Mechanism of Ball Burnishing Process for Radius of Curvature for Elastic and Plastic Deformation between Ball and Hole

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ABSTRACT

Ball burnishing (ballizing) is a chip less process which produces a smooth surface and surface hardness. The pressure generated by the ball exceeds a plastic deformation stage and create a new surfaces. The plastic deformation created by ball burnishing is a cold flows under pressure into the valleys surface is smooth, Ballizing is a technique for sizing and finishing holes in metal components. It is a rapid and relatively low cost process. A suitably oversized precision ball is pressed through an unfinished undersized hole, A simple tooling such as a hardened ball and a push rod is required for this process. However an intensive analysis is essential for analysing the mechanics of the process. The ball burnishing is very useful process to improve upon surface roughness and can be employed. It will help to impart compressive stress and fatigue life can be improved. The Al alloy is a difficult to machine material and burnishing is difficult process for this grade material. A low surface roughness and hardness was obtained in increasing the operating parameters. It may develop flaw and micro cracks on the surface.

Key words: Ballizing, Alluminum Alloy, Alloy steel, C.L.A., Elastic Pressure, Plastic Deformation, BHN, Machining; Surface roughness; Technology devices and equipment

INTRODUCTION

Ball burnishing used the surface integrity must be maintained Plastic deformation, micro-crack, phase transformation and residual stress. It is a cold working process and involves plastic deformation under cold working conditions by pushing hard. The burnishing process help to improve surface roughness super finishing.

Mathematical models incorporating the effect of speed, hardness of work piece on the surface finish improvement are essential for a thorough investigation of this process. This will lead to discovery of important parameters on surface to engineer to achieve desired goals of centre line average values etc.

In this technique metal is not removed, as such it differs form other hole finishing processes. The burnishing action of ballizing not only refines the surface structure but also gives a layer of denser material. The surface layer is deformed very little; but and finishing of the bore depends upon the accuracy and smoothness of the ball.

The hole wall expands due to the interference between the ball and hole. The material of the ball is so selected that it is not permanently deformed. After the ball has passed through the
hole, it adopts its original diameter, whereas the hole wall springs back by the amount of elastic expansion. Some metal is also displaced by the plastic flow.

Ballizing can be carried out with or without lubrication. Generally lubricated ballizing gives better results. When ballizing is done on soft and ductile materials like Aluminum, the particles of base material get detached and remain stick to the ball. If velocity is high and interference is more, local welding is caused due to heating. With lubrication, ballizing can be carried out without any scoring of the particles from base metal.

**Favorable Conditions for ballizing**

**Mechanics of Ballizing**

The ballizing process can be explained with the help of two distinct models. The first one comprises of conditions of elastic contact between the ball and the hole. Over a width 2b. The Hertzian equations of contact between two elastic bodies can be applied to estimate the normal pressure between the ball and the bush material.

The material of the bush ahead and underneath the ball is also subjected to plastic flow. The interference between the ball and the hole is substantial say 90 microns and 180 microns for a hole diameter of 18mm and a coronet or builtup edge of the plastically deformed material is developed ahead of the ball as shown in fig. Slip line field technique can be applied to estimate the pressure between the ball and the hole due to plastic deformation. The force required for Ballizing is the sum of elastic and plastic contact.

**Research technique and methodology used**

*Mathematical Model with Hertzian Equation to Ballizing:* In Ballizing and elastic ball diameter $D_b$ is passed through a cylindrical bush of inside diameter $D_h$. Where $D_b$ is only a few microns greater $D_h$. To determine the width of contact the general case of Hertzian equations can be applied.

\[
a = m 3 \sqrt{\frac{3\pi}{4}} \frac{P (K_1 + K_2)}{(A + B)}
\]

Where

- $a$ = Semi axes of ellipse of contact
- $b$ = Semi axes of ellipse of contact
- $P$ = Load (radial)
A and B are constants depending on the magnitude of principal curvatures of the surfaces in contact.

\[ k_1 = \frac{1 - \nu^2}{\pi E}, \quad k_2 = \frac{1 - \nu^2}{\pi E} \]

and on the angle $\psi$ between the principal planes of curvatures.

$m$ and $n$ are constants whose value depends upon the value of $A$ and $B$.

\[ A + B = \frac{1}{2} \left( \frac{1}{k_1} + \frac{1}{k_2} \right) \]

If $2\psi = 180^\circ$

Radius of curvatures of contacting bodies in two mutually perpendicular planes in ballizing. In the ballizing problem

<table>
<thead>
<tr>
<th>$q$</th>
<th>30°</th>
<th>35°</th>
<th>40°</th>
<th>45°</th>
<th>50°</th>
<th>55°</th>
<th>60°</th>
<th>65°</th>
<th>70°</th>
<th>75°</th>
<th>80°</th>
<th>85°</th>
<th>90°</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m$</td>
<td>2.731</td>
<td>2.397</td>
<td>2.136</td>
<td>1.926</td>
<td>1.754</td>
<td>1.611</td>
<td>1.486</td>
<td>1.378</td>
<td>1.284</td>
<td>1.202</td>
<td>1.128</td>
<td>1.061</td>
<td>1.000</td>
</tr>
<tr>
<td>$n$</td>
<td>0.493</td>
<td>0.530</td>
<td>0.567</td>
<td>0.604</td>
<td>0.641</td>
<td>0.678</td>
<td>0.717</td>
<td>0.759</td>
<td>0.802</td>
<td>0.846</td>
<td>0.893</td>
<td>0.944</td>
<td>1.000</td>
</tr>
</tbody>
</table>

This proves that the contact between the ball and hole is circular with

\[ a = b = \sqrt{\frac{E}{4} \left( k_1 + k_2 \right)} \] ...(1)

The value of $b$ calculated from the circular contact can be applied for load calculation due to elastic mode in ballizing.

\[ F_{\text{elastic}} = \pi D \times 2b \times \mu \times p \] ...(2)
The axial force $F_{\text{elastic}}$ is given by equation (2) where $2b$ is width of contact, $p$ is length of contact, $p$ the radial elastic pressure (to be derived from Lame's equation) and $\mu$ is coefficient of friction. Sticking conditions can be assumed to prevail between the ball and the hole wall and a value of $\mu$ equal to $K/5.14$ $K = 0.2$ is adopted.

**Plastic Deformation in Ballizing**

In ballizing the ball tends to iron out the surface of the hole wall. Depending upon the values of $i$ and $H_{\text{max}}$, two modes of plastic flow can be contemplated:

(a) When $i < H_{\text{max}}$, the ball will ride over the asperities and cause surface finish improvement owing to filling of troughs by crests.

(b) When $i > H_{\text{max}}$, the ball carries out a forward extension of the material in the hole wall. In the experimental work taken up for research the $i = 40 \mu m$ and $h_{\text{max}}$ has a maximum value of about $25 \mu m$.

There is a development of a built up nose (coronet) ahead of the ball as ballizing proceeds. The size of the built up 'coronet' increases in size from magnitude zero at the beginning of the stroke to its full size by end of the stroke.

Contact between ball and material of the holes comprises of elastic portion. Thus the Ballizing process is the outcome of Elastic and Plastic properties in combinations.

**Plastic Portion**

Due to extrusion of the material ahead of the ball with plastic contact length $AB$, a build up nose is developed. It is difficult to develop a mathematical mode to estimate $F_{p1}$ as a function of ball travel and accounting for the size of built up nose, however, a simplified model for the estimation of $F_{p1}$ is proposed.

\[ P = 2K (1 + \psi) = 2K (1 + p/2 - q) \]  

... (3)

The value of $q$ can be approximately calculated as

\[ \theta = A'B/AA' = \frac{i_j / 2}{\sqrt{R}} \]  

\[ = \frac{1}{2} \frac{\sqrt{i_j}}{\sqrt{R}} \]
Thus the angle $\theta$ will be 0.005 radians (for $i = 0.18$ mm and $R = \text{mm}$).

Neglecting $\theta$ in equation (3) we get

$$P = 2K \left(1 + \pi/2\right) = 5.14K \quad \ldots(4)$$

Considering the effect of elastic material underneath the coronet.

**RESULTS AND DISCUSSION**

**Linear Relationship**

For M.S. $\frac{i_D}{D} = 0.989 \left(\frac{i}{D}\right) - 0.49275 \times 10^{-3}$

For Aluminium: $\frac{i_D}{D} = 0.9644 \left(\frac{i}{D}\right) - 2.2 \times 10^{-3}$

**Correlation Factor:**

(a) For CLA equation: 0.9583
(b) For load equations: 0.8677

In the above equation $v$ is in mm/minute

Load Equation:

$$\text{Load} = 3653.4858 \left(\frac{r}{D}\right)^{1.4646} \left(\frac{v}{\text{B.H.N.}}\right)^{1.16394}$$

**Surface Effects**

With the same ball and bush diameters.

<table>
<thead>
<tr>
<th>S No.</th>
<th>Final Material obtained.</th>
<th>Final C.L.A. Diameter</th>
<th>Initial Hardness value obtained</th>
<th>Final Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Mild Steel</td>
<td>18.06 mm</td>
<td>0.14</td>
<td>209 BHN</td>
</tr>
<tr>
<td>2.</td>
<td>Aluminiumalloy</td>
<td>18.08 mm</td>
<td>0.3</td>
<td>63 Vickers</td>
</tr>
</tbody>
</table>

**Bush Interference 90 Microns**

<table>
<thead>
<tr>
<th>S No.</th>
<th>Final Material obtained.</th>
<th>Final C.L.A. Diameter</th>
<th>Initial Hardness value obtained</th>
<th>Final Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Mild Steel</td>
<td>18.12 mm</td>
<td>0.2</td>
<td>209 BHN</td>
</tr>
<tr>
<td>2.</td>
<td>Aluminiumalloy</td>
<td>18.08 mm</td>
<td>0.75</td>
<td>63 Vickers Hardness</td>
</tr>
</tbody>
</table>
DISCUSSIONS

following Concluding remarks can be made

1. Ballizing process distorts and reduces the grains size which increases hardness in the ballized layer. The thin surface film gets hardened up to a depth of 0.06mm, in Mild steel, and 0.08 mm in Aluminium.
2. Width of contact (2b) is also found to be more with more interference or in softer material.
3. Temperature does not rise so much during ballizing that it may affect the surface finish.
4. Linear relationship in ballizing show that there is no plastic deformation in M.S. upto \( i/D = 0.547 \times 10^{-3} \) and in Aluminum upto \( i/D = 0.372 \times 10^{-3} \).
5. Linear relationship between \( i_p \) and \( i \) is plotted in the authors model. Slightly different values are obtained which affect \( m \) and \( c \) as shown in figs. 5.4 & 5.5.

REFERENCES