**Kayser A .Ameen**
Refrigeration and Air-Conditioning Dept.
Al-Esra'a University - Iraq
kayser@esraa.edu.iq

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# Fatigue Life and Surface Hardening Investigation of Aluminum Shot Peening Process

***Abstract***- *Two different tests are used in order to analyze the shot peening foraluminum 6061-T6 alloys. Stress amplitude versus fatigue life (S-N curves) are established experimentally using different shot peening ball size (three diameters of balls are used in this paper are 1.5, 3, and 3.5 mm). Also the hardening via Vickers hardnessis evaluated due to shot peening experimentally and by ANSYS software, the three dimensional finite element model of a square plate shot by ball is demonstrates the application of shot peened of hardening surface.The influences of the ball's diameter on the hardening and S-N curves are studied. The results showed that the fatigue strength is increased when increasing the ball diameter. The higher strength was obtained when using the ball diameter of (3.5 mm) compared to the other diameters (1.5 and 3 mm). Good agreement of hardening results is evident between experimental and Ansys results with average discrepancy 3.6%*
.

***Keywords***: *Shot peening, ANSYS, Fatigue test, Hardness test*

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## 1.Introduction

Many of machine components are subjected to dynamic loads. It fails at a stress below the yieldingstress; this failure is a fatigue [1]. Fatigue may be constant or variable. Constant fatigue loading means that thefatigue with cyclic load under consistent abundancy and a steady mean stresses or load in benefit the segments of structures are subjected to different sufficiency stackingthat can be a somewhat complex load time history [2].Shot peening is the cold working procedure in which a huge number of peening media are shot onto a surface. The impacts of these media produce the compressive stress's layers over atarget part. This residual compressive layer has been proven to significantly improve fatigue life by reducing the magnitude of alternating stress applied to the part over a typical life cycle [3].From the matters which has to be put into consideration when exposing the mechanical components to dynamic loads, is the life of these components, i.e. the duration of their service, and to know the life of this in advance will avoid sudden failures. For this, several studies had been done, for improving of the resistance through the shot peening of balls, also the methods of case hardening, etc.The balls in the shot peening are cold working formation, because asurface of the metal is attacked by little balls made of steel or glass and the main application of the shot peening processing is to automotive parts. [4] investigated the residual stress's model and simulated the process of shot-peened. Single and twin spherical indentations are investigated using dynamic elasto-plastic analysis via finite element method.. [5], examined the : (1) the improvement for numerical models to assess deflection and fatigue stresses related with the impact procedure, (2) the utilization of spatially resolved residual stress estimations to confirm the numerical investigation by the experimental process.The value of the fatigue stress resulted in this procedure will reach half the yield stress, or a little more in a surface region of depth (0.1-0.5)mm and the higher values of the compression stresses will reach (50-60)% of the max. tensile stress.. [6] studied the effect of ball size used in shotpeeningoperation on the fatigue strength of low carbon alloy steel (4135-AISI).. [7] studied the model for the shot peening process, using finite element method via the elastic–plastic dynamic procedure for shots the metal target. [8],proposed the model of residual stress assessment that results from shot peened and its working into the ANSYS Solver, the new analytical methods, techniques and algorithms developed in this study aimed to address the issue of limited integration of shot peening residual stress into structural applications . [9] studied the effect of a fatigue-creep combination and shot

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peening.Cumulative fatigue damage program is used to determine the optimal set of process. It's conclusion was that the combination of shot peening and fatigue-creep interaction can be applied successfully to increase fatigue life for some specimens. Ref. [10] studied anaccumulation of fatigue damage byseveral ways i.e.Corton-Dalon (CD),Corton-Dalon Marsh(CDM), new model for non-linearity and experimental wayare investigated in this studied. [11] studied experimentally and analytically of the mechanical properties of composite materials, which made using four layers of reinforced fiber-glass with polyester. This composite materials are investigated under fatigue test to evaluate the fatigue life. There are several factors which affect the shot peening operation, one of the major effect is the ball diameter of the shot ball as discussed in this paper.

## 2. Experimental Part

*I- Process of Shot Peening*

The process of shot-peening are impacting the surface of the metallic parts with little spherical balls made of steel, with relatively high velocity (40 – 70 m/s). After contacting between the target's surface and the shot, thelittle plastic indentation is formed made an expanding for the top layers of the surface.Fig.(1)shown the apparatus for shot peening is designed and manufactured in this work and three diameters of balls are used in this paper are (1.5, 3, 3.5)mm. This shot peening device comprises: a rotatable suspension and support section that suspends and supports the work piece; projector , ball chamber; gauge control adjacent the notch in the tube for propelling shot peening balls ; propelling the shot peening balls through the slot and rotating the work piece by using motor.

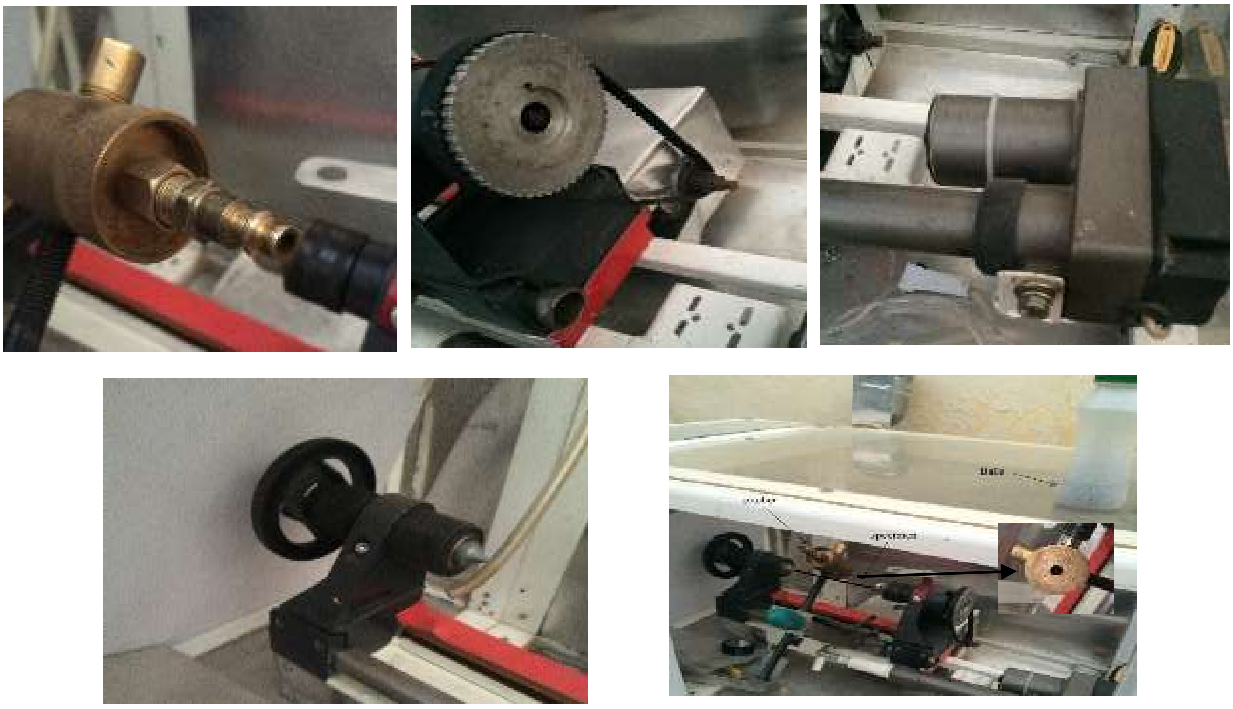


**Figure 1: The apparatus for shot peening**

*II- Material used*

A specimen of 6061-T6 alloyis used. The chemical composition of the used metal is shown in Table(1). The specimen for fatigue tests was made according to the standard specification to be tested on the instrument for the fatigue test with Rotating Bending [1] [2].

## 3.Specimen Classification

The specimen for fatigue tests was classified into main groups for the purpose of experiments as given in Table(2). The operation of surface hardening through shot peening of balls with different diameters (1.5, 3, 3.5)mm have been chosen from the groups (A1,A2,A3) respectively. Every group was shot peened to show the effect of the diameters of balls on the fatigue resistance of Aluminum material. The time of shot peening was fixed for 10 min. for each group.

## 4.Hardness Test

A test was carried out for hardness on all specimens in Table(2). Threereadings were taken for every specimen, and the average was considered by the apparatus Vickers for measuring the hardness. The test of Vickers hardness consists of the test of indentation the metal usingthe indenter of diamond, the Vickers hardness is get by division the kg as a load by the area ($mm^2$) of indentation. Eq.(1) using to evaluate the hardness.

$$Hv = 1.8544(\frac{P}{d^2}) \quad (1)$$

Where:

Hv …. Hardness ,

P …Load in Kg

d ...Diameter of indentation (mm)

## 5- Fatigue Test

Fatigue tests was carried out using fatigue specimens from the classified groups in Table(2) and S-N curves was derived, i.e. the relation between alternating stress and number of cycles for each groups. The traditional Howler fatigue test HI-TECH alternating bending instrument is used.The load at the end of this instrument imposes a known as bending moment that results in a sinusoidal varying stress due to the cantilever oscillation [12] .The instrument is shown in Fig.(2).

Fatigue test is done at a constant stress amplitude cantilever with fully reversed (R= –1). The specimen is performed according to the machine standard with (100 mm length) and (10mm width) as shown in Fig.(3).

**Table 1: Composition of Chemical alloy of Al 6061-T6**

| Element wt% | Mg | Si | Fe | Mn | Cu | Cr | Zn | Al |
|---|---|---|---|---|---|---|---|---|
| **Measured value** | 1.11 | 0.778 | 0.62 | 0.13 | 0.12 | 0.17 | 0.01 | Rem |
| **Standard value** | 0.8-1.2 | 0.4-0.8 | Max 0.7 | Max 0.15 | 0.15-.40 | 0.04-0.35 | Max 0.25 | Rem |

**Table 2 :Fatigue specimens used in the experiment**

| Specimen Symbol | Treatment |
|---|---|
| A | Without shot peening |
| A1 | diameter of shot ball 1.5 mm |
| A2 | diameter of shot ball 3 mm |
| A3 | diameter of shot ball 3.5 mm |

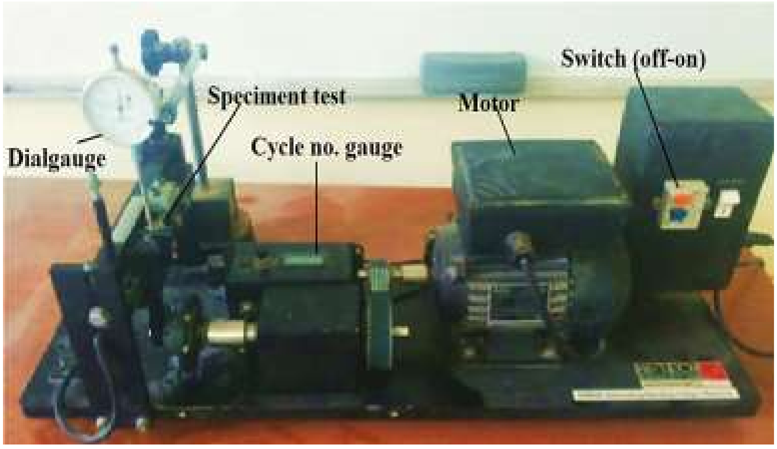



**Figure 2: Fatigue alternating bending test instrument**

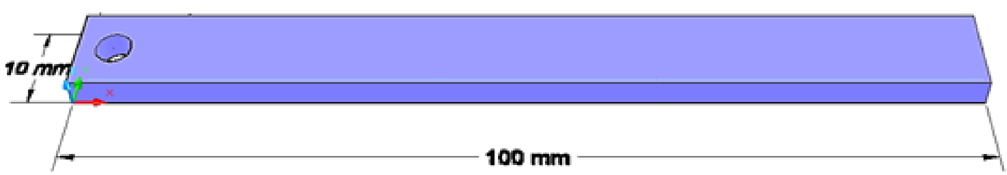


**Figure 3: Fatigue test sample**

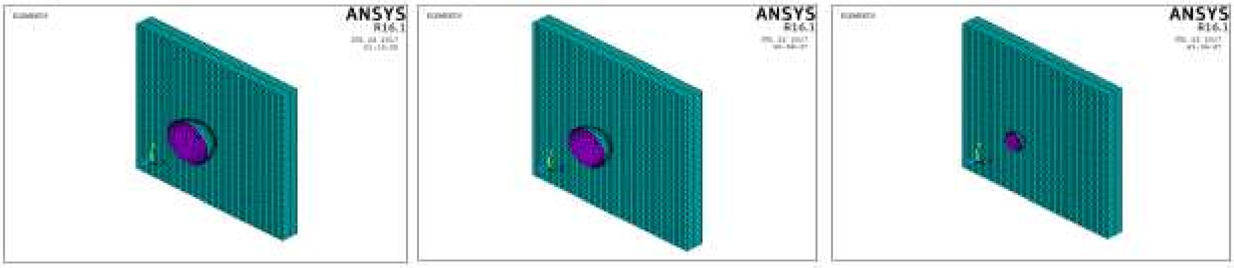
## 6.ANSYS Modelling

The shot-peening model is done by ANSYS software by making APDL ANSYS code for shot peening process. The target is represented half-sphere indicated the ball (rigid). The mesh of the aluminum sheet consists of element solid185.ANSYS provides contact elements either rigid-to-flexible and/or flexible-to-flexible surface-to-surface. The target surface element was (TARGE169 element)and contact surface element was (CONTA174 element). To control on the boundary condition, a pilot node is used.In the simulation of theshot peened procedure, thenonlinear problem is solved by Newton-Raphson method. In this method, the steps of stroke of the ball was characterized over a period traverse. Inside each progression time steps are employed to apply the relocation continuously. At each time step, various balance cycles were employed to acquire a focalized arrangement. The development of the ball was characterized utilizing a pilot node; this node was likewise utilized to acquire the connected power via the simulation. Automatic contact strategy in ANSYS R16.1 was utilized to demonstrate the contact between the ball and plate. For inflexible (ball set), flexible (plate) contact, the TARGE170 element (3D 8-node quadrilateral) was utilized, to indicate 3D target (ball set) surfaces which were related with the deformable body (plate) indicated by 3D 8-node contact elements CONTA174.
The following steps are the ANSYS APDL code is made to run the shot peening process

```
WPSTYLE,,,,,,,,0
R1=1.5
/prep7
*SET,t,0.1*25.4/1000
! Aluminum Plate
et,1,mesh200
keyopt,1,1,6
! steel ball
*SET,w1,1*25.4/1000
*SET,h1,1*25.4/1000
rect,0,w1,0,h1        ! thin beam (target)
!aatt,1,1,1,0         ! mesh attributes
esize,0.5/1000
type,1
amesh,1
et,2,solid185             ! cantilever beam
mp,ex,1,70e9                  ! E=70 GPa
mp,nuxy,1,0.34                 ! unitless
mp,dens,1,6870  ! density =6870 Kg/m3
type,2
mat,1
esize,,2
voffst,1,t
! projectile
*SET,he1,0.25*25.4/1000
wpoffs,,,he1
*SET,Rb,R1/1000
sph4,w1/2,h1/2,Rb
allsel,all
block,0,w1,0,h1,0,w1
vsbv,2,3
vdele,4
adele,15
allsel,all
asel,s,,,3,6,1
nsla,s,1
d,all,all
allsel,all
FLST,5,4,4,ORDE,4
FITEM,5,13
FITEM,5,15
FITEM,5,29
FITEM,5,-30
LSEL,S, , ,P51X
lesize,all,0.5/1000
allsel,all
!/COM,CONTACT PAIR CREATION ! START
CM,_NODECM,NODE
CM,_ELEMCM,ELEM
CM,_KPCM,KP
CM,_LINECM,LINE
CM,_AREACM,AREA
CM,_VOLUCM,VOLU
MP,MU,1,0.4
MAT,1
MP,EMIS,1,7.88860905221e-031
R,3
REAL,3
ET,3,170
ET,4,174
R,3,,,1.0,0.1,0,
RMORE,,,1.0E20,0.0,1.0,
RMORE,0.0,0,1.0,,1.0,0.5
RMORE,0,1.0,1.0,0.0,,1.0
RMORE,10.0
KEYOPT,4,4,2
KEYOPT,4,5,0
NROPT,UNSYM
KEYOPT,4,7,0
KEYOPT,4,8,0
KEYOPT,4,9,0
KEYOPT,4,10,2
KEYOPT,4,11,0
KEYOPT,4,12,4
KEYOPT,4,2,0
KEYOPT,3,1,0
KEYOPT,3,2,0
KEYOPT,3,3,0
KEYOPT,3,5,0
! Generate the target surface
```

```
ASEL,S,,,16
ASEL,A,,,17
CM,_TARGET,AREA
AATT,-1,3,3,-1
TYPE,3
AMESH,ALL
! Create a pilot node
! At center of mass of target geometric
N,8201,
0.0127000131441,0.0126999960793,0.005600250777
2
TSHAP,PILO
E,8201
! Generate the contact surface
ASEL,S,,,2
CM,_CONTACT,AREA
TYPE,4
NSLA,S,1
ESLN,S,0
NSLE,A,CT2
ESURF
*SET,_REALID,3
ALLSEL
ESEL,ALL
ESEL,S,TYPE,,3
ESEL,A,TYPE,,4
ESEL,R,REAL,,3
ASEL,S,REAL,,3
ESEL,ALL
ESEL,S,TYPE,,3
ESEL,A,TYPE,,4
ESEL,R,REAL,,3
ASEL,S,REAL,,3
CMSEL,A,_NODECM
CMDEL,_NODECM
CMSEL,A,_ELEMCM
CMDEL,_ELEMCM
CMSEL,S,_KPCM
CMDEL,_KPCM
CMSEL,S,_LINECM
CMDEL,_LINECM
CMSEL,S,_AREACM
CMDEL,_AREACM
CMSEL,S,_VOLUCM
CMDEL,_VOLUCM
CMDEL,_TARGET
CMDEL,_CONTACT
!/COM, CONTACT PAIR CREATION
!- END
FINISH
/SOL
ANTYPE,4
TRNOPT,FULL
LUMPM,0
CNVTOL,u,2 ,0.001,
ANTYPE,4
NLGEOM,1
DELTIM,1/10000,0,0
AUTOTS,1
EQSLV,SPAR
LNSRCH,1
NCNV,2,0,0,0,0
PRED,ON,,ON
TIME,1/1000
FLST,2,1,1,ORDE,1
FITEM,2,8201
D,P51X, ,-1/1000, , , ,UZ, , , , ,
SOLVE
CNVTOL,u, 2,0.001
ANTYPE,4
NLGEOM,1
DELTIM,1/10000,0,0
AUTOTS,1
EQSLV,SPAR
LNSRCH,1
NCNV,2,0,0,0,0
PRED,ON,,ON
TIME,1.1/1000
FLST,2,1,1,ORDE,1
FITEM,2,8201
D,P51X, ,-1.1/1000, , , ,UZ, , , , ,
SOLVE
CNVTOL,u,4 ,0.001
ANTYPE,4
NLGEOM,1
DELTIM,1/10000,0,0
AUTOTS,1
EQSLV,SPAR
LNSRCH,1
NCNV,2,0,0,0,0
PRED,ON,,ON
TIME,1.2/1000
FLST,2,1,1,ORDE,1
FITEM,2,8201
D,P51X, ,-1.2/1000, , , ,UZ, , , , ,
SOLVE
*do,i,1.3,2,0.1
CNVTOL,u,4 ,0.001
ANTYPE,4
NLGEOM,1
DELTIM,1/10000,0,0
AUTOTS,1
EQSLV,SPAR
LNSRCH,1
NCNV,2,0,0,0,0
PRED,ON,,ON
TIME,i/1000
FLST,2,1,1,ORDE,1
FITEM,2,8201
D,P51X, ,-i/1000, , , ,UZ, , , , ,
SOLVE
*enddo
```

Number of preparatory runs were led to build up the suitable mesh for themodel. The dynamic examination was done utilizing Newmark implicit time-integration scheme with adjustable time steps [13][14][15]. Fig.(4) illustrated the mesh for the shot peening process.




**Dia. of ball=3.5mm** **Dia. of ball=3mm** **Dia. of ball=1.5mm**

**Figure 4: Mesh of the shot peening**

## 7. Results and Discussion

The fatigue strength of metallic can be improved by shot peening process, due to local plastic deformation in the surfaces through the impact procedure. The results illustrated that when the increasing in the shot ball radius caused to increase in the volume of the plastic deformation of the material. Table(3) illustrated hardness for 6061-T6 under shot peening with different size of ball (dia. 1.5,3,3.5mm) experimentally and by Ansys software. Good agreement is evident between these results with average discrepancy 3.6%. Fig.(5) shown the traceindentation in the aluminum plate that used to evaluate the hardness according to Eq.(1). Fig.(6) observed thecurves of S/N for the base material and the three shot peenedcases.It can be cleared in Fig.(6) the improvement of the fatigue's resistance for shot peened specimens. The final results can be summarized in Table(4). The power law's equation for regression is given by fatigue life formula (Eq.2)[16] :

$$\sigma = aN^{b} \qquad (2)$$

where:

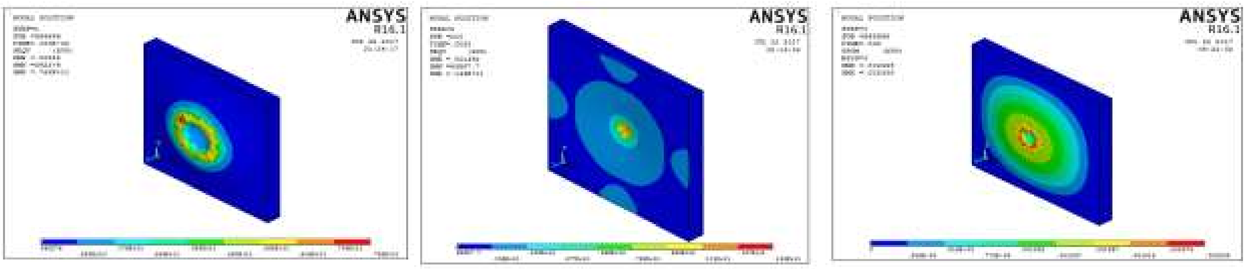
$\sigma$ ……. applying stresses

(a) and (b) ……. fitting parameters.

The constant of regression represent the trends of the fatigue. Table(4) illustrated the life of fatigue equation's parameters for the tested groups. The improvement of the fatigue strength in the fatigue specimens of the groups (A1,A2 and A3) in table(2) when compared with the fatigue strength in the specimens of group (A) which represent the base metal, because the shot peening of balls will lead to dislocation in great density, and at the same time it will cause the fining of grains in the surface case affected after shot peening and which will improve the properties of fatigue, in addition to the plastic deformation happened as a result of the shot peening of balls; and this shot peening will increase the case hardening too, with the generation of compressive stress which retard the growth of the fatigue crack on the surface. An advance in the improvement of fatigue strength in the fatigue specimens of group (A3), which were shot peened with steel balls of diameter 3.5mm, when compared with the fatigue specimens of groups (A1 and A2) which are shot peened with less diameters, and this denotes that the effect of diameter size upon the increase in the compressive stress and surface hardening, knowing that the time duration of the tests is fixed for all specimens which is ten minutes.

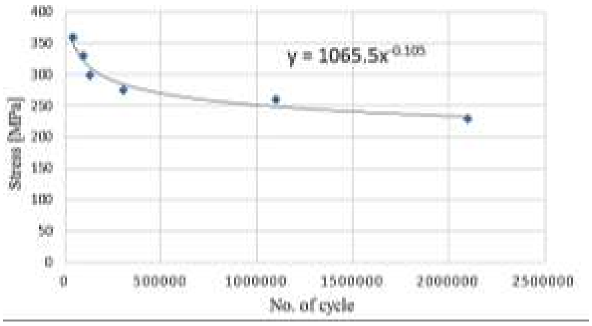
**Table 3: Hardness Results**

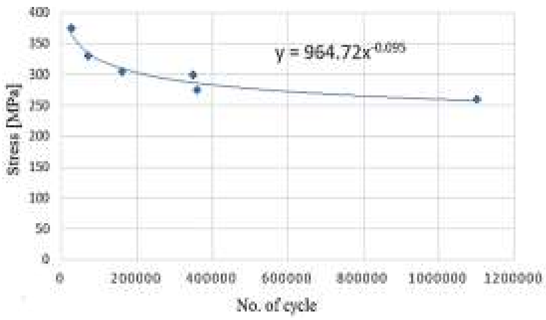
| Specimen Symbol | Hardness Kg/mm$^2$ (Experiment) | Hardness Kg/mm$^2$ (Ansys) | Discrepancy% |
|---|---|---|---|
| A | 120 | 123 | 2.43 |
| A1 | 135 | 141 | 4.25 |
| A2 | 170 | 166 | 2.4 |
| A3 | 195 | 206 | 5.33 |



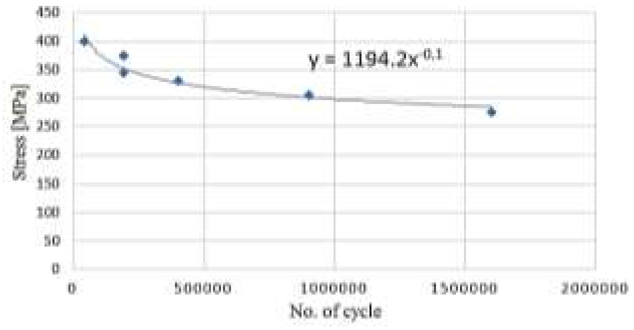
**(a) Dia. of ball=3.5mm (b)Dia. of ball=3mm (c) Dia. of ball=1.5mm**

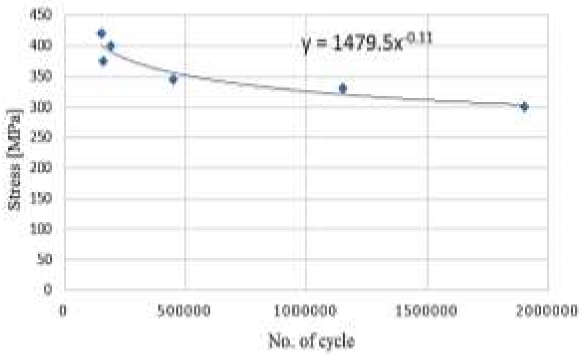
**Figure 5: The Traceindentation in Aluminum plate due to shot peening**




**Specimen –A–** **Specimen –A1–**




**Specimen –A2–** **Specimen –A3–**

**Figure 6: S-N curves for the tested groups**

**Table4 :S-N fatigue results**

| Description | a | b |
|---|---|---|
| Without shot peening | 1065.5 | –0.105 |
| diameter of shot ball 1.5 mm | 964.72 | –0.095 |
| diameter of shot ball 3 mm | 1194.2 | –0.1 |
| diameter of shot ball 3.5 mm | 1479.5 | –0.11 |

## 8 .Conclusions

1. Fatigue strength is improvedsince the plastic deformation done as a result of the shot peening the balls which leads to increase the hardening, in addition to the fatigue residual stress that generated in the metal after shot peening which contribute in the retardation of the growth of the fatigue crack on the surface.
2. An increasing in fatigue strengthwhen the diameter of the shot peened balls are increased.
3. A ball whose diameter is (3.5mm) gave higher strength when compared with balls of lesser diameter.
4. Good agreement for hardening results is evident between experimental and Ansys results with average discrepancy 3.6%.

## References

[1] H.O. Fuchs, Shot-peening, Mechanical Engineering Handbook, Wiley, Cincinnati, OH, pp: 941–951, (1986).

[2] N. E. Frost, K. J. Marsh and L. P. Pook “Metal Fatigue” Clarendon Press, Oxford (1974).

[3]Hussain J. Al-Alkawi, Fikrat Abdul Kareem, and AsmaaAbdulqasimMohammed Ali, “Prediction of Fatigue-Creep Interaction Life of Aluminum Alloy AA7349 Using Electromechanical Devices”, Engineering and Technology Journal, Vol. 33, Part (A), No.3, (2015).

[4] S.A. Meguid, G. Shagal, J.C. Stranart, and J. Daly, “Three-dimensional dynamic finite element analysis of shot-peeninginduced residual stresses”, Journal of “Finite Elements in Analysis and Design”, 31, pp:179 –191, (1999).

[5] B. L. Boyce, X. Chen, J.W. Hutchinson, and R.O. Ritchie, “The residual stress state due to a spherical hard- body impact”, Mechanics of Materials, 33, pp:441-454, (2001).

[6] K. S. Hassan “ The effect of ball diameter shot peen on fatigue strength for low alloy steel” Al-Techani Journal , Vol.21, No.4, (2008) .

[7] T. Hong, J.Y. Ooi, and B. Shaw, “A numerical simulation to relate the shot peening parameters to the induced residual stresses”, Engineering Failure Analysis, 15, pp: 1097–1110, (2008).

[8] Alexander George Broulidakis, “A Model for the Prediction of Residual Stresses Resulting from Shot Peening and its Incorporation into the ANSYS Finite Element Solver”, M.Sc. thesis, Rensselaer Polytechnic Institute Hartford, Connecticut May, (2013).

[9] Hussain J. Al-Alkawi, ShakirSakran Hassan, and Salah F. Abd-El-Jabbar, “Experimental Study of the Effect of Shot Peening on Elevated Temperature Fatigue Behavior of 7075-T651 Al. alloy”, Engineering and Technology Journal, Vol. 31, No.3, (2013).

[10] Hussain J. M.Alalkawi, Saad A. Khuder Al Saraf and Abdul-Jabar H. Ali “A new Cumulative Damage Model for Fatigue Life Prediction under Shot Peening Treatment” , Al-Khwarizmi Engineering Journal, Vol. 10, No. 2, pp:57- 64, (2014).

[11] M.S. Abdu_Lateef , N.S. Abdulrazaq , and A.G. Mohammed , “ Prediction of Fatigue Life of Fiber Glass Reinforced Composite (FGRC) using Artificial Neural Network”, Engineering and Technology Journal , Vol. 35, Part A. No. 4, (2017).

[12] Roberts, N. P., & Hart, N. R. ” Alternating Bending Fatigue Machine (HSM20), Instruction Manual”. Hi-Tech Ltd. UK, 150, 200-250, (2001).

[13] T.G.Meschke, "Advanced finite element methods", Bochum University, Institute for Structural Mechanics, (2005).

[14] H. Lewis Zion “A Dynamic finite element simulation of the shot peening process”, Ph.D. Thesis, Georgia Institute of Technology, April, (2003).

[15] AnsysR16.1 Help, User Guide,(2016).

[16] Hani Aziz Ameen and Asma Hassan Ismail , “Study of the short and long fatigue cracks for brass alloy”, Journal of Mechanical Engineering Research Vol. 3, (6), pp:181-185, June (2011).