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Influence of low plasticity burnishing process (LPB) on the surface characteristics of mild steel alloys

تأثير عملية الصقل منخفض اللدونة على خصائص السطح لسبائك الصلب الطرى

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الملخص

عملية الصقل منخفض اللدونة تعتبر احدى طرق تشطيب الاسطح والتى لا ينتج عنها رايش حيث يمكن الحصول منها على اسطح ملساء وصلبة باستخدام التشكيل الدائم للنتوءات على سطح العينة وهذه الدراسة تسلط الضوء على خشونة وصلادة السطح لعينة من الصلب الطرى وتأثير عوامل الصقل(تغذية الصقل، عمق الصقل، سرعة الصقل) على خشونة السطح وصلادته وقد وجد بالتجارب المعملية ان صلادة السطح وخشونته قد تحسنت بنسبة ٧٨,٥%، ٦٥% بالترتيب وقد وجد ايضا ان قوة الصقل والخشونة الابتدائية للعينة من اكثر العوامل اهمية حيث لها تأثير كبير على سطح الشغلةاثناء عملية الصقل منخفض اللدونة .

Abstract

Low plasticity burnishing (LPB) process is chipless finishing methods which easily produce a smooth and hardened surface by plastic deformation of surface irregularities. The present study focuses on the surface roughness and surface hardness aspects of mild steel work piece and the effect of burnishing parameters (burnishing feed, burnishing depth and burnishing speed) upon surface roughness and surface hardness. It was found that by using LPB process surface hardness, surface roughness has been improved by 78.5%, 65% respectively. It was also found that the burnishing force and work piece initial roughness are the most influencing parameters which have a significant effect on the work piece's surface during low plasticity burnishing process.

Keywords: Low plasticity burnishing (LPB), Ball burnishing, Surface roughness, Surface hardness.

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1. Introduction

The quality of a machined surface is becoming more and more important in satisfying the increasing demands of performance and reliability. In the quality assurance of machine industrial product the so called "final finishing processes" have important role. During the last decades greater and greater the significance of the different cold-plastic forming methods. Such kind of effective and applied plastic forming method is the sliding burnishing using type of turning tools with super hard inserts. This method can be used in piece production and in serial production using NC, CNC lathes or manufacturing centers [1]. The burnishing of metals is a cold-working process that leads to an accurate change on the surface profile of the work piece by a minor amount of plastic deformation. In burnishing process, surface irregularities are redistributed without material loss [2, 3]. The burnishing process gives many advantages in comparison with chip-removal processes. Burnishing increases the surface hardness of the work piece, which in turn improves wear resistance, increases corrosion resistance, improves tensile strength, maintains dimensional stability and improves the fatigue strength by inducing residual compressive stresses in the surface of the work piece [4–7]. The surface of the material is compressed by the application of a hard and highly polished tool (ball). The process of burnishing can be applied to soft and ductile as well as very hard metals. Compressive action by the burnishing tool causes a slight plastic flow of the surface metal to a depth of a few micrometers. Due to the localized cold plastic deformation of burnishing a residual compressive stress will be left at the surface of the metallic component. This process improves surface finish, fatigue resistance, wear and corrosion resistance of surfaces[8].The principle of the burnishing process, shown in Fig.1[9], is based on the rolling movement of a tool (a ball or a roller) against the work piece's surface, a normal force being applied at the tool. As soon as the yield point of the work piece's material is exceeded, plastic flow of the original asperities takes place [10]. This paper presents an experimental based ball-burnishing process undertaken in order to study and determine the optimum values of a range of burnishing parameters for work piece material, namely mild steel. The burnishing parameters considered are the number of tool passes, burnishing feed, burnishing depth, and burnishing speed. These are regarded as the main influential parameters of surface finish and hardness.

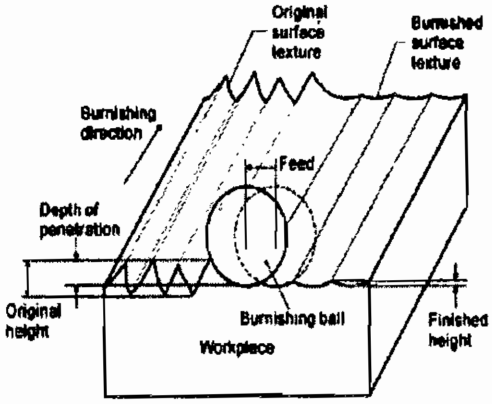


Fig.1. Principle of burnishing [9].

2. Experimental Details

The work piece material used in this study is mild steel. The chemical composition of which is presented in Table 1. The work pieces are received as cylindrical bright bars of 39 mm diameter. Then the experimental specimens are prepared as shown in Figure 2 using the regular conditions for turning, moderate surface roughness is achieved, similar to that obtained in common manufacturing practices.

Table 1: Chemical composition of commercial mild steel (wt. %).

C	Si	Mn	Cu	Nb	Fe
0.118	0.113	0.394	0.185	0.259	98.72

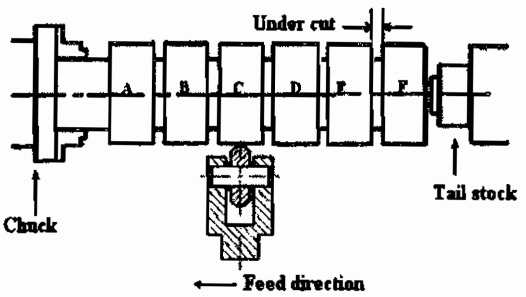


Fig. 2. Work piece geometry.

A modificated ball-burnishing tool was designed, fabricated and used for the work. The tool is made of steel 60 as shown in Fig.3. The chemical composition of steel 60 is presented in Table 2, the tensile strength and yield stress measured of 510 N/mm^2 and 265 N/mm^2 respectively .The tool was hardened by a heat treatment process according to steel heat treatment standard.

Table 2: Chemical composition of steel 60 (wt. %).

C	Si	Mn	Cu	Nb	Ni	Cr
0.2	0.4	0.784	0.3	0.01	0.3	0.3

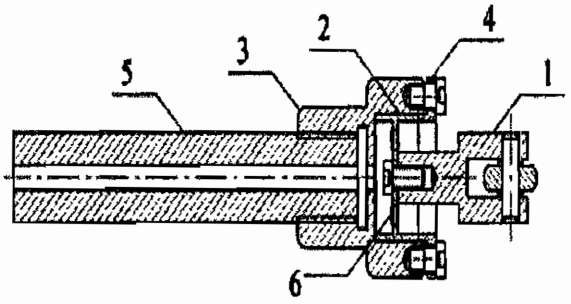


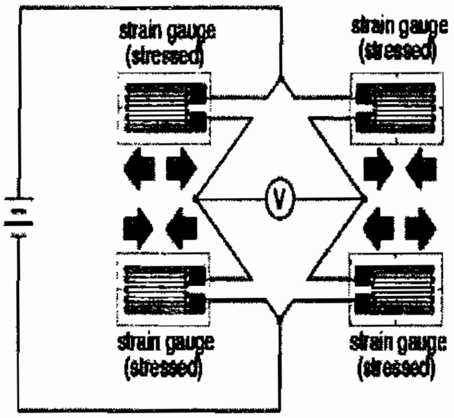
Fig.3. Ball-burnishing tool set up.
(1. Tool head. 2. Diaghram. 3. Cup. 4. Cup cover. 5. Shank. 6. Strain gauge.)

3. Experimental Procedure

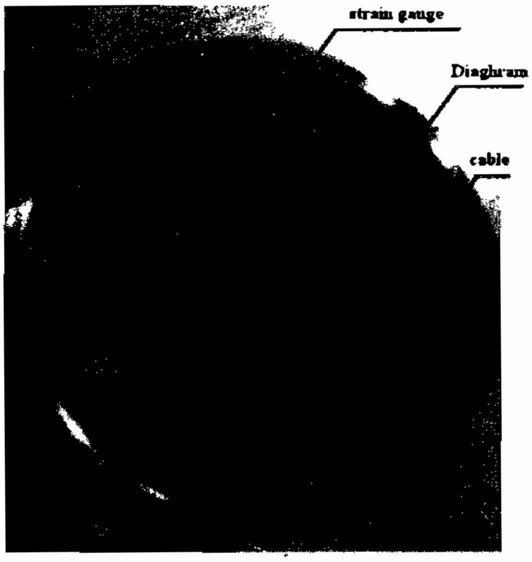
After the burnishing process, SRT-6200/6210 measuring equipment was used to measure surface roughness of the test specimen. All of the tests achieved were repeated three times in order to guarantee its precision. The surface hardness values of the specimens were measured using XHB-3000 digital Brinell hardness tester. The work piece to be burnished is clamped by the three-jaw chuck of the lathe and guided from other side by the lathe tailstock. The burnishing process was applied after turning without release the work piece from the lathe chuck to keep the same turning alignment [11].

Initial dry turning conditions were unified for all work pieces as follows:
Cutting speed= 122.5 m/min., depth of cut =0.25 mm, feed rate= 0.028 mm/rev.
The surface hardness of those specimens found to be 86.72 MPa under Brinell hardness tester using force = 187.5 N and the diameter of ball =2.5 mm.
The surface roughness of machined specimens was measured and averaged to yield of 3.276μm

In the present study, a new type of dynamometer is fabricated with bounded electrical strain gauge (120 ohms resistance and 2.11 gauge factor of 3x7 mm size).the strain gauge are bounded on the strain ring (Diaghram) and connected in the form of Wheatstone bridge. The strain ring and the bridge circuit diagram for measuring the redial component of burnishing force are shown in Fig.4(a-b).



(a) Four arm bridge circuit.



(b) Strain ring with strain gauge.

Fig.4. bridge circuit set up.

Figure 5. shows the testing of single compound lathe tool dynamometer and calibration by a vertical load in steps of 9, 16, 20, 23 Kg_f is loaded and the corresponding output voltage (mV)from the bridge is measured by means of P3 strain indicator and recorder , which gave 9, 16, 20, 23mV.

Fig.5. calibration set up of dynamometer.

A calibration chart for radial component of the load force is drawn as shown in Fig.6, in actual experiments conducted with burnishing tools in action with the work pieces, the output voltage (mV) gives measurement of the burnishing force from the calibration chart [12].

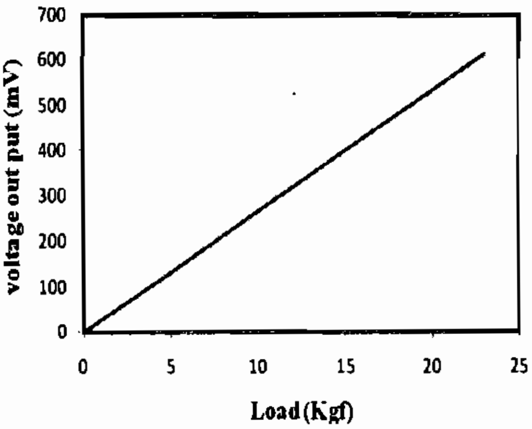


Fig.6. Calibration curve of dynamometer.

After machining operation, test specimen is prepared for burnishing process by rigidly fixing on the lathe. Then burnishing experiments were carried out for different burnishing parameters such as feed rate, compression force, revolution, and burnishing depth. The effects of burnishing process of surface roughness and surface hardness of test specimen have been investigated. Burnishing tests were carried out according to working conditions given in Table 3

Table 3: Burnishing parameters for the test.

Depth of Burnishing (h) mm	0.05 ;0.1 ,0.15 ,0.2 ,0.25
Number of passes	1
Feed (f) mm/rev	0.032 ,0.036 ,0.039 ,0.043 ,0.05
Spindle speed (N) rev/min	500 ,630 ,800 ,1000 ,1250
Burnishing condition	Dry

The ball-burnishing process is a local plastic deformation process acting on the work piece surface; the minimal needed burnishing force should be estimated, to perform the ball-burnishing work. To obtain the needed burnishing force [9], some assumptions were made to simplify the mathematical model Fig. 7, as follows:

(a) The ball will not deform during the burnishing process.

(b) The friction between the ball and the test specimen is ignored.

(c) The derived burnishing force is derived for the first burnishing path.

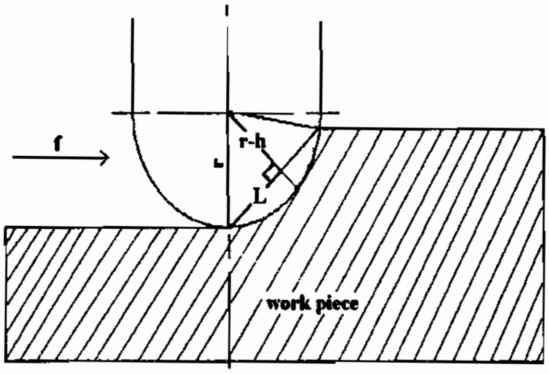


Fig.7. Force acting on the ball-burnishing tool

The required burnishing force can be estimated from Eq. (1).

$$F = \sigma A \qquad (1)$$

Where, σ is the yield stress of the material used (σ=225Mpa), A is the contact area during the burnishing process. The contact area A can be calculated through the surface integral.

$$A = L * W \qquad (2)$$

$$L = (r^2 - (r-h)^2)^{0.5} \qquad (3)$$

Where r is the ball radius (r=5mm) and h is the depth of Burnishing, L is the contact length between the ball burnishing and the burnished surface and W is the width of ball (W=5mm).

The burnishing force is calculated using mat lab program at different burnishing depth as shown in Table 4.

Table 4. Calculated burnishing force.

h (mm)	0.05	0.10	0.15	0.20	0.25
A (mm^2)	3.5267	4.9749	6.0776	7	7.8062
F (N)	793.5	1119.4	1367.5	1575	1756.4

By comparing these results with the measurement burnishing force and calculating the error % as given in Table 5 using the equation:

$$\text{Error \%} = \frac{\text{Calculated force} - \text{Measurement force}}{\text{Calculated force}} * 100\%$$

Table 5. Error % of burnishing force

h(mm)	measurement force(N)	Calculated force(N)	Error %
0.05	293.7	793.5	62.98
0.1	453.9	1119.4	59.5
0.15	614.1	1367.5	55.1
0.2	827.7	1575	47.4
0.25	1068	1756.4	39.2

4. Results and Discussions

4.1 Effect of burnishing speed on surface roughness and surface hardness

The effects of burnishing parameters applied to the test specimen on surface roughness and surface hardness have been evaluated. The variations in roughness and hardness values of the burnished surface depending on burnishing parameters such as revolution, feed and burnishing depth, are experimentally found. The effects of burnishing revolutions on surface roughness and surface hardness are shown in Fig.8 and 9 respectively. From these figures it can be observed that increasing the burnishing revolutions decreases the surface roughness and improves the surface hardness of the specimen. First the surface roughness decreased as the number of revolution is increased until 1000 RPM. When number of revolution increased above 1000 rpm the surface roughness was slightly increased as shown in Fig.8 .the improvement of surface hardness when increasing the number of revolution is expected as the increase of the force increase the depth of penetration resulting in compressing more asperities. Furthermore, increasing the number of revolution increases the metal flow in filling of more valleys of the subsurface which were generated by the previous turning process [2].

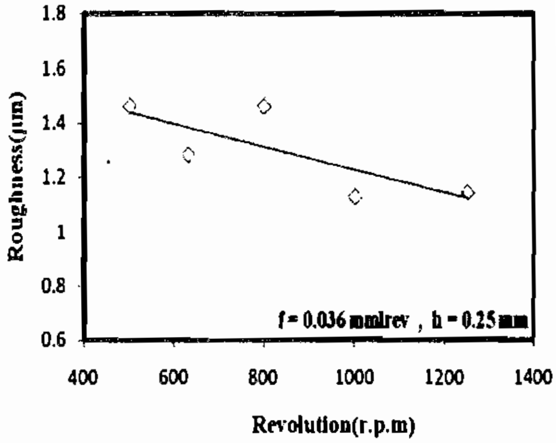


Fig.8. Effect of revolution on the surface roughness.

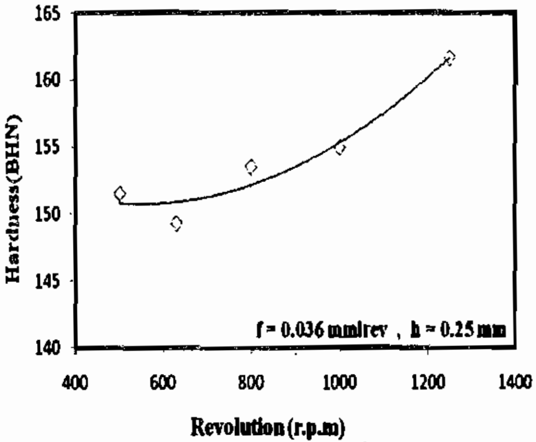


Fig.9. Effect of revolution on the surface hardness.

4.2 Effect of burnishing feed on surface roughness and surface hardness

The effects of burnishing feed on the surface roughness and surface hardness for work piece material are shown in Fig .10 and 11 respectively. Figure 8 shows that the surface roughness increases with the increase of the burnishing feed and the surface hardness decreases with the increase of feed up to 0.039mm/rev. When feed rate increased above o.039mm/rev the surface hardness increases as shown in Fig.11. Thus, to produce good surface finish and hardness via burnishing, a burnishing feed of 0.032 mm/rev is considered to be the best value for Mild Steel. At high feeds, the ball creates feed marks with a centre-line distance between two consecutive indentations widely spaced compared to the contact area between the tool and work piece. Hence less improvement in the surface is available. To prevent this, the value of feed must be less than the length of the contact area between the tool and the work piece.

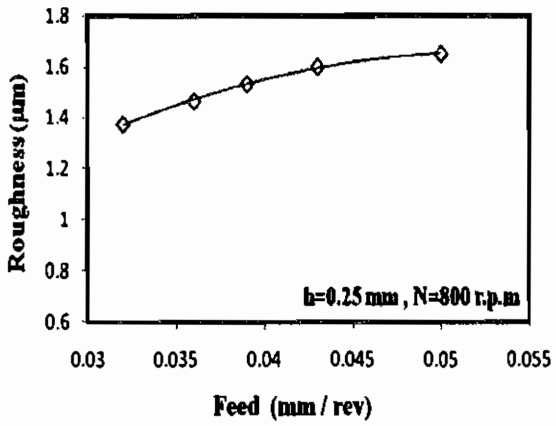


Fig.10. Effect of burnishing feed on the surface roughness.

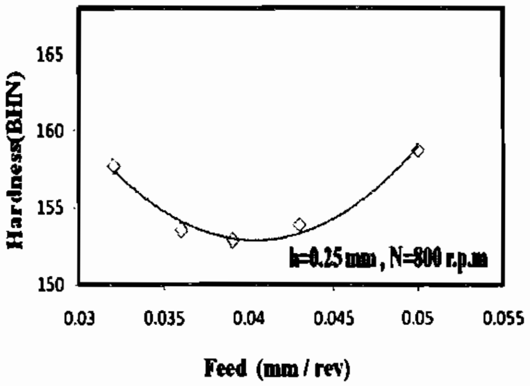


Fig.11. Effect of burnishing feed on the surface hardness.

4.3 Effect of burnishing depth on Surface roughness and surface hardness

The surface hardness is based on the initial surface hardness of the materials to be burnished [13]. The surface hardness is directly proportional to applied force; i.e an increase in force increases the surface hardness. This is due to the increase of depth of penetration, increase in metal flow that leads to an increase in the amount of deformation. At 800 spindle speed .surface hardness value 153.52 BHN and surface roughness of 1.461 µm are achieved under feed rate of 0.036mm/rev with depth of penetration of 0.25 mm .The results of Fig.12 indicate that increasing the burnishing depth decreases the surface roughness. Refer Fig.13, as the depth of penetration was increased from 0.05 to 0.25 mm, surface become more work hardened and showed higher surface hardness.

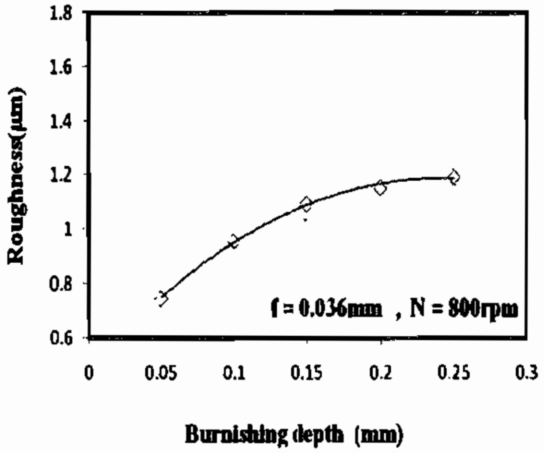


Fig.12. Effect of burnishing depth on the surface roughness.

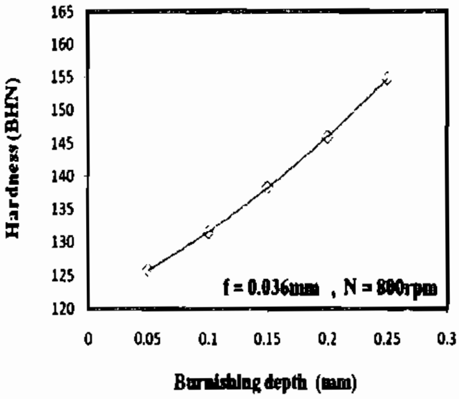
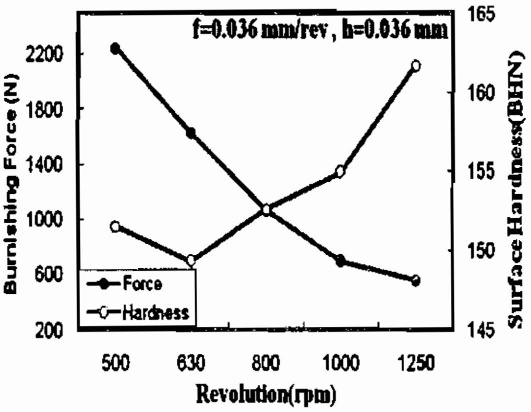


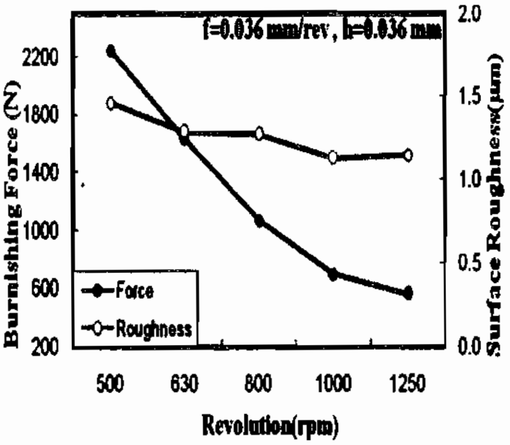
Fig.13. Effect of burnishing depth on the surface hardness.

4.4 Effect of burnishing force on Surface roughness and surface hardness

The surface hardness is based on the initial surface hardness to be burnished [13] the surface hardness is directly proportional to the applied force. The surface hardness increases with decreasing the burnishing force. Improvement in surface roughness with decrease in burnishing force was noticed as shown in Fig. 14(a-b).



(a) The effect of burnishing force on surface hardness.

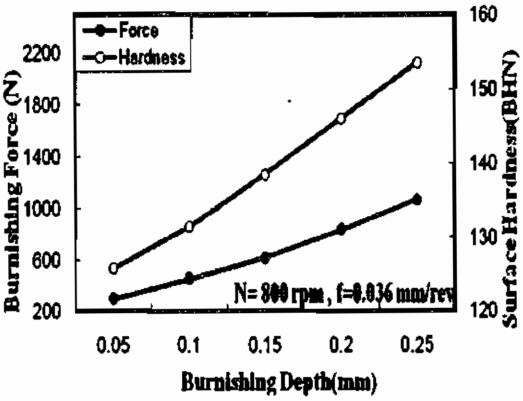


(b) The effect of burnishing force on surface roughness.

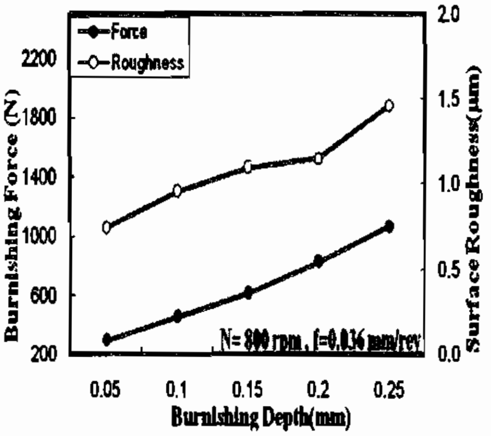
Fig.14. Effect of burnishing force on surface hardness and surface roughness.

The burnishing depth has increased the working hardening effect and hence increases surface hardness as shown in Fig.15-a.

As the burnishing depth was increased, more plastic deformation takes place, i.e. the peaks deforms and produced rough surface and higher value as shown in Fig. 15-b.



(a) The effect of burnishing force on surface hardness.

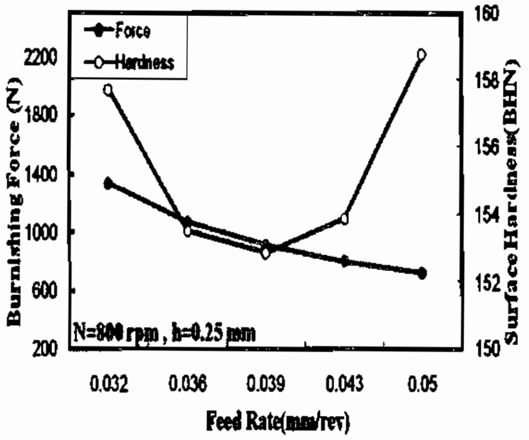


(b) The effect of burnishing force on surface roughness.

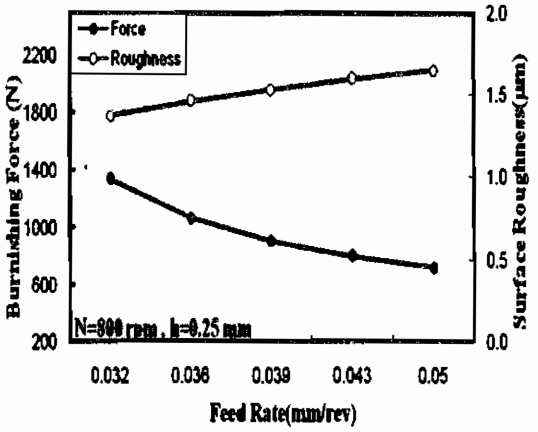
Fig.15. Effect of burnishing force on surface hardness and surface roughness.

It can be seen from Fig.16-a that the surface hardness was decreased with increasing the burnishing feed rate up to specific point then it starts to increase . The best results were obtained at 0.05 mm/rev burnishing feed rate.

It can be seen from Fig.16-b that the surface roughness increases with increasing the feed rate.



(a) The effect of burnishing force on surface hardness.



(b) The effect of burnishing force on surface roughness.

Fig.16. Effect of burnishing force on surface hardness and surface roughness.

5. Conclusion

The following conclusions are drawn based on the results of burnishing experiments on mild steel alloy

1. The test results produced significant improvement on surface roughness and surface hardness.
2. A lower surface roughness value obtained at spindle revolution of 800r.p.m having feed of 0.036 mm/rev.
3. The surface hardness also increased as the revolution, feed, and depth of penetrations was increased.
4. The surface hardness increases with decrease in burnishing force while surface roughness was decreased.

5. Surface hardness decreased with increasing the burnishing feed rate up to specific point then it starts to increase. The best results was obtained at 0.05 mm/rev burnishing feed rate.

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