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Optimizing the Process Parameters and Investigating the Influence of Shot Peening and Roller Burnishing On Surface Layer Properties and Fatigue Performance of Al 6061 T4

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Abstract: In many industrial applications either in the automotive industry or structural applications, appears Al 6061 as a good choice from both economical and mechanical aspects. In this research, an Aluminium alloy (Al6061) was used and processed by shot peening and roller burnishing. A set of parameters were studied to optimize the parameters of each process and meet an enhanced fatigue life. With Almen intensities, 0.105, 0.141, 0.159, 0.173, 0.193, 0.222 and 0.229 mmA samples were prepared and tested by rotating beam fatigue. Microhardness test, residual stresses measurements, and fatigue life values showed that Almen intensity 0.193 mmA provides an increase 36% in fatigue strength. Roller burnishing process was carried out under different burnishing pressures varied from 0.3 to 1.2 bar. Results indicated that increasing burnishing pressure up to 0.8 bar led to an increase in fatigue strength with 61% higher than electropolished samples.

Keywords: Shot peening; Almen intensity; Roller burnishing; Fatigue life.

1 Introduction

Appearance, light weight, good fabricability, good strength to weight ratio, physical and mechanical properties, good weldability, corrosion resistance and easy recycling process are a good combination of properties. Those properties make Aluminum ant its alloys one of the most attractive group of alloys for both economical and wide range of industrial applications. [1] Al6061 proved its importance in many applications either automotive applications for manufacturing vehicles body sheets and frames or marine applications in canoes industry. Besides, Al6061 is also used for structural applications such as pipes and structural members and in railroads applications as a component of railroads car. [1]

In almost all of those applications plays fatigue a significant role due to some forms of fluctuating stress or strain to which those components are subjected. This type of loading causes crack initiation and propagation under this cyclic load. As well as all the intrinsic state of the material and all potential sources of cracks. [2] Therefore, mechanical surface treatments are used to increase surface hardness, strength and creating compressive residual stresses, which enhance the material fatigue strength.

Shot peening and burnishing processes are considered the most common mechanical surface treatments used to improve the fatigue strength due to accomplishing mechanical surface cold working by local plastic yielding on the surface layers. The concept of both methods is to localize pressure to a specific area and to stress it beyond its elastic limit. After pressure removal, store the surface layers a part of deformation. On the other hand, act the layers, which didn't achieve the elastic limit, to return the surface layer to its original state and length causing compressive residual stresses [3-6]. Shot peening met Inducing of compressive stresses in the exposed surface layer up to 0.5mm below the surface with cold working. [7-10] In this process, a stream of shots bombard a subjected area of the material at high velocity and controlled conditions of the angle of impingement and size, hardness and velocity of shots. Shot peening method is not only used in inducing compressive stresses, but also relieving tensile stresses that give to stress corrosion cracking, redistribution of stresses in the surfaces that have been subjected to either mechanical or thermal working [11].

High surface finish is also required to make sure high performance and fatigue strength, so that burnishing process is used in which a hardened steel ball or roller is pressed into the surface of the material with predefined feeding rate, pressure, and rotating velocity. [12-15]This process produces as well compressive stresses on the material surface and plays a vital role in improving fatigue strength, wear and corrosion resistance and surface roughness [16].

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2 Experimental procedures

A. Material

An Aluminum-Magnesium-Silicon-Copper (Al6061), heat treated under temper T4 condition and with chemical composition illustrated in Table 1, was used.

Element	Si	Fe	Cu	Mn	Mg	Zn	Cr	Pb	Ti	V	Zr	Al
Amount %	0.7834	0.5229	0.3218	0.1387	0.932	0.0534	0.2804	0.005	0.0351	0.01	0.0125	96.9037

Table 1. Chemical composition of Al6061.

B. Heat treatment:

A typical temper heat treatment T4 in accordance to AMS 2770H was carried out in an electrical resistance air furnace and indicated. Solution treatment temperature was identified to be 530ºC with a soaking time 90 minutes. Then samples were removed from the furnace and quenched in water with a quench delay time 11 seconds. Finally, samples underwent naturally aging at room temperature for 96 hours.

C. Microstructure examination:

Samples were grinded, polished and etched using etching solution of 0.5% HF with the balance water. With using ImageJ program, the Mg2Si precipitates equivalent diameter was calculated.

D. Tensile test and Hardness measurements:

The tensile test was carried out following DIN 50125 using 50KN force and strain rate of 1mm/min. Macrohardness was measured for as received and after heat treatment temper T4 conditions by using Vickers's indenter and 5 Kg load. On the other hand, Microhardness was determined by a Struers Duramin tester using a square base pyramid shaped indenter for testing in a Vickers tester. A nominal force of 50 gf (HV0.05) and a loading time of 15 s. The hardness testers in the Duramin series conform to the standard (DIN EN ISO 6507). The average of three measurements was taken to construct the hardness-depth profiles.

E. Electropolishing:

Samples were electropolished after performing a mechanical polishing stage using emery papers of grades 800and 1200. Then the samples were polished with diamond paste with size 6 and 0.25 µm by using electrolyte of type A2 (Perchloric acid 60% and water). The cell voltage and temperature were adapted to be 24V and -20ºC respectively with a polishing time 30 minutes, to remove approximately a layer thickness of 100µm.

F. Shot peening:

Shot peening parameters were identified by using impingement angle 90º, a separating distance 90mm using shots of type SCCW 14 with average size 0.36mm and different pressures (1, 2, 3, 3.5, 4 ,5 and 6 bar)to give Almen intensities (0.105, 0.141, 0.159, 0.173, 0.193,0.222 and 0.229 respectively) on an automatic compressed air shot peening machine(OSK-KIEFER). To achieve 100% coverage, samples were shot peened for 20 seconds.

G. Roller burnishing:

Burnishing process was performed using hard steel roller, feeding rate of 0.122 mm/rev, rotating speed 150 rpm and different pressures (0.3, 0.5, 0.7, 0.8, 1 and 1.2 bar).

H. Surface roughness measurements:

Surface roughness was measured by (Mahr – Perthen, Perthometer S8P and Perthometer PRK) using tester of RFHTB-250 of radius 5µm, force 1.3 mN, measurement angle 90º and 250µmmeasurement distance.

I. Fatigue test:

According to figure 1 samples were prepared and tested using a Sinco-Tech rotating beam fatigue machine having a frequency of 50 Hertz. Tests were performed in cantilever rotating beam loading (R = –1) in the air at room temperature. The fatigue strength was measured at a fixed number of cycles for 107 cycles.

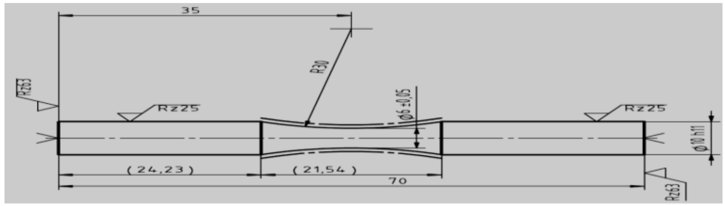

Figure 1. Rotating beam fatigue sample dimensions.

3 Results and Discussion

A. Microstructure examination

Figure2 a and b shows the microstructure of Al6061 before (as received condition was Al6061 T6) and after temper heat treatment T4 at magnifications 500X in mechanical working, long transverse and short transverse directions. The microstructure consists of α Aluminum and Mg2Si precipitates. The average particle size of Mg2Si precipitates and its area fraction were determined using ImageJ program having the values of 13.34 ±1.52μm and 1.80% for as received condition, where the particle size was 8.59±1.06μm and the area fraction was 0.63% for after T4 condition. The change in both size and distribution of Mg2Si precipitates controls the mechanical properties of each condition. [19] This can explain the difference in mechanical properties between T4 and T6 temper conditions, where T6 condition has higher precipitates equivalent diameter and volume fraction than T4 condition, which results in higher yield strength and ultimate tensile strength. However, on the other side negatively affects both toughness and resistance to fatigue.

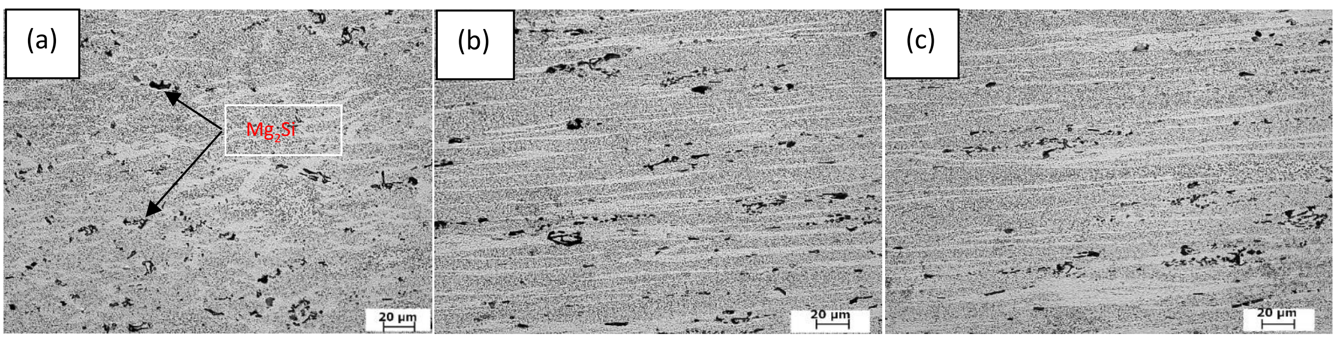

Figure 2a. (a) Microstructure in mechanical working direction, (b) Microstructure in the long transverse direction and (c) microstructure in the short transverse direction for as received condition at magnification 500X.

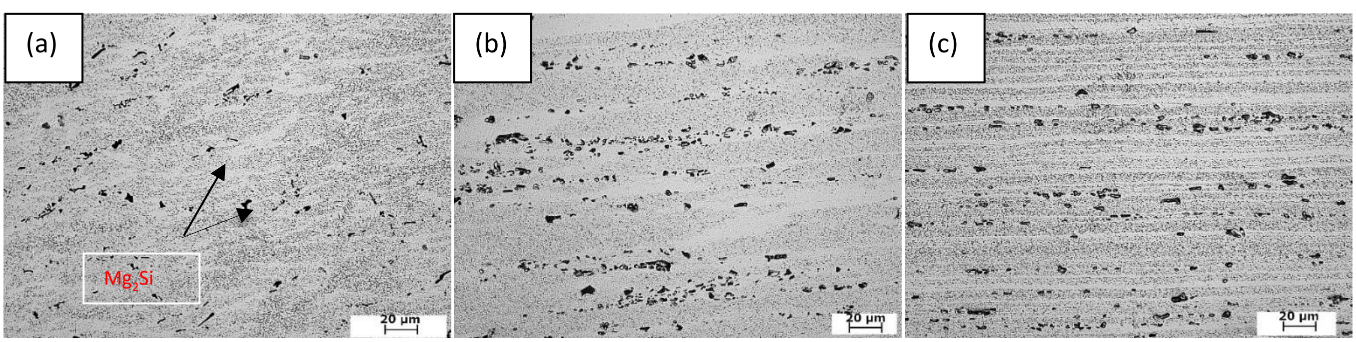

Figure 2b. (a) Microstructure in mechanical working direction, (b) Microstructure in the transverse direction and (c) microstructure in the short transverse direction after T4 condition at magnification 500X.

B. Tensile test and macrohardness

Table 2 shows the difference between tensile strength and macrohardness values for both as received and after T4 conditions. Because of the precipitates size, both tensile strength and hardness are affected by precipitates size, volume fraction, and distribution. As the increase in those parameters leads to an increase in the ratio of yield strength to ultimate tensile strength accompanied by an increase in the material bulk hardness.

Sample	As received	After Temper T4
σ_{yield} (MPa)	334	173
σ_{UTS} (MPa)	359	300
Elongation %	13.55	25.3
Reduction in area%	36	34.66
Elastic modulus(GPa)	77.79	79.67
Hardness(HV5)	103	75.7

Table 2. Tensile strength and hardness for as received and after T4 Al6061.

C. Electropolishing

Figure 3 indicates the S-N fatigue curve for the electropolished samples. This condition was set to be a reference condition in optimization the effect of both shot peening and roller burnishing effect on fatigue strength of Al6061 T4.

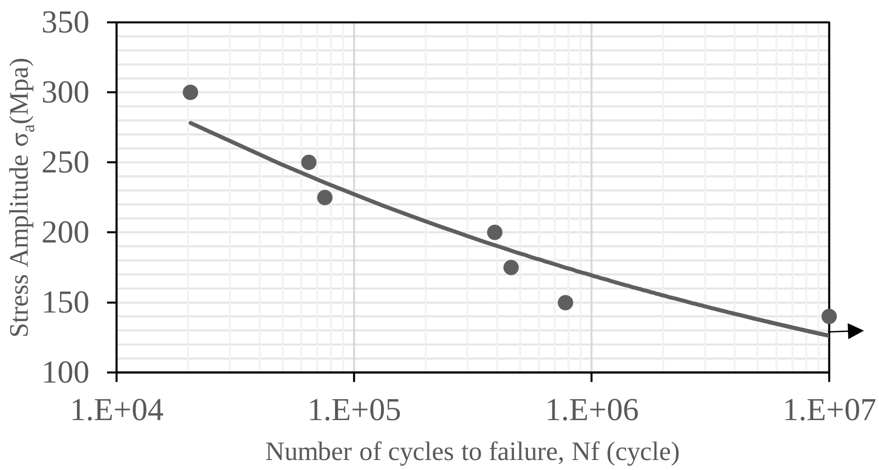

Figure 3. S-N fatigue curve for electropolished condition.

D. Shot peening and roller burnishing optimization

Figure 4 indicates the number of cycles to failure against different Almen intensities and at constant stress amplitude of 225MPa. For Roller burnishing condition, figure 5 shows the number of cycles to failure at different burnishing pressures and constant stress amplitude of 250MPa.

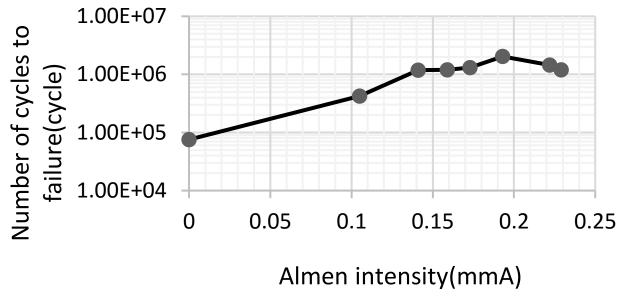

Figure 4. Fatigue life of shot peened condition at different Almen intensities and constant fatigue strength 225MPa.

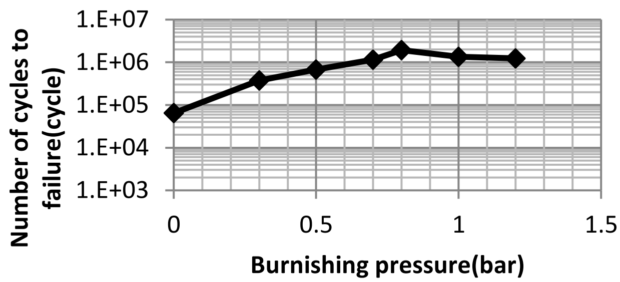

Figure 5. Fatigue life of roller burnished samples at different burnishing pressure and constant fatigue strength 250MPa.

The greatest fatigue limit was achieved at 0.193mmA Almen intensity for when of shot peening and at burnishing pressure of 0.8 bar for the roller burnishing condition. The mechanism of mechanical surface treatment based on generating plastic deformation of the layer next to such treatments. This layer is characterized by high dislocation density in a layer of thickness about 0.2mm in shot peened condition, and it can be extended to 0.50mm in roller burnished condition. In this region, the increase in either shot peening Almen intensity or in burnishing pressure leads to an increase in the hardness and the amount of residual stresses stored in this region. At a certain Almen intensity or burnishing pressure, further increase in one of those factors causes a saturation of the dislocation density and the hardness stops to have about a constant value causing 'overpeening' or 'overburnishing'. It could be also explained by the state of the material under heavy plastic deformation and thermodynamic instability, which may cause internal stress relief and decrease the amount of residual stresses. At the saturation point, localized high-stress concentrations or fatigue initiation sites can be formed and resulting in a reduction in the fatigue life. It was observed, that the surface roughness was having a noteworthy role in improving the fatigue life, due to retardation of crack initiation mechanism. [17, 18] Microhardness and surface roughness are functions in the amount of plastic deformation caused by either shot peening Almen intensity or burnishing pressure. Increasing both Almen intensity and burnishing pressure lead to an increase in the surface roughness and the microhardness.

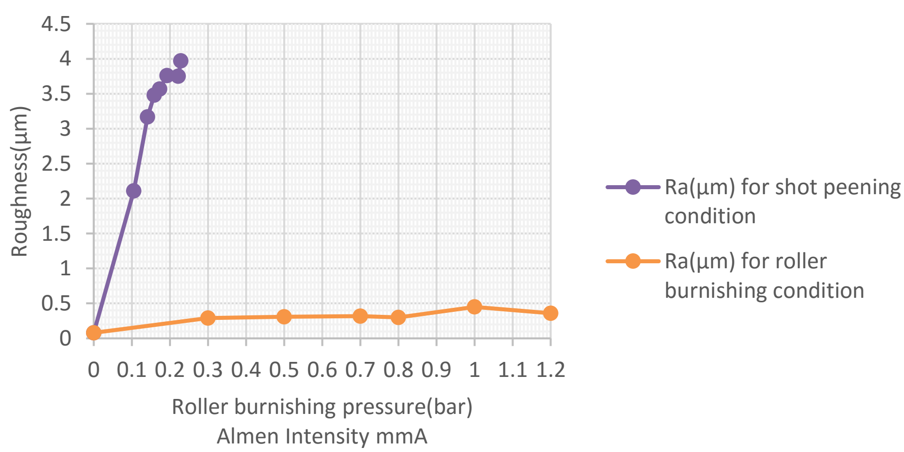

Figure 6. Surface roughness of shot peened and roller burnished samples (reference Electropolished)

The influence of Almen intensity and burnishing pressure on the surface roughness Ra is indicated by figure 6. From figure 7, 8 and 9, it can be observed that the microhardness depth profile is affected by the Almen intensity and burnishing pressure increase, due to the induced plastic deformation the microhardness depth varied from 0.2mm for shot peened sample to 0.50mm for roller burnished samples. The undesirable increase in surface roughness as a result of increasing Almen intensity or burnishing pressure leads to increase the crack initiation sites and reduce the fatigue life of the material dramatically. [8]

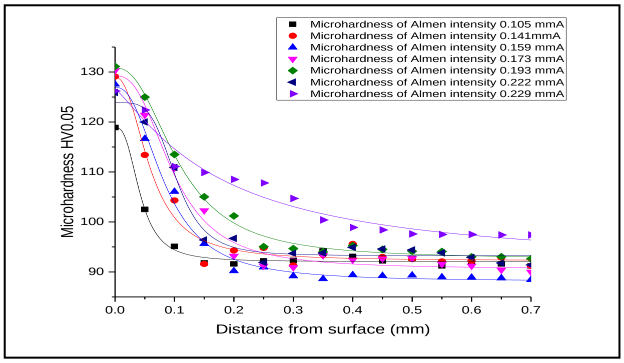

Figure 7. Microhardness measurements for shot peened samples.

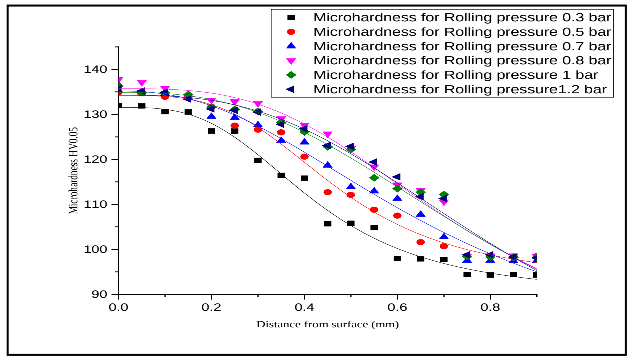

Figure 8. Microhardness measurements of roller burnished samples.

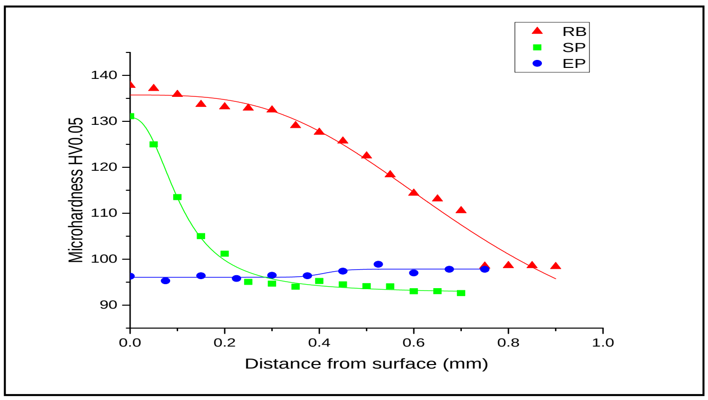

Figure 9. Microhardness comparison between roller burnishing, shot peening and electropolishing conditions.

For Almen intensity 0.193mmA, rotating beam fatigue test was carried out, and an S-N curve is shown in figure 10. The fatigue limit was estimated to be 190MPa with an increase about 36 % than the fatigue strength of the electropolished condition (EP). For Roller burnishing condition, an S-N curve was conducted at the optimum characteristic of 0.8 bar burnishing pressure and indicated by figure 11, which show an increase in the fatigue limit of 61% compared to the reference condition (EP).

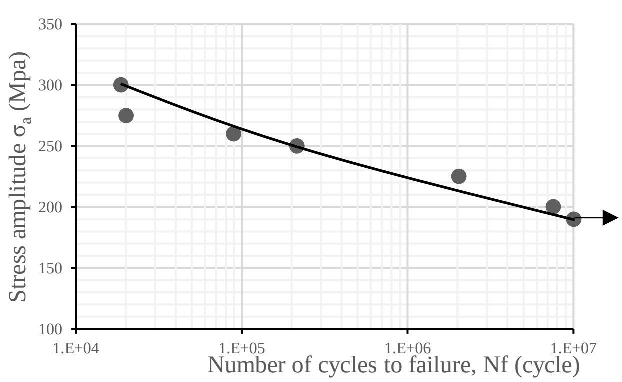

Figure 10. S-N fatigue curve for shot peened Al6061 T4 at Almen intensity 0.193mmA.

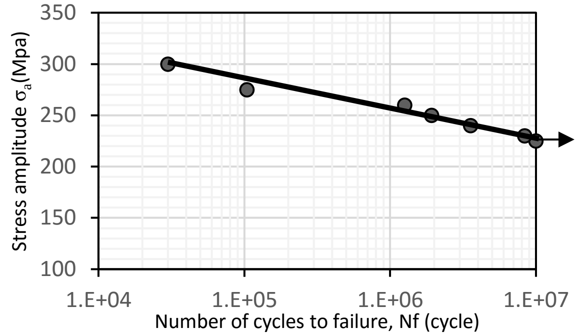

Figure 11. S-N fatigue curve for roller burnished Al6061 T4 at burnishing pressure 0.8 bar.

Figure 12 shows the S-N curve for electropolished, shot peened, and roller burnished samples. Obviously, the maximum improvement in the fatigue limit is counted for the Roller burnishing condition, which can be explained by the increase in the amount of compressive residual stresses induced by the plastic deformation and accompanied with relatively low surface roughness compared to this obtained by shot peening shown by figure 13.

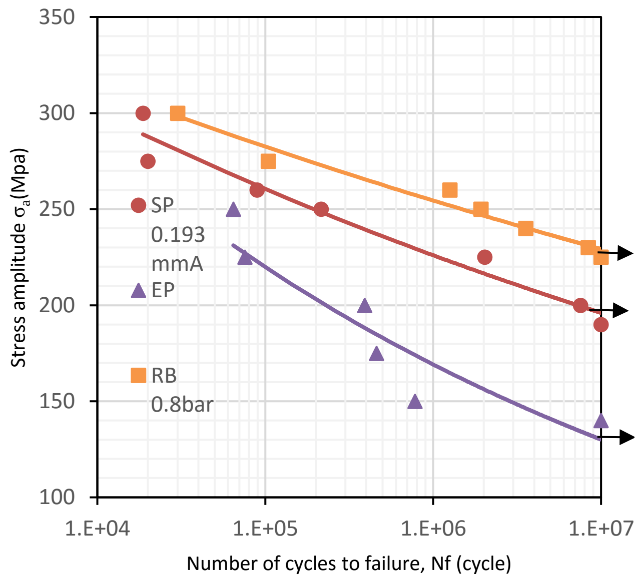

Figure 12. S-N fatigue curve for electropolished, shot peened and roller burnished conditions.

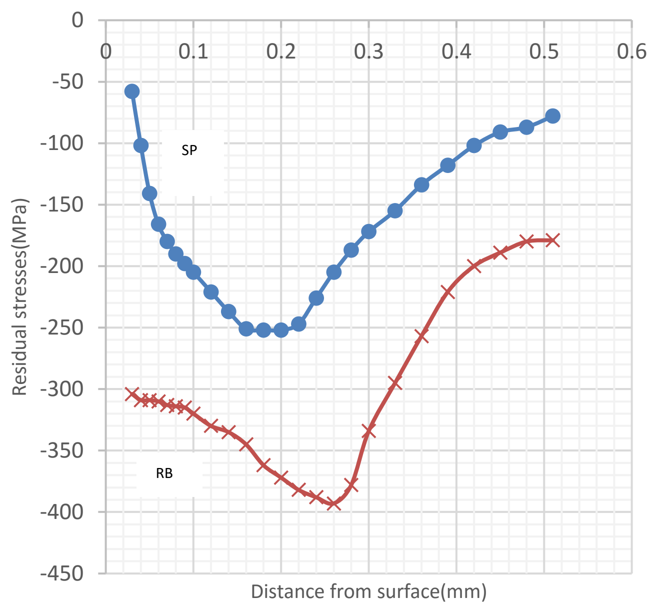

Figure 13. Residual stresses depth profile after shot peening and roller burnishing.

4 Conclusions

2. Mechanical surface treatments such as shot peening and roller burnishing increase the fatigue strength of Al6061 T4, until a certain value, at which overpeening or overburnishing occur.

2. The greatest fatigue limit for Al6061 T4 was achieved at Almen intensity 0.193mmA for shot peened samples resulting in an increase in the fatigue limit from 140MPa to 190MPa compared to Electropolished samples and at burnishing pressure 0.8 bar, feeding rate 0.122 mm/rev and rotating speed 150 rpm for roller-burnished samples with fatigue limit of 225MPa.

3. Roller burnishing with 0.8 bar gives the largest fatigue strength with an increase 61% than electropolishing and 18% than shot peening with 0.193 mmA Almen intensity due to the higher compressive stresses accompanied with lower surface roughness compared to the shot peened samples.

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