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The influence of shot peening on static and dynamic fatigue loading

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ABSTRACT

The present work was aimed to evaluate the effects of shot peening on the mechanical properties and the fatigue life of 5052- H34 aluminum alloy at different shot peening time SPT. Shot peening to full coverage (100%) was performed using carbon steel shots with an average shot size of 0.6 mm and at shot peening times of 10, 15, 20, 25 and 30 min. The 10 minutes shot peening time gave the highest value of (σ_u, σ_y) which is about 9.489% for (σ_u) and 10.36% for (σ_y). The fatigue endurance limit was raised by 10.93% at 10 minute shot peening time and then reduction was observed.

Introduction

Fatigue is an important parameter to be considered in the behavior of mechanical components subjected to constant and variable amplitude loading [1]. Although overall changes in material properties can influence the fatigue life, remarkable property changes can be achieved by localized modifications of the components surface. This is due to the fact that fatigue cracks generally tend to initiate from the weakest zone, which is normally at the surface [2]. There are many techniques to modify the surface and improve its fatigue properties, e.g. mechanical surface treatments such as shot peening and laser peening, thermal treatments such as induction hardening, and surface coating such as nitriding and carbonitriding [3]. One of the known treatments ways to improve fatigue behavior of metals is by using the shot peening technique. This technique employs blasting of the component surface by hard, small, high velocity shots creating localized inhomogeneous plastic deformation. The elastic sub-surface layers should theoretically recover to their original shape during unloading, however continuity conditions between the elastic and plastic zones do not allow for this to occur. Consequently, a compressive residual stress field is developed in the near-surface layer of the structural component [4]. Surface modifications produced by the shot peening treatment are: (a) roughening of the surface; (b) an increased, near-surface, strain hardening and (c) the development of a characteristic profile of residual stress [5]. Considering fatigue damage, surface roughening will accelerate the nucleation and early propagation of cracks, strain hardening will retard the propagation of cracks by increasing the resistance to plastic deformation and the residual stress profile will provide a corresponding crack closure stress that will reduce the driving force for crack propagation [6]. One the other hand, over peening can form craters and folds on the surface, which may cause cracks origins, due to the local plastic deformation or impact extrusion of the material parallel to the surface [7]. Shot peening conditions usually comprise the distance between the target material surface and the nozzle, the orientation between the surface normal and the particles flow, the size, shape, velocity, mass, hardness and flow rate of shot media, the treatment time, as well as the mechanical characteristics of the target surface [8]. The objective of this paper is to evaluate the shot peening time influence on the mechanical and fatigue properties of aluminum 5052- H34 alloy.

Experimental material

The aluminum alloy 5052-H34 was chosen for the present investigation. This alloy has good resistance to stress erosion in marine atmosphere and has good welding characteristics. This class of alloy has been widely used in low temperature applications, which satisfy the most severe requirements of liquefied fuel storage in aircraft and transportation at cryogenic temperature [9]. The chemical composition in wt% of the above alloy is given in table (1). Chemical analysis of 5052-H34 aluminum alloy was done at S.C of Geological survey and **Mining using X- Rays method.**

Experimental procedures

Shot peening

S-N curves were obtained for the aluminum alloy treated with different shot peening time (10, 15, 20, 25 and 30 min). The peening operation was performed in a special test device (Shot Tumblast Control Panel model STB-OB). This apparatus enables a defined shot peening treatment on round and flat specimens. The ball material was cast steel with an average ball size of diameter 0.6 mm and a Rockwell hardness of 48-50 HRC, with coverage of 100% for all conditions. 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 40 m/s. Figure (1) shows the shot peening device.

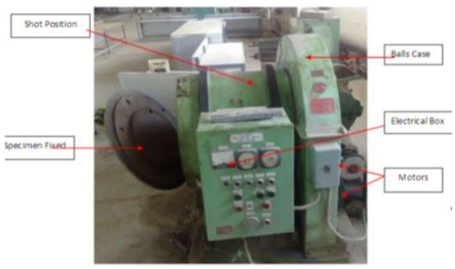

Fig. (1): Shot peening devic

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Tensile testing

Tensile tests were performed with testing machine type SHIMADZU with maximum capacity 600 KN. Figure (2) shows the tensile test rig used for the tensile specimens.

Fig. (2): Tensile test machine type (SHIMADZU-600KNI)

Tensile tests were done before and after shot peening at different time (10, 15, 20, 25 and 30 min).

Fatigue testing

Fatigue tests were performed using fatigue test rig type HI-TECH at stress ratio $R = -1$ and a frequency of 50 Hz (2870 r.p.m) at room temperature. The machine is shown in figure (3).

Fig. (3): Fatigue test machine

The specimens represented in figure (4) were tested in rotating-bending fatigue tests. S/N curves for all conditions studied were obtained by average results of three specimens in each stress level.

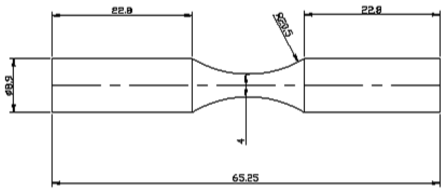

Fig. (4): Rotating bending fatigue testing specimens

Residual stress measurement

` The compressive residual stress field induced by shot peening can be calculated at different life by base on the S-N curve equations for different shot peening time compared with the S-N curve equation of unpeened specimen.

Results and discussion

Tensile tests

The results of tensile tests showed that the ultimate tensile strength (σ_u) and yield strength (σ_y) values increases and reached its maximum value at shot peening time (SPT) of 10 minutes. The values are gradually reduced at the time of 30 minutes as compared with unpeened specimen. The 10 minutes shooting time gave the highest value of σ_u and σ_y which is about 9.489% for σ_u and 10.36% for σ_y. The elongation percentage decreased up to 10 minutes and then increased. The results described above are shown in fig. (5) and table (2). Shot peening is known to improve the mechanical properties of metallic materials. The improvement in the mechanical behavior is derived from compressive residual stresses that are introduced into the near-surface of the components and which hinder crack initiation and growth [10]. Surface integrity changes induced by shot peening mainly include work hardning due to the increase in the dislocation density, gives the surface layer higher ultimate, yield strength and hardness but lower ductility [11].

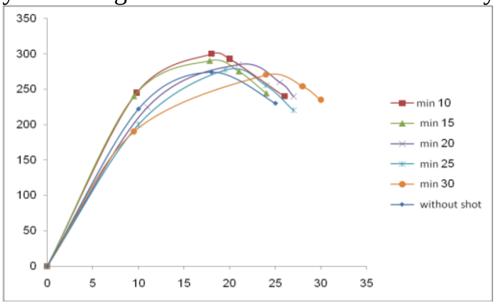

Fig. (5): Effect of shot peening times on the tensile test

Fatigue tests

The S/N curves for 5052-H34 aluminum alloy at different SPT are shown in fig. (6).It can be seen from the figure that the shot peened treatment at shot peening time 10 minutes show an increase in the figure life as compared to the as-machined S/N curve across the whole range of stress amplitudes, as well as an increase in the fatigue endurance limit, but over the value of 10 minutes SPT, the reduction in the fatigue life will be occurred. The average increase in fatigue life for shot peened specimens is often greatest at lower stress amplitudes and diminishes at higher stress amplitudes [10].

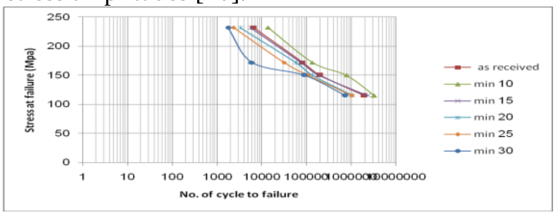

Fig. (6): S-N curve with different times of shot peening.

According to the Basquin equation, the S-N curve equations with shot peening time is expressed as

$\sigma_f = AN_f^m$ ------- (1)

The experimental constant (A, m) for the S-N curve equations can be shown in Table (3).

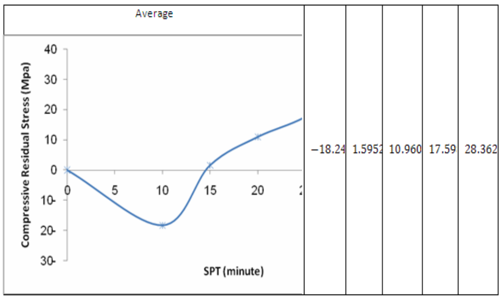

Fig. (7): Effect of shot peening time on compressive residual stress

The percentage increase in $\sigma_{E.L}$ is 10.93% in comparison with the as received $\sigma_{E.L}$ at shot peening time 10 minutes. Surface roughness from shot peening can also be a major detrimental effect to fatigue life. Shot peening roughens the surface, and thus produces many shallow pits which cause localized regions of stress concentration, which tend to lower the resistance to fatigue [12]. The performance of shot peening in terms of fatigue, depends on the balance between its beneficial (compressive residual stress and work hardening) and detrimental effects (surface roughness) [13], therefore, it occurs reduction in the fatigue life after 10 minutes shot peening time because of increase of surface roughness.

Table (1): Chemical composition of Al-alloy 5052-H34 (wt.%).

Elements	Si	Fe	Cu	Mn	Mg	Zn	Cr	Al
Nominal composition	0.25 max.	0.4 max.	0.1 max.	0.1 max.	2.2-2.8	0.1 max.	0.15-0.35	Rem.
Actual composition	0.14	0.31	0.027	0.014	2.41	0.02	0.23	Rem.

Table (2): Mechanical properties results under different shot peening times

SPT (minute)	σ_u	σ_y	El%
0	274	222	13.3
10	300	245	12.65
15	290	240	13.5
20	285	225	14
25	277	200	14
30	265	185	15.5

Table (3): S-N curve constant with shot peening time

SPT (min)	*A*	*m*	S – N curve equation	$\sigma_{E.L.}$	Increase in $\sigma_{E.L.}$%
Zero	691.83	-0.1243	$\sigma_f = 691.83 N_f^{-0.1243}$	93.3	0
10	753.328	-0.12315	$\sigma_f = 753.32 N_f^{-0.12315}$	103.5	10.93
15	640.73	-0.1177	$\sigma_f = 640.73 N_f^{-0.1177}$	96.111	3.01
20	624.05	-0.1204	$\sigma_f = 624.05 N_f^{-0.1204}$	89.622	-3.94
25	568.64	-0.11528	$\sigma_f = 568.64 N_f^{-0.11528}$	88.653	-4.98
30	472.121	-0.104	$\sigma_f = 472.121 N_f^{-0.104}$	88.319	-5.33

Table (4): Residual stresses at different fatigue life .

Fatigue life	10 min	15 min	20 min	25 min	30 min
10^3	−28.605	8.988	21.4999	36.709	62.983
10^4	−22.127	3.481	14.307	23.529	39.033
10^5	−17.101	0.1232	9.351	14.573	22.8077
10^6	−13.208	−1.808	5.967	8.568	12.006
10^7	−10.195	−2.808	3.68	4.6124	4.9841

Residual stresses

The residual surface compressive stresses reduce the possibility of a propagating fatigue crack by reducing the peak applied tensile stress [14]. Experimental surface residual stresses can be seen in Table (4). Figure (7) shows the variation of residual stresses against SPT. It is clear that the residual stresses is compressive residual stresses at 10 minutes and then tensile residual stress was created.

Conclusions

1. The mechanical properties ultimate and yield strength (σ_u, σ_y) increased by 9.489% and 10.36% respectively at 10 minutes SPT.
2. The elongation percentage decreased at 10 minutes SPT and then increased.
3. The S-N curve equations which may described the constant fatigue behavior at different SPT were found as:

SPT (min)	S – N curve equation
Zero	$\sigma_f = 691.83 N_f^{-0.1243}$
10	$\sigma_f = 753.32 N_f^{-0.12315}$
15	$\sigma_f = 640.73 N_f^{-0.1177}$
20	$\sigma_f = 624.05 N_f^{-0.1204}$
25	$\sigma_f = 568.64 N_f^{-0.11528}$
30	$\sigma_f = 472.121 N_f^{-0.104}$

4. The shot peening increased the constant fatigue life at 10 minutes and then reduction in life was occurred. The greatest increase in average fatigue life is about 3.85% at 150 Mpa for 10 minutes SPT.
5. Fatigue endurance limit was increased by 10.93% at 10 minutes SPT and then reduction was observed.
6. Compressive residual stresses increased at 10 minutes SPT and then tensile residual stress was created.

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