10^5	C10	3.2×10^5	1.266×10^5	3.74×10^5	1.954
C8	1.8×10^5	C11	5×10^5				
C9	0.9×10^5	C12	3.02×10^5				
C13	0.88×10^5	C16	2.08×10^5	0.876×10^5	2.4×10^5	1.751
C14	0.75×10^5	C17	2.15×10^5				
C15	1×10^5	C18	3×10^5				
C19	3×10^4	C22	6.2×10^5	3.116×10^5	6.9×10^4	1.214
C20	2.1×10^4	C23	7.7×10^5				
C21	4.25×10^4	C24	6.8×10^5				

Shot peening under 12 min. improved the cumulative fatigue damage live. It can seen that table (4), the FLPF is more than zero value which indicates significantly improves the fatiguelives under cumulative damage. These results are in good a agreement with the results of Gao [2].

9. Fatigue Strength Improvement Percentage [FSIP]

The FSIP may be calculated as [2]:

$$FSIP = \left(\frac{\sigma_{E.L. \text{ modified specimen}}}{\sigma_{E.L. \text{ baseline specimen}}} - 1 \right) * 100\% \quad (4)$$

For the case study here, the FSIP was determined as 28.43%.this value presents an improvement in fatigue strength at 12 min. shot peening. Gao[2] found a variation in the FSIP value based on the time of peening (2.7% to 42.2% for different shot peening time) for 7050-T7451 aluminum alloy.

9. Conclusions

1. The effect of shot peening on the fatigue behavior of 7001-T6 aluminum alloy has been studied under reversed bending room temperature, stress ratio $R=-1$ and shot peening time 12 min.
2. A significant improvement in the fatigue life was provided, which an increase in the fatigue life of up to 2.49 times depending on the applied stress.
3. The fatigue strength at 10^7 cycle of 7001-T6 aluminum alloy was increased by shot peening .An increased in fatigue strength was 28.43% higher than the unpeened fatigue strength at 12 min. shot peening time.
4. The cumulative fatigue peened specimens lives were increased due to 12 min. shot peening i.e the FLPF was more than zero value i.e 0.952 to 1.954.

10. References

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