EFFECT OF SHOT PEENING PARAMETERS ON FATIGUE LIFE OF AL 6063

Vinkel Arora[1], Abhay Nagpal[2], Vikas Anand[3] and Manish Kumar[4]

[1]Assistant Professor, Department of Mechanical Engineering
ITM University, Sector-23A, Guragaon-122017, Haryana, India

[2, 3, 4] PG Student, Department of Mechanical Engineering
ITM University, Sector-23A, Guragaon-122017, Haryana, India

Abstract

Fatigue failure is responsible for heavy losses in industries which produce parts like springs, gears, crankshafts, connecting rods and aircraft equipments. The engineering community is constantly working on improvement of fatigue life of these components. From the open literature it has been found that shot peening increases the fatigue life, thereby inducing a compressive stress on the tension surface, which reduces the propagation of the crack which eventually will enhance the fatigue life. In the present study a portable shot peening machine is designed and fabricated to improve the fatigue life of aluminium Al 6063 grade specimen and to study the effect of various shot peening parameters on fatigue life of the specimen. The specimens are subjected to different NTD (nozzle tip distance) and air pressures, and the fatigue life of the specimen is determined using rotary bending fatigue testing machine. It was observed that shot peened specimen had a longer cycle time before the failure occurred and showed a considerable increase of 6%-10% in fatigue life. The effect of NTD and air pressure on fatigue is also determined experimentally.

Keywords – Fatigue life, shot peening, compressive residual stresses field, Al 6063.

1. INTRODUCTION

Fatigue failure is a major problem which is responsible for heavy losses in various industries which produce parts like springs, gears, crankshafts, connecting rods and aircraft equipments. It occurs due to the formation of cracks at the microscopic level and lengthened by continued applications of stress. It differs however in the manner the stress is applied. Fatigue fracture is instigated by cyclical stresses on the material to induce a compressive stress on the tension surface, which reduces the propagation of the crack which eventually will enhance the fatigue life. Shot peening is widely used method for fatigue life enhancement Aggarwal M.L (2006) Shot peening is a process in which the surface of a component is bombarded with small spherical media called shot. Each piece of shot, on striking the surface, imparts a small indentation or dimple, all of which jointly deform the surface in tension. The surrounding elastic material, on attempting to return the yield surface to its initial shape, creates a residual compressive stress field within the cold work-hardened surface layer. While many fatigue strength data are available from test specimens, and the engineer can use these data as a starting point, the best data are obtained by full-scale testing of actual components under realistic conditions Olivier Higounenc (2009) discusses that compressive stress is not the only surface characteristic to be considered in Shot Peening. There are other characteristics like elimination of tool marks/surface defects, modification of surface roughness, work hardening, surface elongation, contamination etc which must be considered depending on the application when we specify the shot peening parameters i.e. nature, size, hardness, angle, intensity, coverage. Franck Petit-Renaud (2009) demonstrated the effect of a range of process parameters on the residual stress profiles by performing shot peening on carburized 17CrNiMo6 steel is studied using a 0.6mm diameter shot. The process parameters investigated included air pressure, the mass flow, the impact angle, the distance between the nozzle and the specimen, the exposure time and the nozzle size. The results were analysed using Minitab v 12 software, and it was found that the most significant parameters were air pressure, the mass flow, the impact angle and the exposure time. Significant interactions were also detected between exposure time and air pressure; nozzle size and mass flow; air pressure and impact angle; nozzle size and air pressure. . Kumar and Vijayrangan (2007) describes static and fatigue analysis of steel leaf spring and composite multi leaf spring made up of glass fibre reinforced polymer using life data analysis. The dimensions of an existing conventional steel leaf spring of a light commercial vehicle are taken and are verified by design calculations. Static analysis of 2-D model of conventional leaf spring is also performed using ANSYS 7.1 and compared with experimental results. Hawang and Han (1986) worked on the fatigue life of the composites. Al-Qureshi (2001) has described a single leaf, variable thickness spring of glassfiber reinforced plastic (GFRP) with similar mechanical and geometrical properties to the multileaf steel spring, was designed, fabricated and tested. Fuentes *et al* (2008) in this work, the origin of premature failure analysis procedures, including examining the leaf spring history, visual inspection of fractured specimens, characterization of various properties and simulation tests on real components, were used. Rajendran and Vijayarangan (2002) A formulation and solution technique using genetic algorithms (GA) for design optimization of composite leaf springs is presented here. Shiva Shankar and Vijayaragan (2006) explain the automobile industry has shown increased interest in the replacement of steel spring with fiberglass composite leaf spring due to high strength to weight ratio. Hou et al. (2004) aimed to present a low cost fabrication of complete mono composite leaf spring and mono composite leaf spring with bonded end joints. Aggarwal et al (2006b) evaluated the axial fatigue strength of EN45A spring steel specimen experimentally as a function of shot peening in the conditions used for full-scale leaf springs testing in industries. S/N curves of the specimens are correlated with leaf springs curve in vehicles. The process is time consuming and costly. In the present work, a CAE system predicts all variables in complex assemblies of leaf springs and the results are compared with experimental testing. Aggarwal et al. (2006a) has worked on the influence of high contact pressure and temperatures which results in the micro weld between the two leaf surfaces. The fatigue strength of the leaf springs is studied as a function of shot peening parameters. Junior et al. (2010) suggested a thermal sprayed HVOF technology which is normally used to protect components against wear and corrosion, and are being considerate an alternative to replace chromium by the aeronautical industry. With respect to fatigue life, the HVOF technique induces residual stress on the interface. Bagherifard et al. (2010) worked on surface nano crystallization which is verified and affirmed through different experimental procedures. Rotating bending fatigue tests are performed to evaluate the effect of this high energy shot peening and the nanocrystallized layer on fatigue life. Dalaei et al. (2010) performed fatigue tests in strain control environment with parallel recording of stress relaxation and recovery of the work hardened surface zone at different total strain amplitudes exerted to the test specimens. Gubeljak et al. (2011) worked on high strength steel grade 51CrV4 in thermo-mechanical treated condition is used as bending parabolic spring of heavy vehicles. Pre-stressing and shot-peening cause's higher compress stress magnitude and consequently change of loading ratio to more negative value and additionally extended life time of spring.

2. DESIGN AND FABRICATION OF A PORTABLE SHOT PEENING MACHINE

2.1 Portable shot peening machine Material

The basic requirements of a portable shot peening machine is that the selected grade of steel must have sufficient harden ability for the size involved to ensure a partly martenstic structure throughout the entire section.

Table 1: Mechanical properties of MS

Parameter	Value
Ultimate Tensile strength	250 MPa
Yield strength	150 MPa
HRC	48
Poisson's Ratio	0.29

2.2 Design of Pressure Vessel (Safety Considerations)

Internal diameter of cylinder (d) = 356mm
Thickness of cylinder (t) = 5.08mm
Internal Pressure in the Cylinder (P) = 140psi = 0.958 MPa
Maximum Permissible Tensile Stress of Mild Steel = 150 MPa
The ratio of t/d = 1/20 can be considered suitable line of demarcation between thin and thick cylinders.

$$(\frac{t}{d} = \frac{5.08}{356} = 0.015) < \frac{1}{20}$$

As $(\frac{t}{d} < \frac{1}{20})$ designed by considering thin pressure vessel.
When a cylinder is subjected to internal fluid pressures, the following two types of stresses are developed:

2.2.1 Circumferential or Hoop's stress

Bursting Force (pressure) = Resisting Strength

$$P \times d \times l = 21 \times t \times \sigma_c$$

$$\sigma_c = \frac{0.958 \times 356}{2 \times 5.08} = 33.56 \text{ MPa}$$

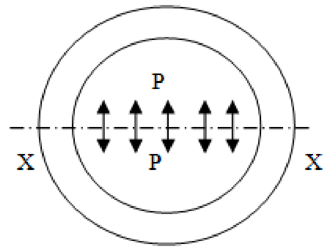

Figure 1: Hoop's stress on the vessel

Factor of safety (Hoop's stress) = $\frac{150}{33.82} = 4.43$

2.2.2 Longitudinal Stress

Pressure on the Ends = Resisting Force

$$P \times \pi/4 \times d^2 = \pi \times d \times t \times \sigma_l$$

$$\sigma_l = \frac{0.958 \times 356}{4 \times 5.08} = 16.78 MPa$$

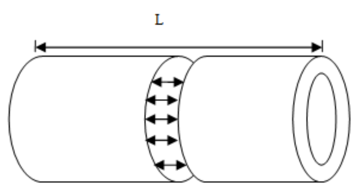

Figure 2: Longitudinal stress on the vessel

2.3 CAD Modelling and Analysis

CAD modeling of any project is one of the most time consuming process. One cannot shoot directly from the form sketches to finite element model. CAD modeling is the base of any project. Finite element software will consider shapes, whatever is made in CAD model. Although most of the CAD modeling software have capabilities of analysis to some extent and most of finite element software have capabilities of generating a CAD model directly for the purpose of analysis, but their off domain capabilities are not sufficient for large and complicated models which include many typical shapes of the product. The model of the portable shot peening machine includes many complicated parts, which are difficult to make by any of other CAD modeling as well as finite element software. CAD modeling of the portable shot peening machine is performed by using solidworks.

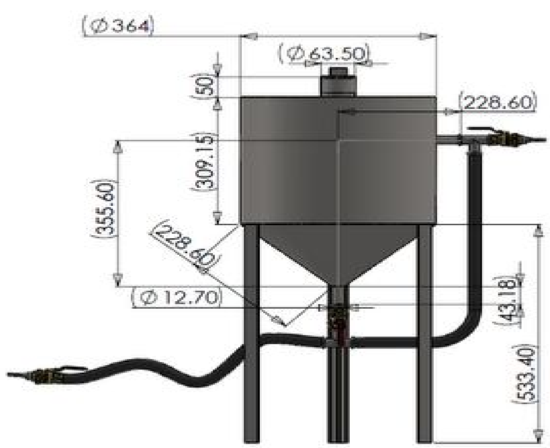

Figure 3: CAD model of portable shot peening machine

2.4 Fabrication of portable shot peening machine

A cylindrical pipe (Ø364mm, Mild Steel 1040) was cut using Gas Cutting (Oxy-Acetylene Flame). It was then welded to a customized MS cone using the Electric Arc welding process. This was followed by simultaneous cutting and welding operations. In the end the piping and fitting operations were carried out. A wooden box with sheet metal coating is being used to avoid discharge of shots in the nearby environment, for safety of the worker and to avoid any wastage of shots. The specimen in placed in this box fitted with a nozzle at a pre-determined distance, and is bombarded by shots at a pre-determined high pressure. This way we can take different readings by varying the NTD and pressure.

Figure 4: Portable Shot Peening Machine

3. SHOT PEENING PARAMETERS

Shot peening can be done by varying various parameters like diameter of the shot, air pressure, Nozzle tip distance, ball material, intensity of the current, depth of indentation required, flow rate. For the present study two parameters Nozzle tip distance (NTD) and Air pressure are taken into consideration. For varying the nozzle tip distance a wooden compartment is fabricated and at a distance of 5cm, 13cm, 21cm, 30cm and 38cm slots are cut for placing the specimen. The position of the nozzle is kept fixed. The second sets of observations are taken by varying the air pressure. The air pressure is varied from 100psi, 130psi, 150psi and 180psi.The main objective is to determine the NTD and Air pressure at which the fatigue life is maximum.

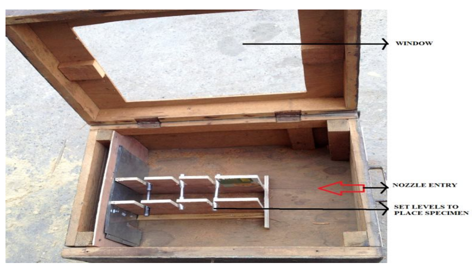

Figure 5: Shot Peening Environment for varying Nozzle tip distance (NTD)

3.1 Shot Material

The cast iron shot used for this study for the peening of the specimen. The diameter of the shot is 0.25mm and the BHN is 130.The indentation required is 0.1mm.

3.2 Force required for shot peening

From the hardness number the force required for the requisite indentation is calculated so that the force produced by the air blast by the shot should be more or equal to that force.

Diameter of shot = 0.25mm

Indentation required = 0.1mm

BHN = 130 (Mild Steel)

$$BHN = \frac{2P}{\pi \times D \times (D - (D^2 - d^2)^{0.5})}$$

P= 2.13 kgf = 20.81 N

Where,
BHN = Brinell hardness number
P = load on the indenting tool (kgf)
D = diameter of shot (mm)
d = indentation (mm)

3.3 Force produced by shot peening using air blast

Mass of shot (m) = 0.2 gm =1.962*E^{-03}N
Velocity of air (v_a)= 200 m/sec
Velocity of shot (v_s)= 48.6 m/sec = 50 m/sec
Length of nozzle (s) = 100mm = 0.1 m

$$v_s^{\,2} = 2 \times a \times s$$

a = 12500 m/sec^2

$$F = m \times a = 12500 * 1.962 * \text{E} - 03 = 25N$$

3.4 Specimen Material

For the present study Aluminium grade Al 6063 material is taken into consideration .The mechanical properties of the material is listed in the Table 2 and chemical composition in Table3.

Table 2: Mechanical properties of Al 6063

Properties	Values
Ultimate Strength, S_{ut}	186MPa
Yield strength, S_y	167MPa
Young's Modulus, E	68.9GPa
Poisson Ratio, μ	0.33
Density, ρ	2.8 g/cm^3
BHN	60

Table 3: Chemical composition of Al 6063

Component	% by Weight
Al	97.5%
Cr	0.1%
Cu	0.1%
Fe	0.35%
Mg	0.4-0.9%
Mn	0.1%
Si	0.2-0.6%

3.5 Dimensions of the specimen

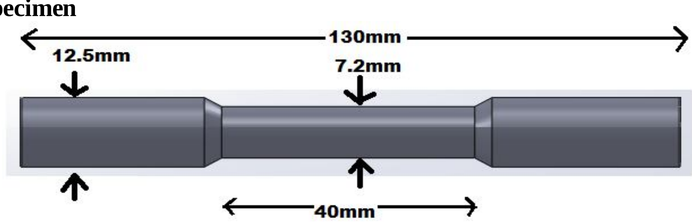

Figure 6: Dimensions of standard specimen (CAD Model)

4. EXPERIMENTAL SET UP FOR FATIGUE LIFE DETERMINATION OF THE SPECIMEN

A standard rotary bending machine is used for determination of the fatigue life of the specimen. The figure of the experimental setup is shown in Figure7.

Figure 7: Specimen mounted in a rotary bending fatigue testing machine

Using the equation

$$\frac{M}{I}=\frac{\sigma}{y}=\frac{E}{R}$$

$$\sigma=\frac{P\times l\times d/2}{\pi/64\times d^{4}}=\frac{15.22*9.81*40*64}{2*3.14*7.2*7.2*7.2}=163.2MPa$$

Where,
M – Bending Moment
I – Moment of Inertia
σ – Bending Stress
y = d/2

Where:
Load (P) = 35lbs*0.435 = 15.225 Kg
Effective Length of the specimen (l) = 40mm
Effective diameter of Specimen (d) = 7.2mm
RPM of rotary bending fatigue testing machine = 2960 rpm

5. RESULTS AND DISCUSSIONS

5.1 Fatigue life before shot peening operation

For the purpose of comparison between fatigue life without shot peening and with shot peening a specimen is tested for fatigue life without shot peening on rotary bending fatigue testing machine .The results obtained from the experiment are shown in the Table 4.

Table 4: Fatigue life of specimen without Shot Peening

Specimen	Cycle time before failure	Number of cycles before failure occurs
X	10m 20s	30576

Figure 8: Surface of Specimen Before Shot Peening (X)

5.2 Fatigue life by varying the NTD at 150 psi

The effect of varying the nozzle tip distance on the fatigue life of the specimen is observed. Five specimens are tested by varying the NTD. The specimen are placed at a distance 5cm, 13cm, 21cm, 30cm and 38cm.Each specimen is tested on rotary bending fatigue testing machine. The results obtained from the experiment are shown in the Table 5:

Table 5: Fatigue life of specimen with Shot Peening at 150psi and varying NTD

Specimen	NTD (cm)	Cycle time before failure	Number of cycles before failure occurs	Increase in fatigue life (%)
1	5	11m 28s	33941	9.86%
2	13	11m 30s	34040	10.17%
3	21	11m 22s	33625	9.06%
4	30	11m 10s	33033	7.43%
5	38	11m 02s	32648	6.34%

Figure 9: Surface of specimen after shot peening

5.3 Effect of NTD on fatigue life of the specimen

A graph is ploted in between NTD and fatigue life of the specimen from the results obtained from the experiments

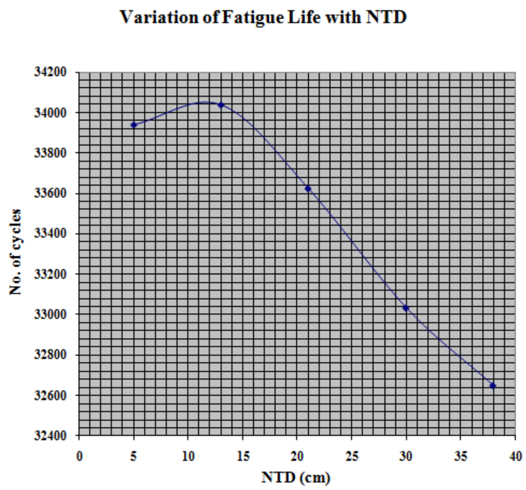

Figure 10: Variation of Fatigue Life with NTD

5.4 Fatigue life by varying the Air pressure at NTD of 13 cm

From the graph it was observed that at NTD of 13cm the fatigue life of the specimen is maximum. The effect of the variation in air pressure is studied at 13cm NTD. The effect of varying the air pressure on the fatigue life of the specimen is observed. Four specimen are tested by varying the air pressure at 100psi, 130psi, 150psi, 180psi 13cm NTD. The results obtained from the experiment are shown in the Table 6:

Table 6: Fatigue life of specimen with Shot Peening at 13cm NTD and varying air pressure

Specimen No.	Pressure (psi)	Cycle time before failure	Number of cycles before failure occurs	Increase in fatigue life (%)
6	100	11m 03s	32708	6.51%
7	130	11m 18s	33448	8.58%
2	150	11m 30s	34040	10.17%
8	180	11m 40s	34543	11.40%

5.5 Effect of Air pressure on fatigue life of the specimen

A graph is ploted in between air pressure and fatigue life of the specimen from the results obtained from the experiments

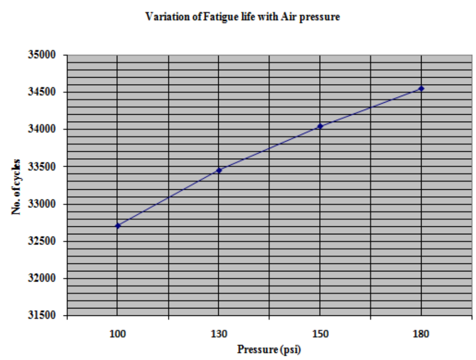

Figure 11: Variation of fatigue life with pressure

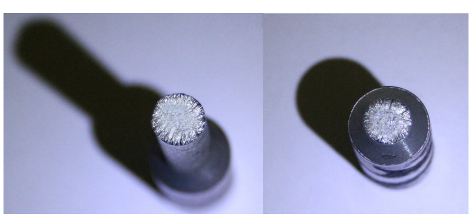

Figure 12: Fatigue failure of the specimen

CONCLUSIONS

From the experiment performed and results obtained various discussions have been made. The various observations show that shot peening increases the fatigue life of a material by reducing the propagation of crack. Following conclusions have been made:

1. Shot peened specimen had a longer cycle time before the failure occurred and showed a considerable increase of 6%-10% in fatigue life of the specimen.
2. The fatigue life of the specimen is directly proportional to the air pressure and at air pressure of 180psi the fatigue life of the specimen has increased by 11.40%.
3. The fatigue life of the specimen is inversely proportional to the Nozzle tip distance and the fatigue life of the specimen has increased by 10.47% at NTD of 13cm.
4. Maximum increase in fatigue life was observed at 180 psi air pressure and 13 cm NTD.

REFERENCES

[1.] Olivier Higounenc,(2009) 'Correlation of shot peening parameters to surface characteristic', international conference on shot peening (ICSP9), pp.28-35.

[2.] Franck Petit-Renaud(2009) 'Optimization of the Shot Peening Parameters', international conference on shot peening (ICSP9), pp.55-68.

[3.] Aggarwal M.L. et al. (2006) 'Optimization of Micro welds used in leaf springs', *Indian journal of Engineering Materials and Science*, Vol.13, No.3, pp. 217-220.

[4.] Aggarwal M.L., Agarwal V.P., Khan R.A. (2006) 'A stress approach model for predicting fatigue life of shot peened EN45A spring steel', *International Journal of Fatigue*, Vol.28, No.12, pp.1845-1853.

[5.] Al-Qureshi, H. A. (2001) 'Automobile leaf springs from composite materials', *Journal of Material Processing Technology*, Vol.118, No.1, pp.58-61.

[6.] Bagherifard,S et al. (2010) 'Fatigue properties of nanocrystallized surfaces obtained by high energy shot peening', *Procedia Engineering*, pp.1683–1690.

[7.] Dalaei, K. et al. (2010) 'Stability of residual stresses created by shot peening of pearlitic steel and their influence on fatigue behavior', *Procedia Engineering*, pp. 613–622.

[8.] Fuentes, J.J., Agulilar, H.J., Rodriguez, J.A., Herrera E.J. (2008) 'Premature fracture in automobile leaf springs', *Engineering Failure Analysis*, Vol.16, No.2, pp. 648-65.

[9.] Gubeljak, N. et al. (2011) 'Variation of Fatigue Threshold of Spring Steel with Prestressing', *Procedia Engineering*, pp. 3339–3344.

[10.] Hawang, W., Han, K. S. (1986) 'Fatigue of composites 'Fatigue Modulus Concept and Life Prediction', *Journal of Composite Materials*, Vol.20, No.2, pp. 154 – 165.

[11.] Hou, J.P., Cherruault, J.Y., Nairne, I., Jeronimidis, G., Mayer, R.M. (2004) 'Evolution of the eye-end design of a composite leaf spring for heavy axle loads', *Composite Structures*, Vol.78, No.3, pp.351-358.

[12.] Junior, G.S. et al. (2010) 'Evaluation of WC-10Ni thermal spray coating with shot peening on the fatigue strength of AISI 4340 steel', *Procedia Engineering*, pp. 649–656.

[13.] Kumar, M.S,and Vijayarangan, S. (2007) 'Analytical and Experimental Studies on Fatigue Life Prediction of Steel and Composite Multi-leaf Spring for Light Passenger Vehicles Using Life Data Analysis', *Materials Science*, Vol. 13, No.2, pp. 141-146.

[14.] Norton RL.(2001) *Machine design – An integrated approach.*,2nd ed., pp. 366–383, Pearson Education, Asia

Author:

Vinkel Arora is working as Assistant Professor in Mechanical Engineering department at Itm University, Gurgaon. He received his B Tech degree in Mechanical Engineering from Government College, Bathinda in 2004 and M-Tech in CAD/CAM from NIT, Kurukshetra in 2009. He is working on fatigue life determination and enhancement of leaf springs, in association with Friends Auto (India) Ltd, Faridabad as part of his research work. He has published two papers in international journals, and five papers in national and international conferences.