



Effect of Shot Peening on the Fatigue Life of 2024 Aluminum Alloy

Arshad Mehmood and M. M. I. Hammouda

Department of Mechanical Engineering, University of Engineering & Technology Taxila-Pakistan

ABSTRACT *Experimental study of the effect of shot peening parameters such as shot size, nozzle pressure, nozzle distance, impingement angle and exposure time on high strength aluminium alloy ASTM 2024 mostly used in air craft industries for cyclic loading applications has been presented. In the first part of research work, following the standard procedure, effect of peening parameters on the Almen strip and finally on the fatigue test specimens was studied. Surface texture changes occurred due to peening was examined using powerful optical microscope. Peening process also led to the formation of compressive residual stresses in the surface layer and was determined using hole drilling method. Based on the results, a set of optimum peening parameters was evolved. Machined (unpeened) specimens and peened specimen were tested using four point rotating bending fatigue testing machine to generate the SN-curves. The results indicated a considerable improvement in the fatigue life of peened specimens when compared with the fatigue life of unpeened specimens.*

INTRODUCTION

Shot peening is a well-established cold working process, widely used in automotive and aircraft industries. [1] The technique involves the impingement of a stream of spherical shots, directed at the metal surface at high velocity under controlled conditions [2, 14]. The process has useful applications in increasing fatigue strength, relieving tensile stresses that contribute to stress-corrosion cracking, forming and straightening of metal parts, and testing the adhesion of silver plates on steel [2,12].

Shot peening generates plastic deformation in the exposed surface layer and, thus, induces compressive residual stresses in that layer [14]. Thus, an improvement in the fatigue strength of shot peened components is commonly reported in the literature [1, 7, 9, 10, 16, 20]. Such an effect depends on the variables of the process, i.e. shot size, nozzle pressure, impingement angle, shot flow rate and nozzle distance from the specimen surface. Those variables are integrated in the form of Almen intensity [3, 7,10,16,]

Aerospace industry has a particular interest in aluminum alloys. Examples of relevant peened parts include fuselage skin, wing ribs, bulkheads, landing gear beam and wing lower skin of air

crafts. Helicopter rotor blades and some parts of their drive elements, high-pressure turbine and compressor discs are other examples. Some of those parts are made of Aluminum alloy 2024.

Fatigue life against shot peening of specimens made of aluminum alloys was experimentally investigated [12, 13, 16-17]. There are reports indicating variations in the fatigue life for peened components.

References [1, 7, 9, 10, 16, 20] have shown that shot peening has beneficial effects on the different grades of aluminium alloys.

On the other hand studies [4] have shown that steel shot peening (steel shot diameter between 0.35 and 0.7 mm to an Almen intensity of 0.010A, per SAE J442 standard) did not result in an increase in the fatigue endurance of aluminium alloy.

In some cases the fatigue limit of the shot peened specimens fell below that of the un-peened specimens. For example studies [6] have shown that steel shot peening with shot S 110 and S280 as per SAE J442 standard has decreased the fatigue life of aluminium alloys. [6]

For the best results, it is essential to optimize the various peening parameters. Analysis of the shot peening variables in terms of the total energy of the shot stream shows that for a given material being peened, a maximum value of surface stress is reached and stays constant over a wide range of energies. An optimum value of shot stream energy exists to obtain maximum fatigue life. This is related to shot size and flow rate through the physical effects of the shot impacting the work surface [7].

The results of different worldwide research works presented above indicates the importance of process quality control and peening parameters in peening aluminium alloys in terms of achieving the optimum improvement in fatigue life. This is not a simple problem and a number of parameters have to be carefully controlled to maximize fatigue life. These include peening media (Shot size, shot material, shot quality), pressure /velocity, Exposure time, peening distance etc. [1].

These references (4-7, 11-12) reveal that shot peening process depends upon peening condition or peening parameters. But it remains unclear how these parameters affect the peening quality and what are the optimum peening conditions for Aluminium alloys. Also, these inconsistent reports do not provide the high level of confidence required for the industrial adaptation of the process in the basic design considerations as long as fatigue strength is concerned. Detailed literature review and above presented results highlights further research areas and may be considered sufficient justification to the selected research work. The research undertaken will provide a good understanding of peening process, optimum peening parameters affecting the fatigue life of aluminum alloys and residual stress measurement.

EXPERIMENTAL WORK

Material and Specimen

The material in the present work was 2024 Aluminium alloy ASTM-B211. Table 1 lists the

mechanical properties of the tested material. The corresponding chemical composition in weight % was as follows: 0.1 Cr, 2.0 Cu, 0.5 Fe, 1.5 Mg, 0.6 Mn, 0.05 Si, 0.15 Ti, 0.25 Zn and remaining Al. Fig.1 shows the geometry of the present fatigue test specimen as per ASTM standard E606 [15]. Forty-five of such specimens were tested to obtain their S/N_f curve in both condition of as machined and after purposely-designed shot peening.

Table 1 Mechanical properties of Aluminium 2024 ASTM-B211

0.2 % Proof stress MPa	Ultimate tensile stress MPa	Elongation %	Poission's ratio	Elasticity modulus GPa	Brinell Hardness
324	393	20	0.33	73.1	120

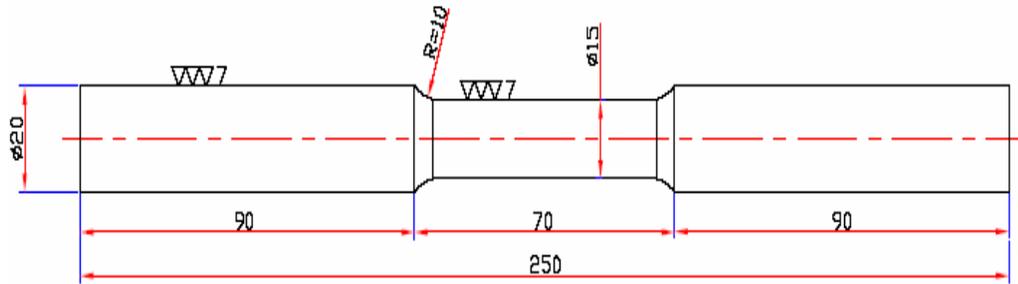


Fig. 1 Geometry of the present test specimen

Evaluation of Almen Intensity

Shots of three sizes were applied for this process. Their material / hardness are listed below in table 2. Experimental work started from peening machine. An air blast machine of 136 MPa pressure rating was selected for the test work. The air blast nozzle internal diameter (6mm) was checked using a standard go-no go gauge before testing. Shot flow rates were calibrated using real time catch tests. The nozzle to test strip / specimen center location was adjusted and was checked before and after testing, the shot impact angle on the test strips was calibrated and checked before and after testing protractor/level. Peening strips of size 3"x 0.75"x 0.031" thick (type A) as per SAE J442 arranged. "A" scale / type Almen strip is recommended for low intensities which are normally used for soft materials like aluminum [3]. Three standard sizes for strips of material SAE 1070 spring steel are used and "A" scale type is shown in the fig.2 [14]

Each strip was individually inspected for flatness using an Almen Gage #2. All strips with a tolerance of less than or equal to 0.0001 inch were selected for use. All strip mountings and removals were done using a systematic method. These strips were

Table 2 Peening Media Properties [14]

S.No	SAE No.	Ø (inches)	Material	Hardness (HRC)
01	S110	0.0197	Cast steel	45
03	S170	0.0280	Cast steel	45
04	S230	0.0394	Cast steel	45

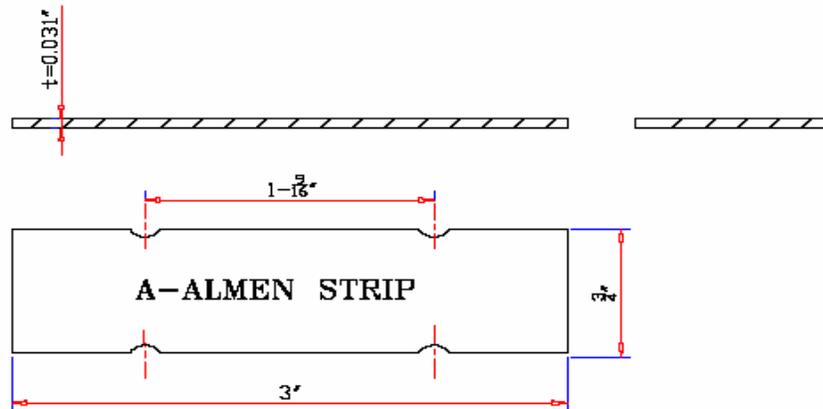


Fig.2 "A" Type Almen Strip

screwed on a solid block and then on the perforated plate of the peening machine as shown in the fig. 3 [14]

Several experiments were performed on Almen strips. Each individual peening process parameter (like shot size, nozzle pressure, impingement angle, exposure time and nozzle distance from the specimen) was varied to determine the relationship with almen height. During each experiment other parameters were kept constant. Finally we were left with individual parameter Almen intensity and its affect on the fatigue life of actual specimen were experimentally determined.

Peening of fatigue test specimen

The same procedure was adopted for the peening of fatigue test specimen as described for Almen strip. Following parameters were selected for the peening of fatigue test specimen.

Process variables	Nominal setting
Nozzle pressure	60-80 psi
Nozzle internal diameter	6mm
Shot sizes:	S-110, S-170, and S-230
Nozzle to specimen distance	7 inches
Shot impact angle:	65°
Specimen motion	25 rpm

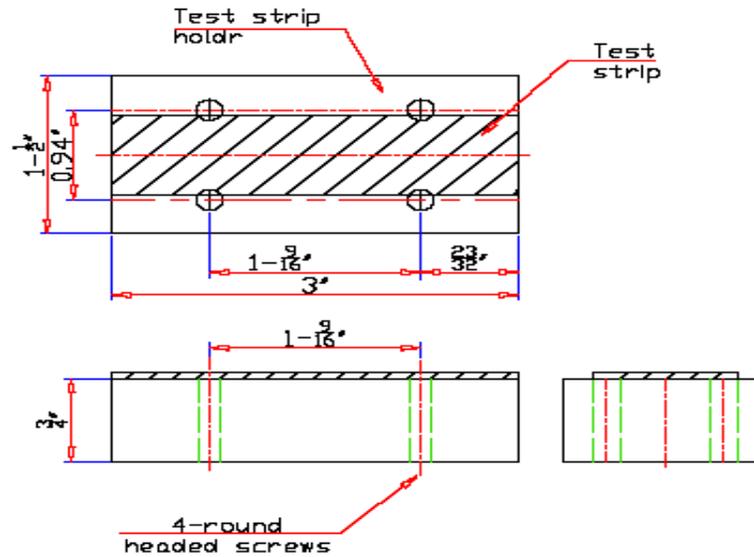


Fig.3 Almen Strip Holder

Fatigue Testing

The fatigue test programme was carried out utilizing a four points rotating bending machine of 20kg-m maximum bending moment and 2860 rpm speed .The preliminary investigations concentrated on establishing base line information regarding the fatigue life of the material. In the main part of the programme as machined and shot peened specimens were utilized and SN curves were determined with the view of examining the effects on peening parameters on the fatigue life in the presence of alternating stresses. All tests were performed with the load ratio of $R = -1$

RESULTS AND DISCUSSION

Results of the first part of experimental work are related to the evaluation of Almen intensity, which depends on different variables like air pressure, impingement angle, nozzle distance and shot flow rate. Relationship between each individual variable and Almen intensity was obtained by keeping the other three parameters constant and are mentioned on each graph.

In fig. 4 nozzle pressure versus Almen height graph is shown. Air pressure exhibited nearly linear behavior regarding intensity until the maximum value is obtained. The combined effect of peening parameters appears in the form of Almen height which is the indication of absorbed energy in the almen strips. It is obvious that higher pressure causes higher values of shot velocities and hence more energy will be transmitted, consequently higher values of almen intensities will appear. Effect of nozzle pressure is related to shot sizes. Larger shots give higher almen intensities than that of smaller shots. Up to certain value of pressure almen height increases and then once again curve bows down. It can be concluded that optimum value of pressure exists somewhere and can be achieved.

In fig.5 relationship between nozzle angle and Almen height is shown. Nozzle angle had the greatest effect on intensity. Changes in nozzle / impingement angles have a pronounced effect at low angles and very little effect at angles greater than 65°. At low angles, this effect is almost parabolic, implying the lower the angle, the greater the effect.

The high velocity shots stream imparts energy in the peening strip. Between 0° and 90° shot velocity is resolved into two components i.e. normal and horizontal. According to Hertzian pressure [21] the normal component of shot velocity produces impact load which causes a maximum shear stress below the surface and it has key role as far as Almen intensity is concerned. As impingement angle increases normal component increases and its effect reaches certain maximum value and after that the curve is almost horizontal. It can be concluded that the value of normal component of shot velocity has maximum effect at 65° and after that up to 90° this effect is almost negligible.

Fig.6 shows that Almen height increases by increasing the nozzle distance until the maximum value is achieved and after that value Almen height once again decreases. But it can be concluded that overall effect of nozzle distance is limited and is inversely proportional. At smaller nozzle distances and larger distances shot stream can not produce the desired effect. Fig.7 shows that media flow rate is inversely proportional to the intensity.

Table 3 Residual Stresses Measurement

S.No	Almen Intensity	Residual Stress (Max.) MPa	Depth (mm)	Residual Stress (Min.) MPa	Depth (mm)
01	8A	-219	0.2	40	0.5
02	10A	-230	0.4	45	0.5
03	12A	-242	0.2	49	1.4

Microstructure changes occurred due to shot peening were also examined using powerful optical microscope. In fig.7 and fig. 8 microphotographs of as machined and peened specimens are shown. It can be visualized that peening has produced indentation / compression in the specimen and has spread material near the impact point against the resistance of neighboring material, thus introducing a complex sub-surface residual stress distribution in which generally, the surface is in elastic compression. Stresses produced due to peening were determined by hole drilling method shown in the table: 3 [14]

In the second part of experimental work effect of shot peening on the fatigue life of aluminium 2024 is determined. Peening process produces residual stresses in the surface layers of peened specimens. A comparison between as machined and shot peened specimens is shown in fig.8 and 9. Microphotographs of machined (before shot peening) and after peened were obtained using powerful microscope. Each shot acts like a hammer and produces residual stresses in the surface and subsurface layers. It can be visualized that peening has produced indentation / compression in the specimen and has spread material near the impact point against the resistance of

neighboring material, thus introducing a complex sub-surface residual stress distribution in which generally, the surface is in elastic compression. Stresses produced due to peening has been determined using hole drilling technique and shown in table 3. For higher values of Almen intensity value of residual stresses will be higher.

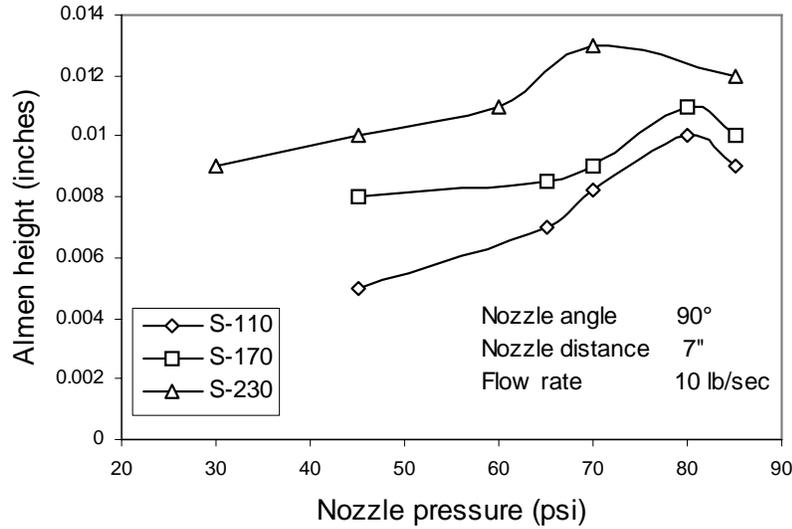


Fig.4 Nozzle pressure vs. Almen height

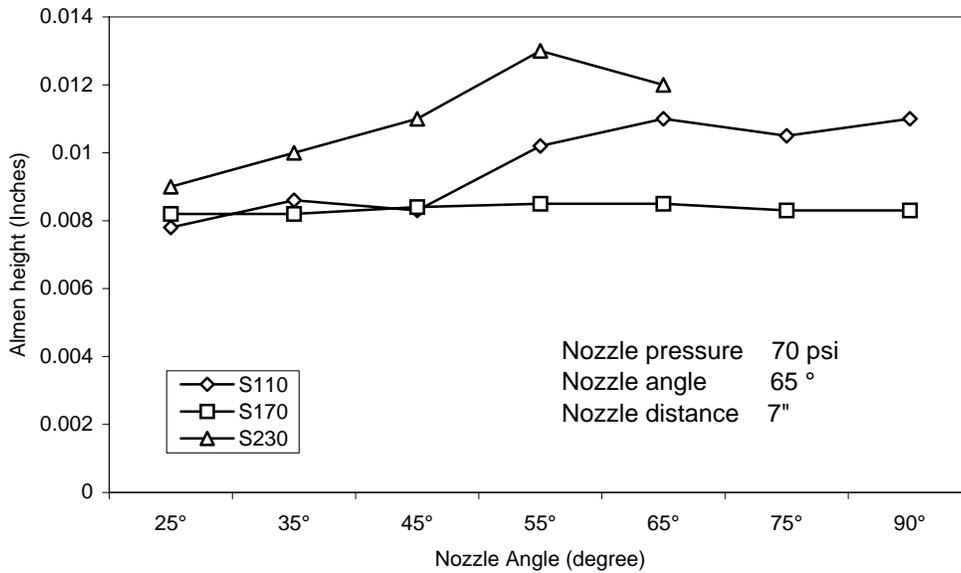


Fig.5 Nozzle angle vs Almen height

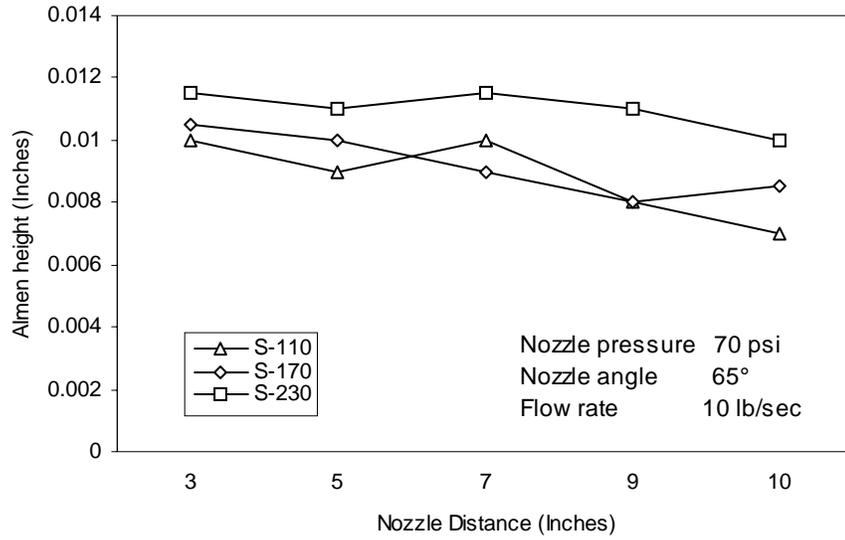


Fig.6 Nozzle distance vs. Almen height

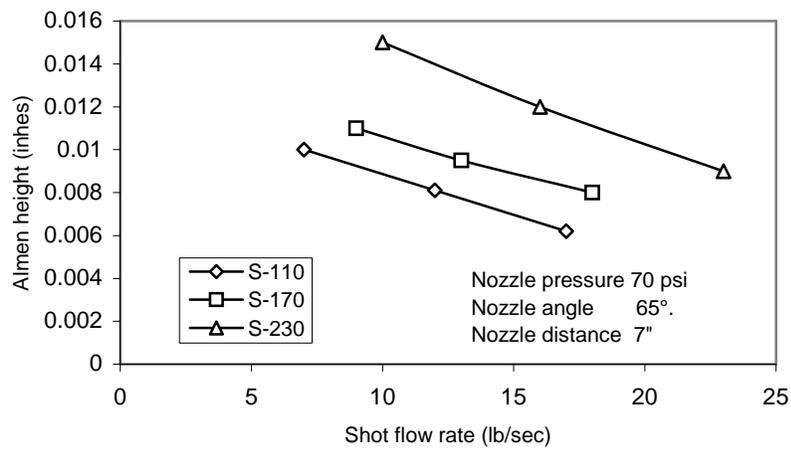


Fig.7 Shot flow rate vs. Almen height



Fig.8 Microphotograph of machine surface with 50x magnification.



Fig.9 Microphotograph of peened surface with 50x magnification

Considerable improvement in the fatigue life of peened component was observed. In table 4 results of as machined and shot peened specimens are shown. 166 % improvement has occurred due to shot peening at the cyclic stress of 60 % of the UTS. This is because of residual stresses produced by shot peening. These stresses slow down crack propagation rate.

At lower stress values fatigue life improvement will be more as compared to higher stress values. As cracks propagation rate is higher at higher stress values.

Almen intensity is the major parameter on which fatigue life of the specimen depends. Number of cycles versus Almen height graph shows that up to certain value of Almen intensity, number of cycles increases and then curve bows down even by increasing the Almen height. This may be due to the residual stress value that should be optimized otherwise peening may produce adverse effects.

Table 4 Fatigue life comparison of as machined and 12A-shot peened specimen at an applied stress of 250 MPa (63% , 38% of UTS)

S.No	σ_b / W MPa-Kg	As machined N_f	Average N_f	Peened-12A N_f	Average N_f	Gain	%(Gain)
01	250/ 66	1.145×10^4	1.898x 10^4	4.85×10^5	5.06×10^4	3.1×10^4	166%
02		2.40×10^4		4.70×10^5			
03		1.80×10^4		4.23×10^5			
04		2.25×10^4		6.46×10^5			
01	150/40		1.25×10^5		8.3×10^5	6.05×10^5	484%

The fatigue life that can be visualized from fig.10. This is because of compressive residual stresses. Larger size media produces more residual stresses than the smaller one which may decrease the fatigue life of specimens. Almen intensity can be optimized from the results of figure: 11. Up to certain value of Almen intensity fatigue life increases and after 12A it once again decreases. Hence 12A can be considered optimized value of Almen intensity.

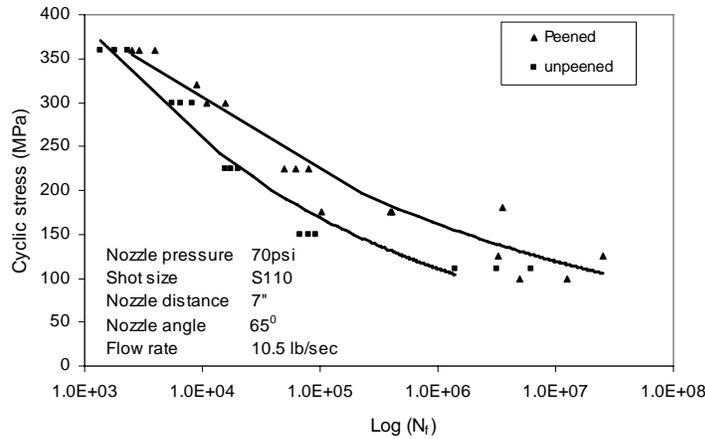


Fig. 10 SN curves comparing the fatigue life of unpeened and 12A peened specimens

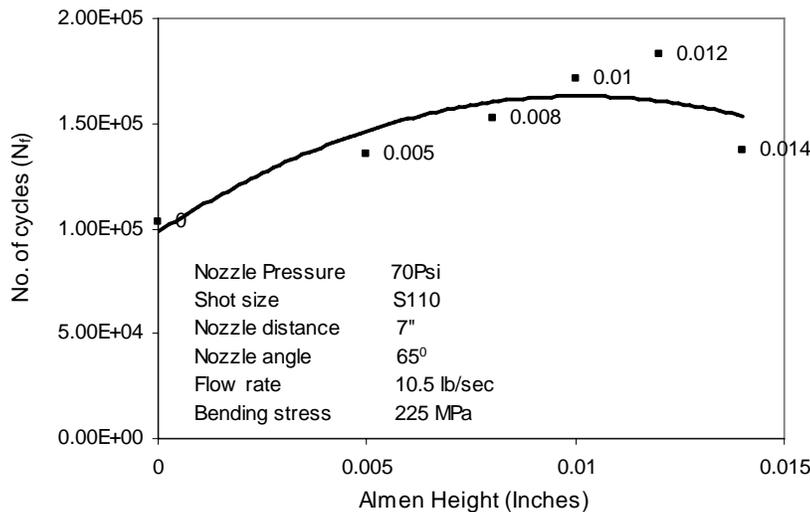


Fig.11 Almen height versus average no. of cycles to failure

CONCLUSIONS

The effect of shot peening on fatigue life of the 2024 Aluminium alloy was studied under constant amplitude loading condition. The results showed that shot peening can be applied to increase the fatigue life of the alluminium alloy under optimum conditions otherwise we may not get the appropriate results and even it may cause adverse effects. Also the beneficial effect of the process is greater at long fatigue lives than at short fatigue lives.

1. Air pressure exhibits nearly linear behavior regarding intensity until the maximum intensity for a particular media size is achieved. Higher intensities can be obtained at lower pressure for large size shots.
2. Nozzle angle had the greatest effect on intensity. Changes in nozzle/impingement angles have a pronounced effect at low angles and very little effect at angles greater than 55° for small shots and 65° for large diameter shots.
3. Nozzle distance has a limited effect on intensity and media flow rates is inversely proportional to the intensity. Value of Almen intensity increases as media size increases.
4. Larger size shots produce more residual stresses in the surface layers of the specimen as compared to smaller size shots and smaller shots are more effective than the larger shots.
5. Optimum value of the peening intensity exists between 8A to 13A for alluminium alloys

ACKNOWLEDGEMENTS

National Institute of Science and Technical Education, Islamabad.

REFERENCES

1. Akber J.A, Kyriacou S., El-Zafrany A.M “ Effect of Shot Peening on the Fatigue Life of Axially Loaded Notched Components” , Conf Proc: ICSP-5, Willey Publisher ,13-17 September,1993, pp.349-358
2. H. O. Fuchs and E. R. Hutchinson, Shot Peening, Machine Design, Vol.30, Feb. 6, 1958, p. 116–125
3. H.O. Fuchs,” Defects and Virtues of the Almen Intensity”, Conf Proc: ICSP-2, Willey Publishers, September 14-17,1984, pp 74-78,
4. Sharp, P K; Clayton, J Q; Clark, G “ The Fatigue Resistance of Peened 7050-T7451 Aluminum Alloy, Repair and Re-Treatment of a Component Surface” Fatigue Fract. Eng. Mater. Struct. Vol. 17, No. 3, pp. 243-252. Mar. 1994
5. Zhuang, W. Z. and Halford, G. R. “Investigation of residual stress relaxation under cyclic load”, Int. Journal of Fatigue, Volume 23, Supplement 1, 2001,pp. 31-37
6. Sharp, P K, Clark, G” The effect of peening on the fatigue life of aluminium alloys” Advances in Fracture Research. ICF9. Vol. 3. Fatigue of Metallic and Non-Metallic Materials and Structures; Sydney; Australia; 1-5 Apr. 1997. pp. 1491-1499, 1997
7. J. A. Horwath ” Effect of Shot Peening Variables on Bending Fatigue” Conf Proc: ICSP-1 Willey Publishers ,14-17 September,1981, pp 229-236.

8. Richard C, Wieland “A Statistical Analysis Of The Shot Peening Intensity Measurement” ICSP5, Oxford, U.K., Willey Publisher, 13-17 September, 1993, (Advanced Metal Process, Doc. #1993015, 1993)
9. Barter, S.L “Repair and Life Assessment of Critical Fatigue Damaged Aluminium Alloy Structure Using a Peening Rework Method” Journal USAF ASIP Conference 5-7 December, 2000, San Antonio, TX, USA, / Australian Science Magazine, DSTO,
10. Jian, L. (Editor), Hand book of Measurement of Residual Stresses, Society For Experimental Mechanics, Inc., The Fairmont Press, 1996 Inc. Chapter 1(p1-4) & Chapter 5(p71-78).
11. Predictive Models For Small Fatigue Cracks Growing Through Residual Stress Fields C. H. Wang And Q. Li
12. S.T Kim, D.Tadjiev, “Fatigue Life Prediction under Random Loading Conditions in 7475-T7351 Aluminum Alloy using the RMS Model” Int. Journal of DAMAGE MECHANICS, Vol. 15—January 2006, (pp89-101)
13. Roger.S “Effects of Peening on Fatigue Life of Wrought 5454 Aluminum Automotive Road Wheels” Conf Proc: ICSP-2, Willey Publishers , 14-17 May, 1984, pp. 58-62
14. Puchi-Cabrera .E.S , Villalobos-Gutiérrez .C., I. Irausqui’n, La Barbera-Sosa, G. Mesmacque “Fatigue behavior of a 7075-T6 aluminum alloy coated with an electroless Ni-P deposit” Int.J of Fatigue, Vol.28 2 Dec, 2005 , pp-1854-1860
15. Rodopoulos C.A, Curtis S.A. de los Rios, E.R. Solis Romero.J, “Optimisation of the fatigue resistance of 2024-T351 aluminium alloys by controlled shot peening—methodology, results and analysis”, Int.J of Fatigue, Vol.26 2 19 Jan., 2004 , pp-849-856
16. Benedetti .M., Bortolamedi.T., Fontanari.V., Frenedo.F “Bending fatigue behaviour of differently shot peened Al 6082 T5 alloy” Int.J of Fatigue, Vol.26 2 17 Dec, 2004 , pp-889-897.
17. Sonsino C.M. , Radaj D., Brandt U., Lehrke H.P., ”Fatigue assessment of welded joints in AlMg 4.5Mn aluminium alloy (AA 5083) by local approaches” Wang Q.Y, Kawagoishi.N., Chen.Q. “Fatigue and fracture behaviour of structural Al-alloys up to very long life regimes” Int.J of Fatigue, Vol.28, 19 Sep. 2005 , pp-1572-1576
18. Turkmen H.S., Loge R.E., Dawson P.R., Mill M.P., “On the mechanical behaviour of AA 7075-T6 during cyclic loading” Int.J of Fatigue, Vol.25, 8 Oct. 2003 , pp-267-281
19. Ali A., An.X., Rodopoulos C.A., Brown M.W., Hara P. O., Levers A., Gardiner S., “The effect of controlled shot peening on the fatigue behaviour of 2024-T3 aluminium friction stir welds” Int.J of Fatigue, Vol.30, 16 Oct. 2006 , pp-267-281

High-strength aluminum alloys (AA) are extensively used for landing gears given their low density compared to steel. All AA parts undergo special processes after machining such as shot peening and anodizing. Because the impact of the special processes on the fatigue properties of the material is not very well known, conservative security factors are used leading to an increase in the wall thickness of the parts and, thus, weight increase. This project will help better understand the effect of process parameters on the fatigue life of the components and will ultimately lead to design optimization of landing gear parts. Get email updates on Mitacs opportunities. The fatigue tests showed that the fatigue life of 2024-T62 aluminum alloy treated by LSP had been improved significantly. With 95 percent confidence, the median fatigue life of shocked specimens was 1.9 to 2.5 times that of unshocked ones. It is expected that LSP will be used as a good treatment for improving the fatigue life of aviation structures. © (1996) COPYRIGHT Society of Photo-Optical Instrumentation Engineers (SPIE). Downloading of the abstract is permitted for personal use only. Citation Download Citation. Hongtao Zhang, Boliang Lu, Shuren Zhang, Yaxin Tang, and Chengye Yu "Effect... Fatigue of aluminium-lithium alloys. K. T. Venkateswara Rao and R. O. Ritchie. Aluminium-lithium alloys are a class of low density, high strength, high stiffness monolithic metallic materials that have been identified as prime candidates for replacing 2000 and 7000 series aluminium alloys currently used in commercial and military aircraft. Effect of surface treatment Surface treatments using shot peening, ion implantation, nitriding, and laser glazing techniques are commonly employed to improve fatigue crack initiation resistance through the introduction of compressive residual stresses at the surface; work. Venkateswara Rao and Ritchie Fatigue of Al-Li alloys 163.