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MODELING THE SURFACE CHARACTERISTICS OF SHOT PEENED 2024 ALUMINUM ALLOY

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Abstract

The present research aims to study the effect of shot peening time (SPT) using metal balls (stainless steel balls) on surface roughness ,hardness and residual stresses .the above first two parameters (roughness, hardness) were measured before and after shot peening،While the third parameter i.e. the residual stresses were calculated based on the original yield stress of the ALUMINUM ALLOY 2024. The above three parameters were empirically modeling using the curve fitting equations The following conclusions can be drawn from this work:

1- Surface roughness increases with increasing the (SPT).
2- The hardness increases with increasing SPT (For the current study an improvement of 36.75%) using shot peening of 2024-Al alloy.
3- The compressive residual stresses increases with increasing SPT (for the present study an improvement of 11%using shot peening of 2024 –Al alloy.

KEY WORDS: shot peening, aluminum alloy2024, roughness, hardness , residual stresses.

الخلاصة:

يهدف البحث الحالي دراسة تأثير زمن القذف بالكريات المعدنية (كريات مصنعة من الفولاذ الصلد) على خشونة السطح، والصلادة، والاجهادات المتبقية.العامل الأول و الثاني أعلاه تم قياسها قبل و بعد عملية القذف، بينما العامل الثالث أي الاجهادات المتبقية حسبت اعتمادا على إجهاد الخضوع الأصلي لسبيكة الألمنيوم 2024 حيث تم نمذجة العوامل الثلاثة أعلاه بواسطة معادلات رياضية تعتمد على النتائج العملية المستخرجة وتوصل البحث الى الأستنتاجات التالية:-

1_ خشونة السطح تزداد مع زيادة زمن القذف بالكريات.

2_ الصلادة تزداد مع زيادة زمن القذف بالكريات(الدراسة الحالية أعطت تحسن 36.75% باستخدام القذف بالكريات).

3_ الاجهادات المتبقية الضغطية تزداد بزيادة زمن القذف بالكريات (الدراسة الحالية أعطت تحسن 11% باستخدام القذف بالكريات) لسبيكة المنيوم 2024 .

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Introduction and literature survey

Shot peened components have three important surface characteristics these are:

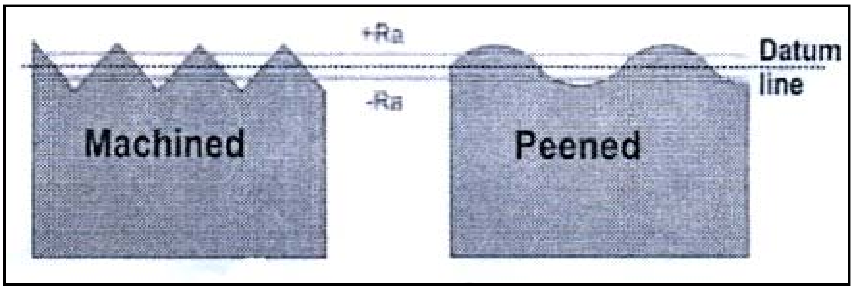
1- Surface Roughness

Which depends mainly upon the size of shot used .There is a simple analogy with the use of emery papers .The coarser the grit size the rougher will be final finish. Two stages shot peening involves using a finer grade of shot after a coarser grade .That is equivalent to using a finer grade of emery after using a coarser grade. Average roughness is easily measured and is well understood. The commonest roughness parameter is Ra which is the average vertical deviation from reference line .Measurement techniques can be either two-dimensional or three dimensional and may involve either direct contact or non-contact sensors. Peening is normally applied as a final treatment .The change of surface roughness induced by shot peening will therefore depend on the initial roughness of the component. [1]

Roughness induced by machining and peening

Machined as compared with peened surface are illustrated in fig. (1) Showing model profiles most components submitted for shot peening are “finish-machined”. Shot peening is normally a final stage of processing, the roughness imparted by machining is quite different from that imposed by shot peening .Machining involves deforming a chip until it fractures away from the surface. The difference in roughness generation mechanisms means that we have different “textures” for of machined and peened surface that have the same roughness (Ra) values [1].

Fig (1)



comparison of machined and peened cross-sections. After [1]

Influence of shot peening on surface roughness

Fig (2) Shows the variation of roughness on the surface before and after peening.

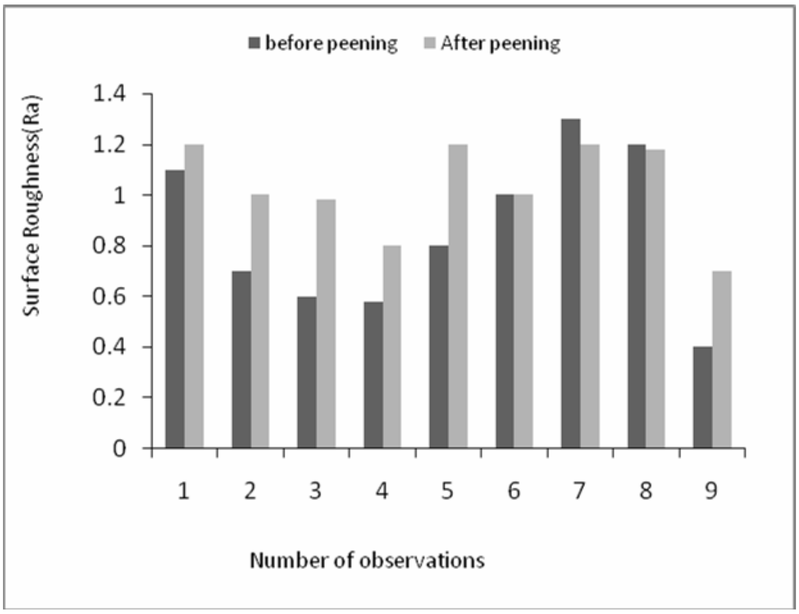


Fig. (2) variation of surface roughness on Aluminum alloy 6063-T6. After [2].

2-Residual Stress

Fig . (3) Shows the influence of shot peening on compressive residual stresses before and after peening.

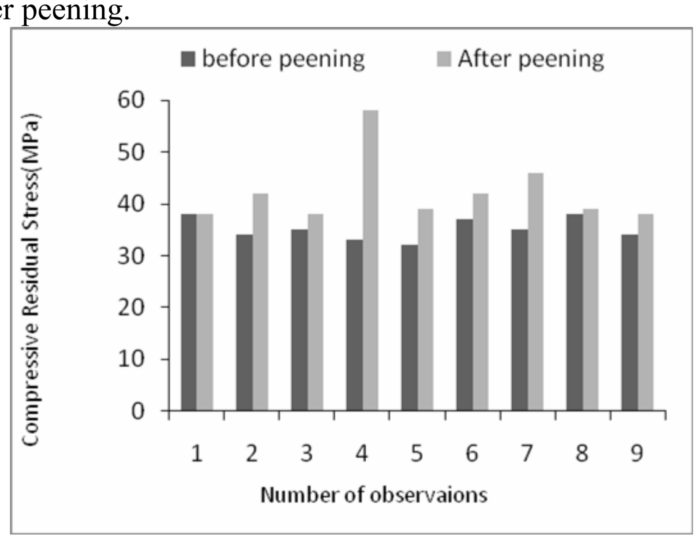


Fig. (3) Variation of residual stresses on 6063-T6 aluminum alloy After [2].

From the above figure, it is clear that the maximum increase in compressive residual stress occurred at number of observation (4).

3-Hardness

Fig. (4) Shows the influence of shot peening on the Vickers Hardness number of 6063-T6 aluminum alloy before and after peening.

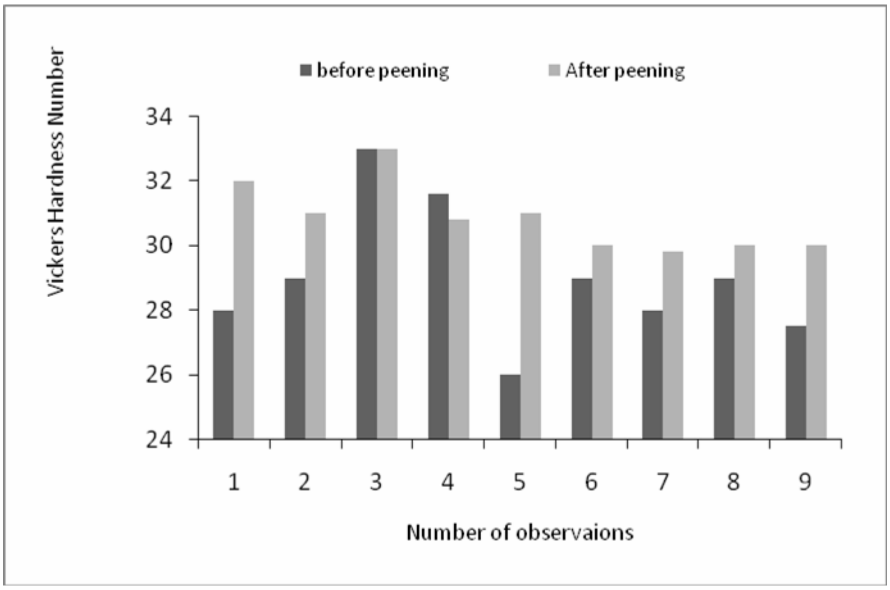


Fig.(4)Variation of hardness 0n 6063-T6 aluminum alloy with water peening. After [2]

Experimental Procedure and material

The material investigated in this paper is 2024 aluminum alloy whose chemical composition is presented in table (1).

Table (1) chemical composition of 2024 aluminum alloy in wt%

Cu	Mg	Mn	Zn	Si	Fe	Ni	Al
4,0	0.244	0.43	0.43	0.12	0.28	0.1	Rem.

Chemical composition was carried out at S.C.of Geological survey and mining using x-Ray method.

Tensile Test (mechanical properties)

The tensile test was done using Instron 225 testing machine that has a maximum capacity of 150 KN .Shapes and dimensions of specimen were taken according to German engineering standard (DIM50123).The results are shown in table(2).

Table (2) mechanical properties of 2024 –aluminum alloy

σu(MPa)	σy(MPa)	Elongation	HB
502	352	15.4	117

Brinal Test (HB)

A diameter of the ball of ø=1.25 mm was used under the applied load to 15 Kg. The average of three readings was recorded

Surface roughness

After machining, the specimens were polished using the following steps:

1-The surface of the specimen was smoothed using different wet Silicon Carbide papers starting with (260) to (1000) µm for finishing.

2- The specimen was polished using three different diamond lapping compounds (dialap):

a- Coarse compound, average micron 3/2.

b- Fine compound, average micron 1/1.

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Distilled water was used for three minutes to clean the specimen followed washing them with alcohol. After washing, the surface roughness of the specimen was measured.

Shot peening process

The peening operation was performed in a special apparatus (Shot Tumblast Control Panel model STB-OB).This enables defined shot peening treatment on round and flat specimens. The following properties of shot process are:

1-The ball material was cast steel with 0.6mm in diameter and 48-50 HRC(Rockwell hardness).

2-The number of balls at whole operation time was kept constant 100 balls per minute.

3-Pressure is about 12 N/m^2.

4- Ball velocities are nearly 40 m/s.

5- Transverse distance (distance from the nozzle to the specimen) is 20 mm.

<u>Specimens</u>

Fig. (5) Shows the shapes and dimensions of flat specimen. The dashed area is the shot peened region. This specimen was used as a fatigue reversed bending specimen and more details are given in [3].

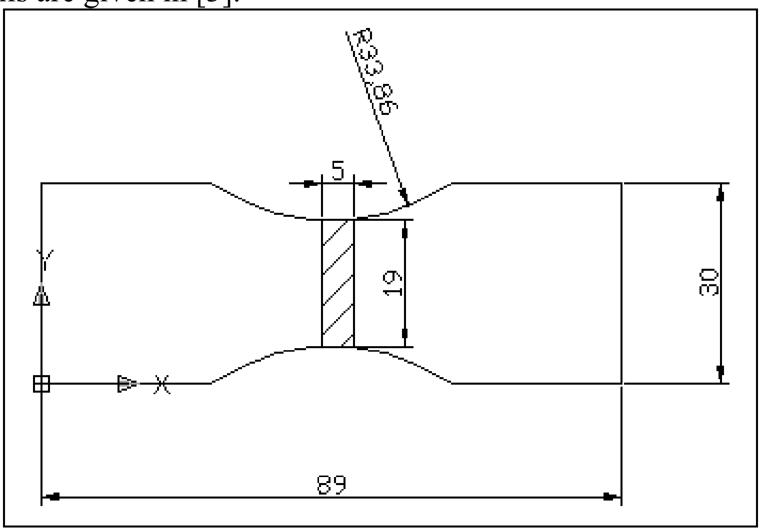

Fig. (5) test specimen (all dimensions in mm) after [3].

Experimental Results

Roughness before peening

Ten specimens were tested for measuring the surface roughness the results are given in table (3).

Table (3) surface roughness results of 10 specimens before peening

Average roughness Ra(µm)				
A1	**A2**	**A3**	**A4**	**A5**
0.3	**0.25**	**0.17**	**0.27**	**0.19**
A6	**A7**	**A8**	**A9**	**A10**
0.22	**0.24**	**0.29**	**0.31**	**0.23**

Roughness after peening

The same specimens, in table (3), were shot peened at different blasting time in order to investigate the influence of shot peening on roughness. The results are summarized in table (4).

Table (4) roughness measurements at different shot peening time

Specimen No.	Time of shot peening(min) SPT					
	Zero	2	4	6	8	10
	Average roughness Ra(µm)					
A1	0.3	0.7	1.2	1.8	1.9	2.5
A2	0.25	0.7	1.4	2	2.1	2.7
A3	0.17	0.35	1.1	1.9	2.3	2.9
A4	0.27	0.33	0.6	1.25	1.77	1.9
A5	0.19	0.8	1	1.2	1.7	2
A6	0.22	0.6	0.9	1.3	1.9	2.3
A7	0.24	0.45	0.7	0.9	1.3	1.8
A8	0.29	0.6	0.9	1.8	2.2	2.7
A9	0.31	0.8	1.2	1.9	2.1	2.8
A10	0.23	0.85	1.2	1.8	2.2	2.8

The above results can be illustrated in fig. (6).

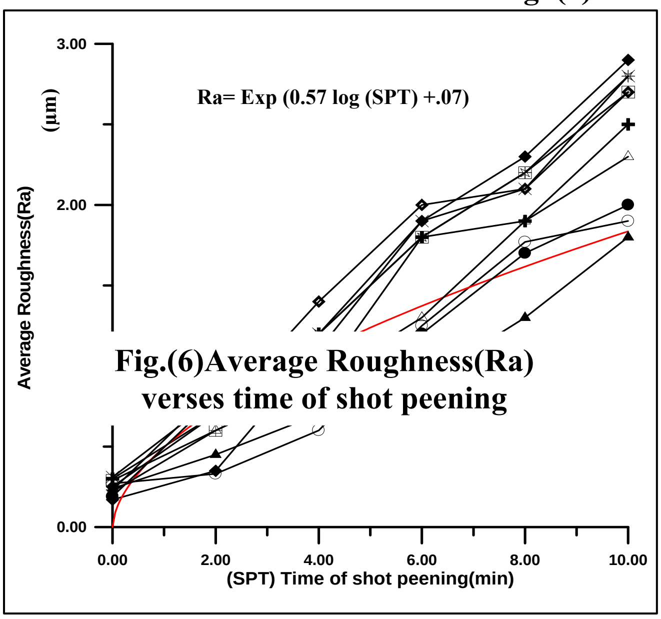

Fig.(6)Average Roughness(Ra) verses time of shot peening

Hardness after peening

During the measurement of roughness, the hardness was measured and recorded for each (time of shot peening) number of observations. The results are summarized in table (5).

Table (5) hardness readings at different number of observations

Specimen No.	Time of shot peening(min) SPT					
	Zero	2	4	6	8	10
	Brinel hardness (HB)					
A1	117	121	129	140	150	155
A2	117	123	133	142	152	154
A3	117	120	131	140	149	155
A4	117	122	130	139	148	152
A5	117	119	128	138	145	154
A6	117	125	130	140	150	158
A7	117	122	130	141	144	157
A8	117	120	132	142	148	160
A9	117	121	131	139	150	153
A10	117	120	128	140	149	154

The above results of Brinel hardness against shot peening can be plotted in fig. (7).

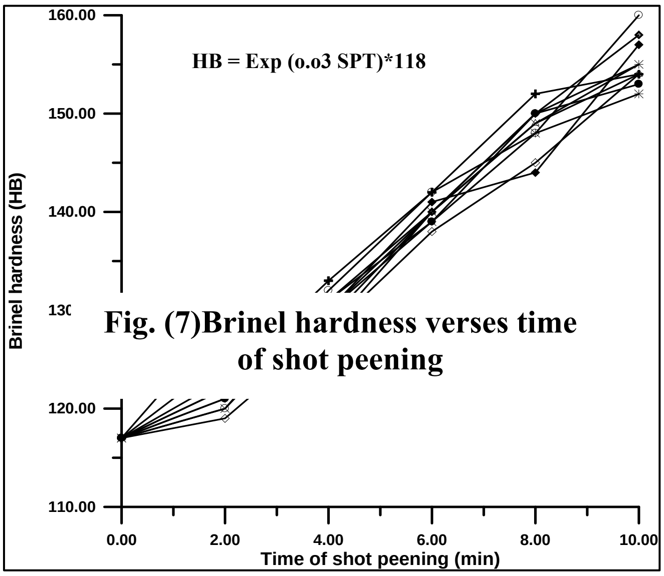

Fig. (7)Brinel hardness verses time of shot peening

Residual Stresses

From a tensile test for 4 specimens at different time of shot peening, the residual stresses are summarized in table (6).

Table (6) Yield and Residual stresses after shot peening with different peening time

Spec. No.	A11	A12	A13	A14
SPT	2	4	6	10
σ_R (Mpa) residual stress	-12	-26	-34	-40

The results of table (6) can be plotted in fig. (8).

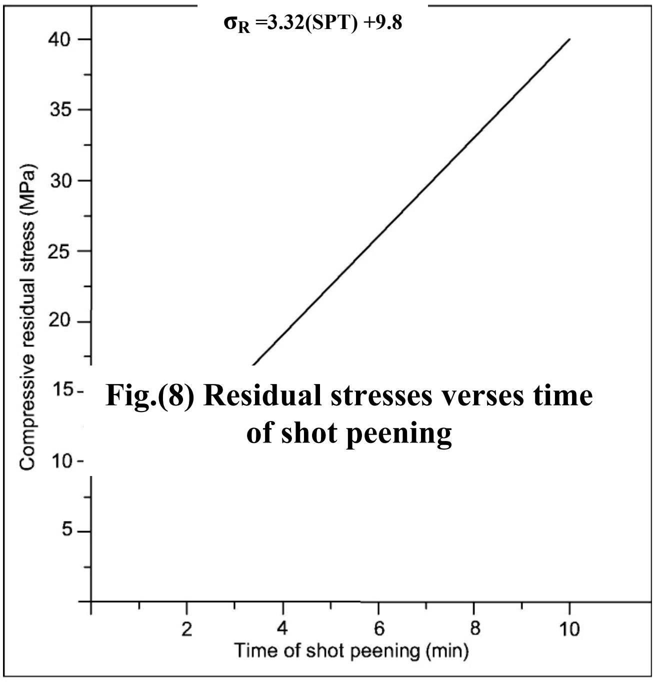

Fig.(8) Residual stresses verses time of shot peening

Discussion

The obvious improvement will be that shot peening will prevent surfaces of metal parts there by allowing the part to function under greater stress levels,for example, springs life will be increased 400% to 1000% depending on the extent of peening already imparted on the spring . Gear life will increase up to 500% and drive pinions display a 40% to 414 %life increase with peening.These are just a few of the improvements[6].

Influence of shot peening on surface roughness

The effect of shot peening time (SPT)on the average surface roughness (Ra) is shown in fig (6).An empirical equation was developed which can be expressed as

$$Ra\ (\mu m) = Exp\ (0.57 \log (SPT) + 0.7) \qquad (1)$$

Rajesh etal. [7] proposed an empirical model for describing the surface roughness using water jet peening method of 6063-T6 Aluminum alloy. This model based on the mean analysis that relates the results with process parameters. The model is:

$$Ra = 1.345 - 8.4*10^{-4}p - 0.058d + 3.5*10^{3}\,n + 0.2964(n-3)^2 + 3.3*10^{-3}V \qquad (2)$$

Where:

P: is the pressure,(jet pressure in the range of 175-225 Mpa).
n: is the number of passes.
d: is the standoff distance (5-10) mm.
v: is the traverse rate (in the range of 20-40 mm/min).

From the current results, one can notice a slight deviation in the results predicated with the model compared to the results obtained from the experiments. This can be attributed to the nature of experimentation [7].

Influence of shot peening on hardness

The influence of different shot peening time (SPT) (from 2 min to 10 min) on the HB (Brinell hardness) is shown in figure (7). The best fit equation which describes this effect may be written as:

$$HB = Exp\,(0.03\ SPT)*118 \qquad (3)$$

Kunaporn etal.[8] formulated an equation describing this effect as:

$$VHN = 29.869 - 0.0406(p-200) - 2.304*10^{-4}(p-200)^2 - 0.1925d + 0.35n + 0.043\,V \qquad (4)$$

Where VHN is the Vickers hardness number.
Equation (4) is generated from the experimentation of 6063 – T6 aluminum alloy subjected to the water – jet peening.
The analysis obtained from equation (4) that the jet pressure contributes with nearly 42% in improving the hardness of the surface treated with water jets. While the current study is improve the hardness with nearly 36.75%.

Influence of shot peening on residual stresses

Fig (8) shows the variation of residual stress against the (SPT). The maximum compressive stress of 40 Mpa is calculated based on the original yield stress of 352 Mpa .This corresponds to 11% improvement of residual stresses on the surface treated with shot peening .An empirical equation which describes the improvement of residual stresses may be written as:

$$\sigma_R = 3.32(SPT) + 9.8 \qquad (5)$$

Where σ_R is the residual stress due to shot peening .Miter etal. [8] Presented linear model describing the residual stresses after shot peening sheets of Al Mg 4.5 Mn alloy.
Rajesh etal. [2] Also formulated an empirical model using water – jet peening of 6063 – T6. This model can be written as:

$$\sigma_{Rs} = -38.418 + 0.02P + 2.166d - 0.75\,(d-7.5)^2 - 0.667n - 0.35V \qquad (6)$$

The above model improved the residual stresses by 11 % in comparison with the stresses on unpeened surface.

<u>Conclusion</u>

1- An attempts have been made to investigate the influence of shot peening time on 2024 – Al alloy resulted in empirical model that can estimate the surface roughness,hardness and residual stresses. These models are:

1_Ra=Exp (0.57 log (SPT) +.07)

2_HB=Exp (o.o3 SPT)*118

3_ σ_R =3.32(SPT) +9.8

2- The hardness increase with increasing SPT (For the current study an improvement of 36.75%) using shot peening of 2024-Al alloy.
3- The compressive residual stresses increase with increasing SPT (for the present study an improvement of 11% using shot peening of 2024 –Al alloy

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Introduction and literature survey

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Which depends mainly upon the size of shot used .There is a simple analogy with the use of emery papers .The coarser the grit size the rougher will be final finish. Two stages shot peening involves using a finer grade of shot after a coarser grade .That is equivalent to using a finer grade of emery after using a coarser grade. Average roughness is easily measured and is well understood. The commonest roughness parameter is Ra which is the average vertical deviation from reference line .Measurement techniques can be either two-dimensional or three dimensional and may involve either direct contact or non-contact sensors. Peening is normally applied as a final treatment .The change of surface roughness induced by shot peening will therefore depend on the initial roughness of the component. [1]

Roughness induced by machining and peening

Machined as compared with peened surface are illustrated in fig. (1) Showing model profiles most components submitted for shot peening are “finish-machined”. Shot peening is normally a final stage of processing, the roughness imparted by machining is quite different from that imposed by shot peening .Machining involves deforming a chip until it fractures away from the surface. The difference in roughness generation mechanisms means that we have different “textures” for of machined and peened surface that have the same roughness (Ra) values [1].

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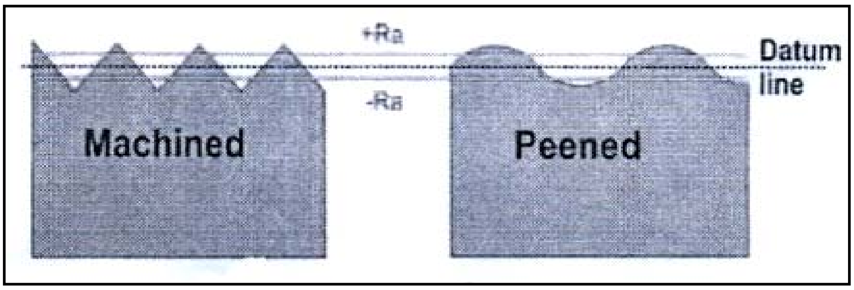

comparison of machined and peened cross-sections. After [1]

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Fig (2) Shows the variation of roughness on the surface before and after peening.

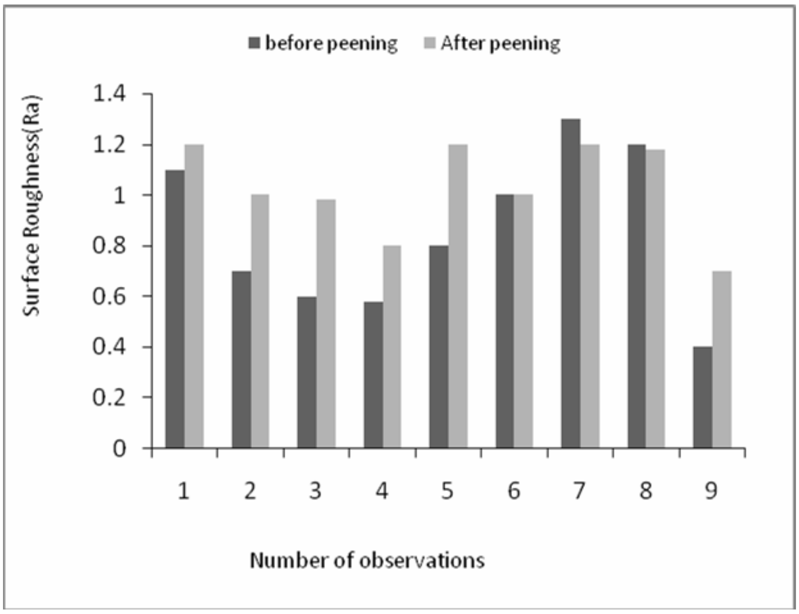

Fig. (2) variation of surface roughness on Aluminum alloy 6063-T6. After [2].

2-Residual Stress

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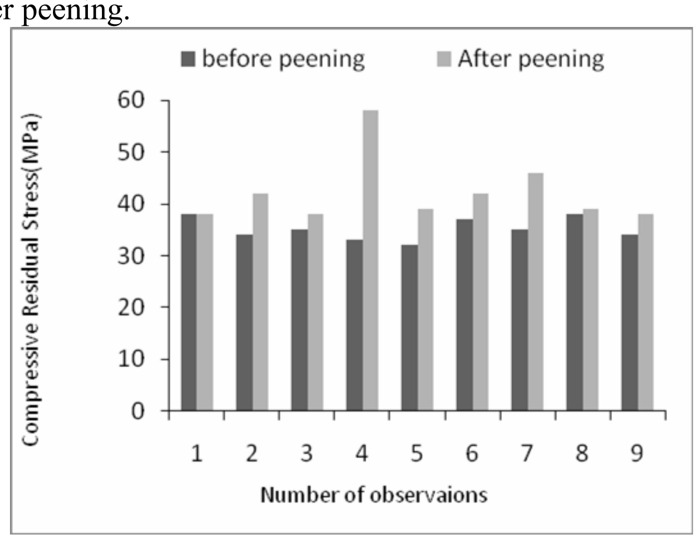

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3-Hardness

Fig. (4) Shows the influence of shot peening on the Vickers Hardness number of 6063-T6 aluminum alloy before and after peening.

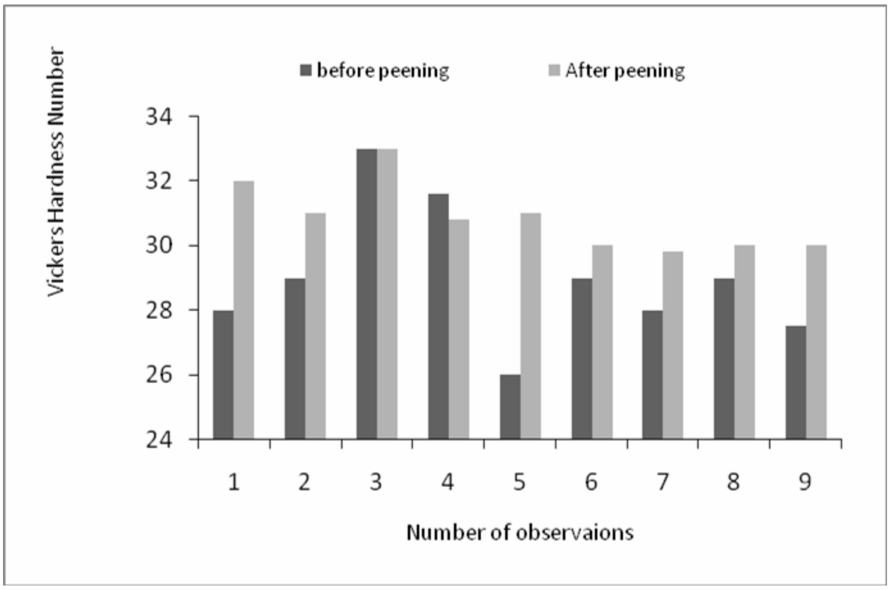

Fig.(4)Variation of hardness 0n 6063-T6 aluminum alloy with water peening. After [2]

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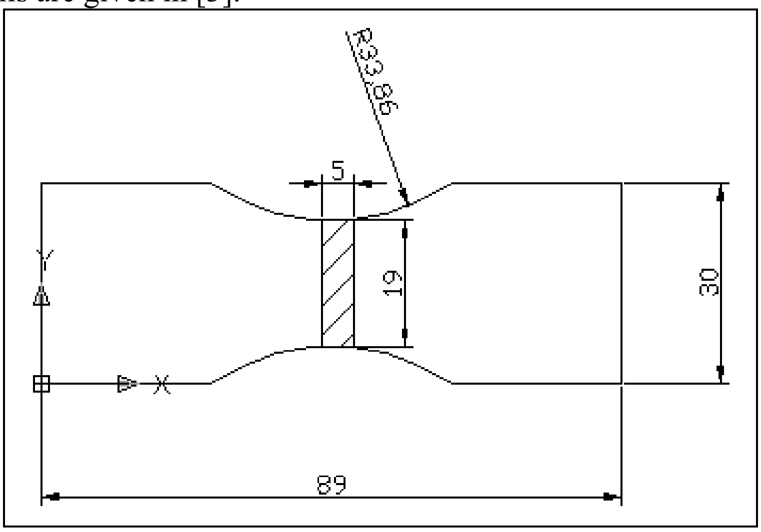

Fig. (5) test specimen (all dimensions in mm) after [3].

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Roughness before peening

Ten specimens were tested for measuring the surface roughness the results are given in table (3).

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Average roughness Ra(µm)				
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A5	0.19	0.8	1	1.2	1.7	2
A6	0.22	0.6	0.9	1.3	1.9	2.3
A7	0.24	0.45	0.7	0.9	1.3	1.8
A8	0.29	0.6	0.9	1.8	2.2	2.7
A9	0.31	0.8	1.2	1.9	2.1	2.8
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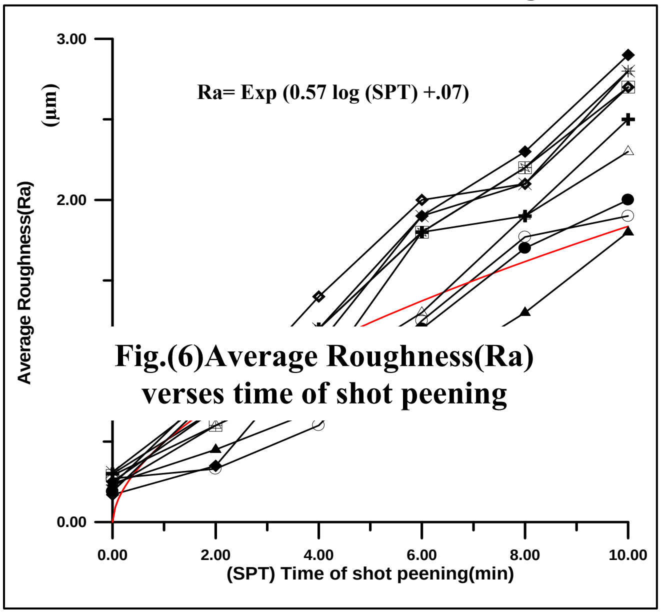
The above results can be illustrated in fig. (6).



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The above results of Brinel hardness against shot peening can be plotted in fig. (7).

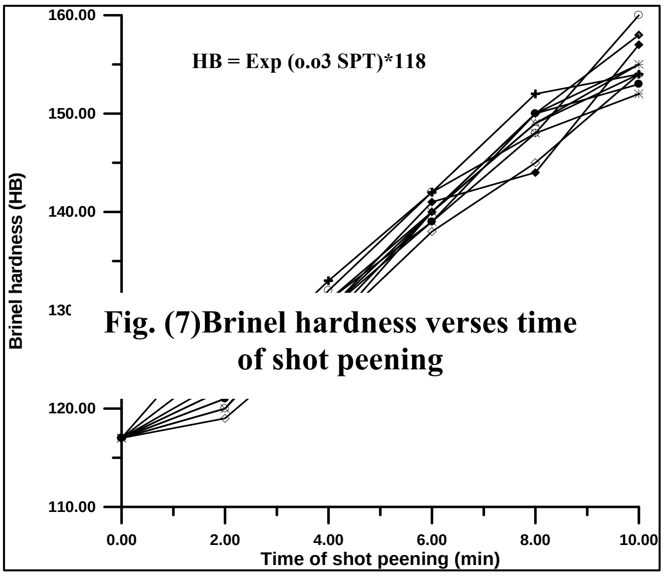

Fig. (7)Brinel hardness verses time of shot peening

Residual Stresses

From a tensile test for 4 specimens at different time of shot peening, the residual stresses are summarized in table (6).

Table (6) Yield and Residual stresses after shot peening with different peening time

Spec. No.	A11	A12	A13	A14
SPT	2	4	6	10
σ_R (Mpa) residual stress	-12	-26	-34	-40

The results of table (6) can be plotted in fig. (8).

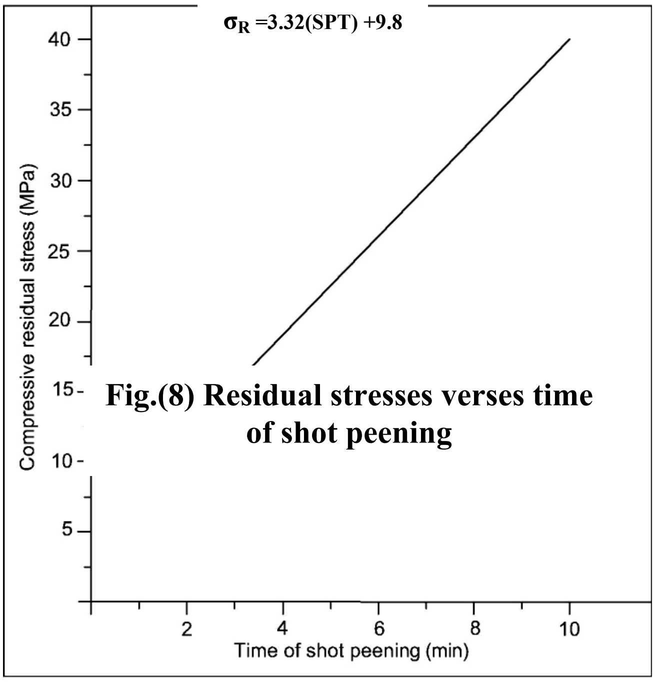

Fig.(8) Residual stresses verses time of shot peening

Discussion

The obvious improvement will be that shot peening will prevent surfaces of metal parts there by allowing the part to function under greater stress levels,for example, springs life will be increased 400% to 1000% depending on the extent of peening already imparted on the spring . Gear life will increase up to 500% and drive pinions display a 40% to 414 %life increase with peening.These are just a few of the improvements[6].

Influence of shot peening on surface roughness

The effect of shot peening time (SPT)on the average surface roughness (Ra) is shown in fig (6).An empirical equation was developed which can be expressed as

$$Ra\ (\mu m) = Exp\ (0.57 \log (SPT) + 0.7) \qquad (1)$$

Rajesh etal. [7] proposed an empirical model for describing the surface roughness using water jet peening method of 6063-T6 Aluminum alloy. This model based on the mean analysis that relates the results with process parameters. The model is:

$$Ra=1.345-8.4*10^{-4}p-0.058d+3.5*10^{3}n+0.2964(n-3)^{2}+3.3*10^{-3}V \qquad (2)$$

Where:

P: is the pressure,(jet pressure in the range of 175-225 Mpa).
n: is the number of passes.
d: is the standoff distance (5-10) mm.
v: is the traverse rate (in the range of 20-40 mm/min).

From the current results, one can notice a slight deviation in the results predicated with the model compared to the results obtained from the experiments. This can be attributed to the nature of experimentation [7].

Influence of shot peening on hardness

The influence of different shot peening time (SPT) (from 2 min to 10 min) on the HB (Brinell hardness) is shown in figure (7). The best fit equation which describes this effect may be written as:

$$HB = Exp\,(0.03\ SPT) * 118 \qquad (3)$$

Kunaporn etal.[8] formulated an equation describing this effect as:

$$VHN = 29.869 - 0.0406(p - 200) - 2.304*10^{-4}(p-200)^2 - 0.1925d + 0.35n + 0.043\ V \qquad (4)$$

Where VHN is the Vickers hardness number.
Equation (4) is generated from the experimentation of 6063 – T6 aluminum alloy subjected to the water – jet peening.
The analysis obtained from equation (4) that the jet pressure contributes with nearly 42% in improving the hardness of the surface treated with water jets. While the current study is improve the hardness with nearly 36.75%.

Influence of shot peening on residual stresses

Fig (8) shows the variation of residual stress against the (SPT). The maximum compressive stress of 40 Mpa is calculated based on the original yield stress of 352 Mpa .This corresponds to 11% improvement of residual stresses on the surface treated with shot peening .An empirical equation which describes the improvement of residual stresses may be written as:

$$\sigma_R = 3.32(SPT) + 9.8 \qquad (5)$$

Where σ_R is the residual stress due to shot peening .Miter etal. [8] Presented linear model describing the residual stresses after shot peening sheets of Al Mg 4.5 Mn alloy.
Rajesh etal. [2] Also formulated an empirical model using water – jet peening of 6063 – T6. This model can be written as:

$$\sigma_{Rs} = -38.418 + 0.02P + 2.166d - 0.75\,(d-7.5)^2 - 0.667n - 0.35V \qquad (6)$$

The above model improved the residual stresses by 11 % in comparison with the stresses on unpeened surface.

Conclusion

1- An attempts have been made to investigate the influence of shot peening time on 2024 – Al alloy resulted in empirical model that can estimate the surface roughness,hardness and residual stresses. These models are:

1_Ra=Exp (0.57 log (SPT) +.07)

2_HB=Exp (o.o3 SPT)*118

3_ σ_R =3.32(SPT) +9.8

2- The hardness increase with increasing SPT (For the current study an improvement of 36.75%) using shot peening of 2024-Al alloy.

3- The compressive residual stresses increase with increasing SPT (for the present study an improvement of 11% using shot peening of 2024 –Al alloy

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