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DESIGN A BALL BURNISHING ROLLING TOOL AND INVESIGATING ITS EFFECT ON SURFACE QUALITY

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Abstract:
Improvements of reliability and longevity of machine parts is one of the most important problems in machine building industries. Among the progressive technological processes directed to this purpose, surface hardening by plastic deformation (SPD) is the most widely used process. SPD forms optimal geometry of the surface roughness, improves the mechanical properties of the layer, and develops a negative compressive residual stress in the surface layer. Character of the improvement depends upon the burnishing tools used for SPD. In this work a new ball-burnishing tool is designed reducing the friction of the tool in the axial direction. The rolling ball of the tool can easily be changed giving the opportunity to vary the profile radius of the tool. Different specimens were burnished by varying technological parameters such as force, feed, initial surface roughness, speed, and ball diameter. Quality of the surface layer such as surface roughness, hardness and intensity of plastic deformation are measured. Analysis shows that uses of rotating ball in the tool reduced the height of the leading materials wave and thus improves the working condition of the tool. This gives the opportunity to use burnishing condition allowing increased productivity and surface quality.
Keywords: Surface hardening by plastic deformation (SPD), surface layer, heart of deformation (HOD), surface rolling, residual stresses and ball diameters.

1. INTRODUCTION

For characterisation of the quality of the surface layer now a days following criterion are used: Structural change in the surface layer, geometrical characteristics of the finished surface layer such as surface roughness, surface work hardening, depth of plastic deformation, residual stresses, and intensity of shear strain and percentage of mobilisation of plastic resources of the materials.

During the surface rolling process (Figure 1-1) the surface layer of a plastic materials undergo heavy deformation in the surface layer. As a result uniform structure of the surface layer generally changed to texture, anizotropical deformation to expand the grain in axial direction and shortened it in the radial and circular direction. Sometimes the deformation produces carbides, quantity of which increases the rate of deformation hardening. Thus during the surface hardening process by plastic deformation the layer undergo remarkable changes of physical properties which affects the criterion of mechanical conditions such as surface hardness, residual stresses and other mechanical properties.

During the SPD of machine parts new surface formed with roughness depending upon the principle parameters of the process. In the works [1-5] shows that micro profile after the SPD characterized by increased ratio between the width and height of micro roughness, decreased slope of the hills, increased ratio between rounding radius of the vertex and the height and increased base length.

Chepa P.A [6] concluded that during burnishing operation micro roughness of the surface is totally compressed in the contact zone but when the surface comes out of the contact area new micro roughness is formed. It is due to non-equal hardening in the zone of its hills and valleys. Now a day the degree of deformation of the surface is measured by the degree of work hardening indicated by the change of macro hardness of the metal. For this the following formula is generally used:

$$\partial = \frac{H_f - H_0}{H_0} * 100\%$$

Where, H_0 and H_f is the hardiness of the materials before and after burnishing. ∂ is the degree of deformation of the surface

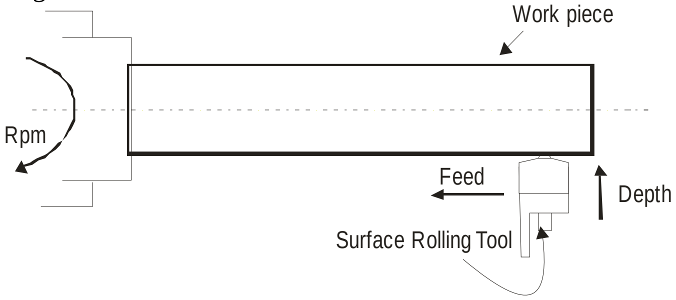


Figure 1-1 Surface Rolling

Due to simplicity of the formula it is widely used. But for the materials where hardness is not changed with the deformation this formula is not valid. Due to non-uniform structure some materials after deformation measurement of hardness gives a scattered results. Besides these different materials have different tendency in increasing the hardness for the same operation conditions. Many resercahers [7-10] were trying to find out the experimental process parameters effect on surface integrity. The present work is an attempt to study the effects of ball burnishing process parameters on the surface roughness, hardness etc. of steel.

2. MECHANISMS OF FORMATION OF SURFACE DURING BURNISHING OPERATION

Surface finishing could be achieved in different ways, such as turning, milling, grinding, surface rolling and etc. The different methods employed in developing the surface have their own advantages and disadvantages with respect to the quality of the surface finish obtained. Surface rolling could be regarded as one of the simple ways by which a smooth and hard surface can be achieved.

Mechanisms of formation of Surface layer during burnishing operation may be described as follows: (Figure: 1-2) the single act of deformation on a cubic element within the material occurs during rotation of the work piece, but deformation occurs only inside some angle of deformation, which depends upon the geometry of the contact, relative position of the cube (φ) in respect of the tools.

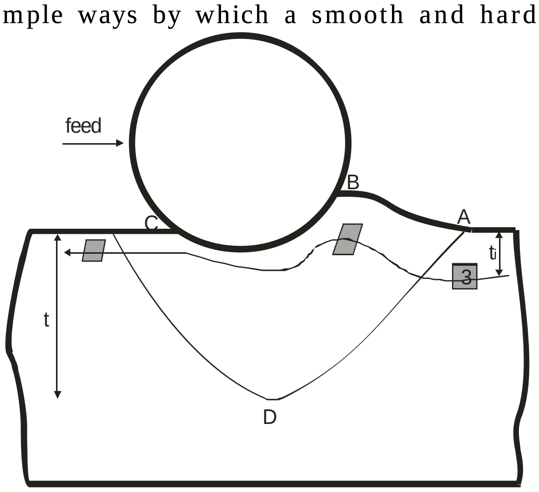


Figure 1-2 Loading and unloading of stress on an element during surface rolling

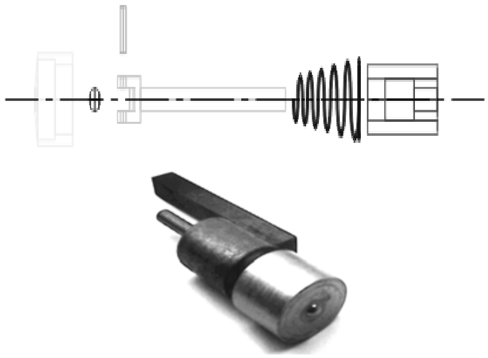
In the contact zone between the instrument and the work piece due to plastic deformation, appears a profile with complex outline. A unit cubic element (3 in the figure1-2) of surface layer taken in a depth $0<t_i<t$, moves in relations to the instrument as a result of circular movement in a speed equal to the feed (mm/rev) of the instrument. In each rotation the cubic will go one act deformation if it enters into the zone of deformation. Initially it will be deformed elastically but with the entrance in the zone of plastic deformation widely known as heart of deformation (HOD) it will change its shape.

Number of the act of deformation depends upon the dimension of the deformation zone and feed per rotation. Moving through a trajectory of relative motion the unit cubic passes through three conditions – initial, current and final. In the initial condition i.e. before entering HOD (Figure 1-2) the element has constant yield shear stress, zero accumulated strain and zero residual stress. The current condition of the material is counted after entering HOD and characterized by strain velocity tensor, stress tensor, intensity of shearing strain velocity, rate of accumulated strain and etc. The final condition of the cubic will be determined by the stress-strain condition of the rear border of the heart of deformation (HOD).

3. DESCRIPTION OF THE SURFACE BURNISHING TOOLS

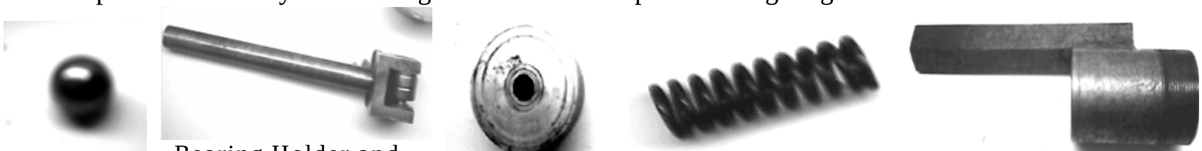
Another important factor that affects the quality of the surface layer is the construction of the rolling tool. In this work a specially designed surface rolling tool (Figure: 2) was designed and constructed. This tool is used to study the effects of different technological parameters on the characteristics of the surface layer. The tool was designed in such a way that it can be used in a centre lathe. Construction of the rolling head gives the opportunity to use balls of different sizes. During the rolling operation the ball rotates on four bearings mounted on a bearing holder having cylindrical shaft end. This type of construction allows rotating the ball with less friction from the supports of the rolling tool.

The bearing holder is mounted on two bronze bushes pressed in the main body. It may slide through these bushes. Compression spring is mounted on shaft of the holder. By compressing the spring the ball is pressed on the work piece. The minimum pressure of the rolling can be fixed by rotating a nut. Actual force may be calculated by measuring the displacement of the shaft end with the help of an indicator. For preventing the ball coming out of the tool during experiment, caps with different holes diameter are used. Each can be used for a group of ball diameter. This enables the tool to work with a wide range of ball diameters. The tool is hold by a rectangular holder construction of which is similar to a turning tool holder. Advantages of the designed tools may be characterized as follows:



Tool for surface rolling

- The tool is capable of working with different ball sizes; hence different areas of contact could be achieved in surface rolling.
- The ball rolls on bearings, which reduce the sliding friction to the minimum. As a result the tool works only on the rolling friction.
- It is possible to vary the rolling force while the process is going on.



Ball | Bearing Holder and Bearings | Cap | Spring | Main Body

Figure 2. Different components of the surface rolling Tool

4. EXPERIMENTAL STUDY

For experimental study of the effects of the technological factors on the quality of the surface layer following experimental variables are considered:

- Radial Force P (N): Radial force P = 300-1800N. Lower value was selected from the condition of formation of SPD-3 i.e. stable HOD for minimum radius of the ball. While upper limit was selected by condition of absence of visual crack in the surface layer
- Longitudinal Feed S (mm/rev): Longitudinal feed S=0.05-0.20 mm/rev. Lower limit was selected for the economical productivity. Upper limit was selected by the presence of visual waviness on the surface
- Radius of the ball R (mm): Radius of the ball R=2.5-6mm, limited by the construction of the tool.
- Initial Surface roughness Rz

Table-1

Observation	Parts Number	Roughness (Micron)	Ball dia (mm)	Feed mm/min	Rolling force (N)
1	S-001	5	4	0.1	450
2	S-002	5	4	0.1	700
3	S-003	5	4	0.1	1000
4	S-004	5	4	0.1	1200
5	S-005	5	4	0.1	1450
6	S-006	5	6	0.1	450
7	S-007	5	6	0.1	700
8	S-008	5	6	0.1	1000
9	S-009	5	6	0.1	1250
10	S-010	5	6	0.1	1450
11	S-011	5	5	0.06	600
12	S-012	5	5	0.1	600
13	S-013	5	5	0.15	600
14	S-014	5	5	0.2	600
15	S-015	5	5	0.25	600
16	S-016	5	5	0.06	1000
17	S-017	5	5	0.1	1000
18	S-018	5	5	0.15	1000
19	S-019	5	5	0.2	1200
20	S-020	5	5	0.25	1450
21	S-021	5	2.5	0.1	450
22	S-022	5	4	0.1	450
23	S-023	5	5	0.1	450
24	S-024	5	6	0.1	450
25	S-025	5	2.5	0.1	700
26	S-026	5	4	0.1	700
27	S-027	5	5	0.1	700
28	S-028	5	6	0.1	700
29	S-029	20	5	0.1	600
30	S-030	10	5	0.1	600
31	S-031	5	5	0.1	600
32	S-032	2.5	5	0.1	600
33	S-033	1.25	5	0.1	600
34	S-034	20	5	0.1	1000
35	S-035	10	5	0.1	1000
36	S-036	5	5	0.1	1000
37	S-037	2.5	5	0.1	1000
38	S-038	1.25	5	0.1	1000

org: Initial surface roughness Rz org=0.25-10 micron, lower limit was selected as the possible surface roughness after the grinding while upper limit was selected by the possible surface roughness after rough turning.

Following parameters were fixed:

- Material of the specimen: AISI 1045
- Diameter of the specimen: 50 mm
- Length of the specimen: 250mm

4.1 Experimental Plan: Experiments were done according to the following common program widely used by the different researchers (Table: 1).

5. EXPERIMENTAL RESULTS AND DISCUSSIONS

5.1 Effect of initial surface roughness on final surface roughness: Surface roughness plays important rolls in maintaining the stability and quality of the product service. Without proper surface finish many defects may cause the deterioration of the functioning of the product with time. The effect of initial surface roughness on the final surface roughness is shown in Figure 3. The effect of initial surface roughness on the final surface roughness for two different forces, 600 (N) and 1000 (N) are also compared. Parallel this effect for burnishing with fixed ball was also shown. With the decrease of initial surface roughness the final surface roughness decreases. But the rate of change of final surface roughness gradually decreases and at last it does not changes and in some cases slightly increases. With the use of rotating ball, final surface roughness decreases in the zone of higher initial surface roughness but in the zone of lower initial surface roughness it remains same. Increase of rolling forces also reduces the effect of initial surface roughness but with a good improvement in the final surface roughness.

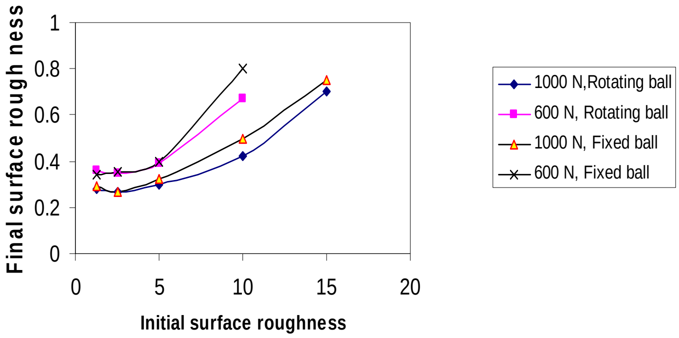


Figure 3 Effect of surface roughness on surface rolling processes

5.2 Effect of Ball diameter on the final surface roughness

The variation of surface roughness in the final product was checked experimentally along with different ball diameter of surface rolling. Figure 4 exhibits the surface roughness variation for different ball diameter.

With the increase in ball diameter surface roughness first decreases to a minimum value and after that it increases. With the increasing in rolling force the curve shifted to the increased ball diameter.

5.3 Effect of longitudinal feed on the surface roughness

To examine the effect of feed in surface roughness, a frictionless surface rolling process with rotating ball is investigated under the different histories of feed shown in Figure 5. It has been observed that for rolling force 1000N with the increase of feed in the range of 0.05 to 0.1 the surface roughness do not varies but after that it increases slowly up to 0.2 mm/min and after that it increases rapidly. If compared with the burnishing with fixed ball the curve rotates clockwise.

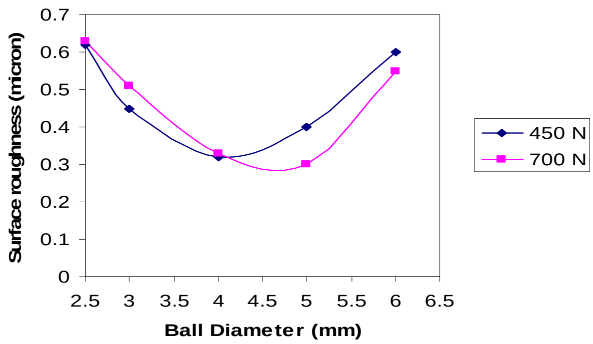


Figure 4: Surface roughness variation at various ball diameters

5.4 Effect of rolling force on the surface roughness:

The conditions of the surface roughness for different forces were investigated and the results are placed in Figure: 6. It has been observed that with the increase of rolling force the surface roughness decrease to a minimum but after that it started to increase. Increase of surface roughness may be due to secondary deformation in the trailing zone. If compared with the results of burnishing tool with fixed ball the curves are found shifted to the higher force at the same time rotated clockwise.

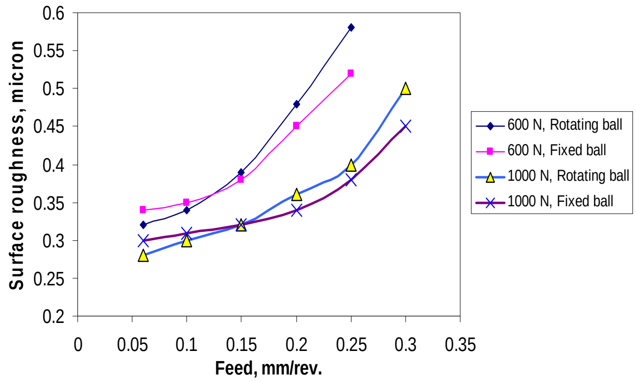


Figure 5: Effect of feed in surface roughness by surface burnishing

5.5 Effect of rolling force and ball diameter on the accumulated intensity of shearing strain and surface hardness

The effect of rolling force and ball diameter on the accumulated intensity of shearing strain and surface hardness are investigated and the results are shown in Figure: 7 and Figure: 8. The values of intensity of shearing strain are calculated from the profile dimensions using the method described in [11]. With the increase in rolling force length and depth of HOD increases. As a result intensity of shearing strain increases.

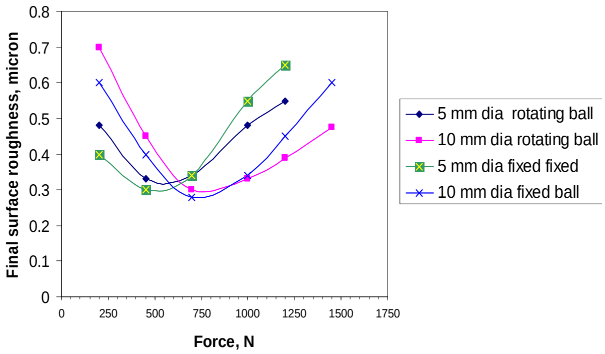


Figure 6: Effect of rolling force on Surface roughness

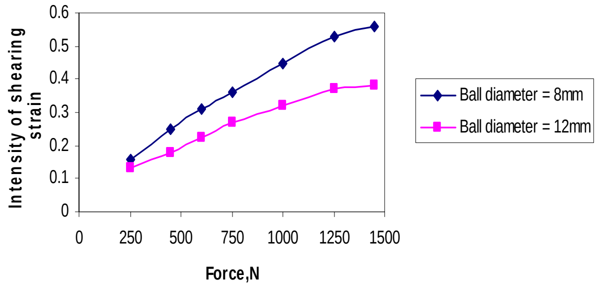


Figure 7: Effect of rolling force on Intensity of shearing strain

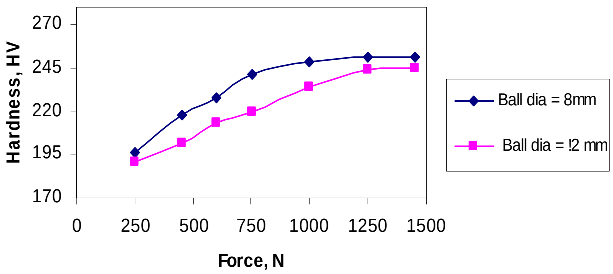


Figure 8: Effect of rolling force on hardness for different ball diameter

With the increase in ball diameter for constant force intensity of shearing strain will decrease due to decrease of penetration of the ball. For fixed ball intensity of shearing strain if all other parameters remain constant will be higher. This is due to increase in height of leading wave of the material.

5.6 Effect of feed on the accumulated intensity of shearing strain and surface hardness

The effect of feed on the accumulated intensity of shearing strain and surface hardness are shown in Figure: 9 and Figure: 10.

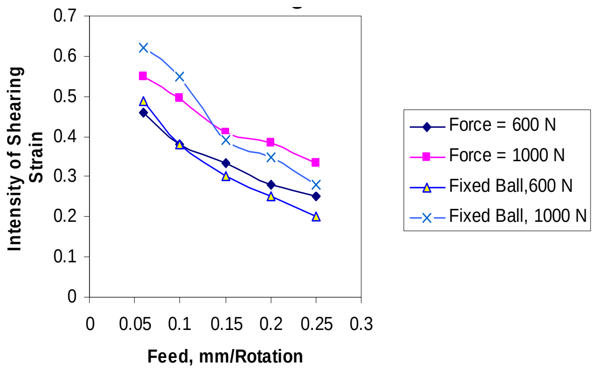


Figure 9: Effect of feed on Intensity of shearing strain

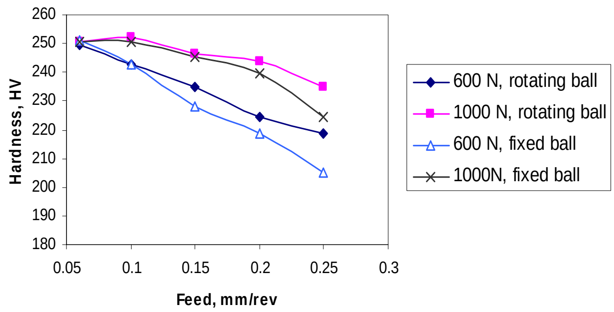


Figure 10: Effect of Feed on Hardness variation by surface rolling

Figures show that with the decrease of feed accumulated intensity of shearing strain increases. If it is compared to the rolling with the fixed ball the value of the accumulated intensity of shearing strain less in the lower feed zone while higher in the high feed zone. It has been observed that harness will decrease with the increase of feed. The predicted tendency will varied with the variation of force applied to the rolled surface. If compared with the fixed ball increase in feed will reduce the hardness faster than the sliding ball. Increase in force increase the hardness.

5.7 Effect of initial surface roughness on the hardness by surface rolling

Fig.11 exhibits the variation of initial surface roughness on the hardness of the surface. With the increase in the initial surface roughness micro hardness of the surface reduced. This may be due to incomplete deformation process on the surface.

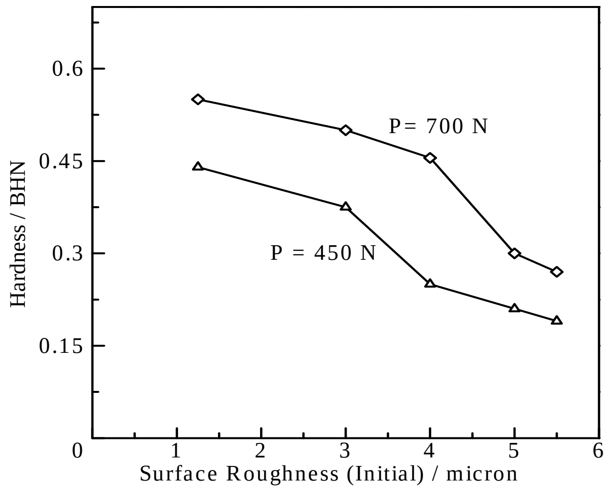


Figure 11: Hardness comparison at various surface roughnesses in surface rolling processes

6. CONCLUSION

A new surface-rolling tool was designed and manufactured to improve the overall surface improvement of product. The tool is capable of working with different ball sizes; hence different areas of contact could be achieved in surface rolling. The ball rolls on bearing which reduce the friction generated by the rolling of the ball. The tool is designed in such a way that it can easily be fixed in the machine. After analysing the results of the experiments following conclusions may be made.

1. Use of free rotating balls decreases the deformation in the cross sectional plane as a result intensity of shearing deformation decreases which effect the micro hardness and roughness of the surface.
2. Use of free rotating ball reduces the surface friction and thus enables to increase the rolling speed. So decrease productivity due to reduction of longitudinal feed for increasing the surface quality may easily be compensated by increasing the speed.
3. Use of free rotating ball decreases the height of the leading wave of materials, which allows using ball of reduced diameter for the same operating conditions and targeted surface quality. This allows using the tool for fillets with lower radius.

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