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A Review Paper on Ball Burnishing Process to Predict Surface Finish and Surface Hardness

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Abstract: **The process of burnishing is performed by applying a highly polished and hardened ball with external force onto the surface of a cylindrical work piece. The burnishing process reduces the surface roughness of work piece and increases 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 including residual compressive stresses in the surface of the work piece.**

Keywords: Ball burnishing tool, Aluminium, Surface roughness, Surface Hardness.

I. INTRODUCTION

In today’s manufacturing industry, special attention is given on surface finish along with dimensional accuracy and geometrical tolerance. Comparing with other finishing process such as grinding, honing, burnishing is chip less process. Burnishing is a cold working surface finishing process which is carried out on material surfaces to induce compressive residual stresses and enhance surface qualities. A burnishing tool typically consists of a hardened sphere which is pressed onto across the part being processed which results in plastic deformation of asperities into valleys. In burnishing process the initial asperities are compressed beyond yield strength against load. The surface of the material is progressively compressed, then plasticized as resultant stresses reach a steady maximum value and finally wiped a superfine finish.[5]

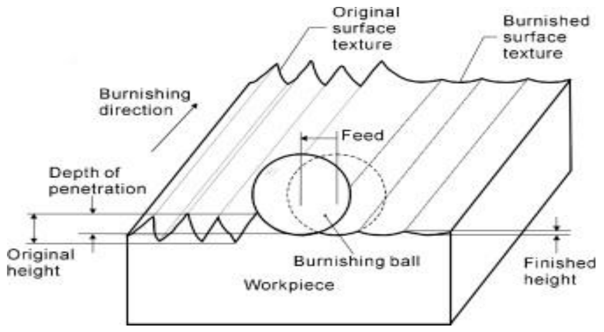

Fig 1 Schematic diagram of Ball Burnishing Process[9]

Burnishing is one of the important finishing operations carried out generally to enhance the fatigue resistance characteristics of components. Burnishing tools are used to impart a gloss or fine surface finish, often in processes that involve the cold working of metal surfaces. Burnishing tools are also used for the sizing and finishing of surfaces. Burnishing tool can be a roller or ball type.[13]

The burnishing process, shown in Fig 1 is based on the rolling movement of a ball against the work piece surface, a normal force being applied at the tool. As soon as the yield point of the work piece material is exceeded, plastic flow of the original asperities takes place. This phenomenon leads to a smoother surface. At the same time, compressive stresses are induced in the surface layer, followed by strain hardening and a series of beneficial effect on mechanical properties. Burnishing can improve both the surface strength and roughness. The increase of surface strength mainly serves to improve fatigue resistance under dynamic loads.[5]

Burnishing is a cold working process in which plastic deformation occurs by applying a pressure through a ball or roller on metallic surfaces. It is a finishing and strengthening process. Improvements in surface finish, surface hardness, wear resistance, fatigue resistance, yield and tensile strength and corrosion resistance can be achieved by the application of this process.[13]
Burnishing process can be typically classified into two categories as:

1. Based on deformation element
    - a. Ball burnishing
        - i. Flexible
        - ii. Rigid
    - b. Roller burnishing
2. Based on the motion of the tool, on the surface
    - a. Normal or ordinary
    - b. Impact
    - c. Vibratory [14]

II. BENEFITS OF BURNISHING PROCESS

1. Mirror like surface finish
   Surface finish ranging from 0.05 Ra – 0.2 Ra can be achieved easily by using Ball Burnishing Tools [17].

2. Dimensional Consistency / Repeatability
   Very close and consistent dimensional tolerance can be achieved in several thousand components by using Ball Burnishing Tools. Assembly problems are totally eliminated since part dimensions are maintained within tolerances [17].
3. Increase in Surface Hardness
   Since Ball burnishing operation is cold rolling process, work hardening takes place on the cold worked surface. Ball burnishing gives a better wear resistance on the rubbing surfaces thereby the increases the part service life [17].
4. Reduces the Reworks and Rejections
   In most of the operations (such as reaming and boring) there is a chance of maintaining the dimensions under size or over size especially in mass production [17].

Some other Advantages of Ball Burnishing Process are-

- ✓ Higher productivity
- ✓ Zero rejection
- ✓ Close tolerance
- ✓ Economical Operation
- ✓ Reduce Time

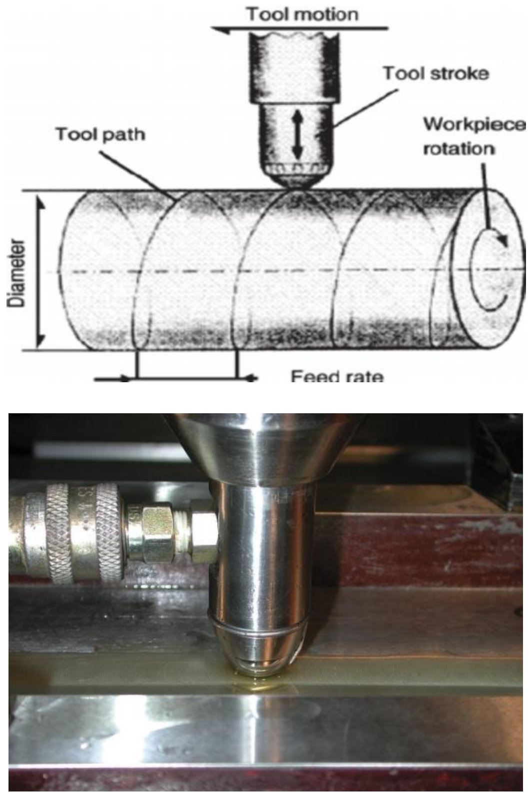

Fig. 2 Ball Burnishing Process [16]

III. THE EFFECT OF VARIOUS BURNISHING PARAMETERS ON SURFACE ROUGHNESS

A. Depth of Penetration

As increase in the depth of Penetration results increase in burnishing force, the roughness value decreases up to a certain point and then starts to increase. The force at that point is termed the optimum force and optimum depth of penetration. It depends on various factors: material being burnished, burnishing speed, ball diameter, pre-machined surface finish, feed-rate and frequency of oscillation [1].

B. Feed-rate

The height of the irregularities and hence the transverse surface roughness is determined by the feed-rate of the ball which is in the general range of 0.1 to 0.2 mm/rev. The figure 2 shows a smaller feed-rate f2 gives irregularities of lower height h2, and hence better surface finish. The use of feed-rate is dependent on other factors such as ball diameter, burnishing speed and depth of penetration. With a larger ball diameter, the feed-rate can be increased as the factors have opposite effects on the surface irregularities. Figure 2 shows the height of the irregularities (shaded area) formed by varying the feed-rate [1].

C. Burnishing speed

As the speed increases the surface roughness start to decreases due to increases in compressive deforming force and the stability of burnishing tool at high speed. But up to a certain value of speed then it starts to decrease [1].

D. Number of burnishing passes

When number of passes is used more, more surface irregularities are suppress into the valley which reduce the surface roughness, but the number of passes must be optimum to avoid increase in machining cycle time[1].

E. Burnishing tool size

The height of irregularities is inversely proportional to tool contact size used as more contact area between work piece and tool. Thus, as the burnishing tool size increases surface finish improves [1].

IV. BALL BURNISHING FE MODELLING

To simulate the ball burnishing process, the commercially available non-linear FE software ABAQUS was used. The 2D FE simulations were carried out using ABAQUS/standard. However, the 3D model involves complex contact conditions and a high-density mesh. Therefore, in order to reduce the computational cost, ABAQUS/explicit was used [15]. The FE models are based on the following assumptions:

1. The ball tool is considered rigid and is modelled by an analytically rigid part.
2. The surface roughness profile is neglected.
3. Because pressurised fluid acts as coolant and lubricant in the process, isothermal conditions (room temperature) and zero friction were assumed.

4. The ball burnishing speed effect is neglected [15].

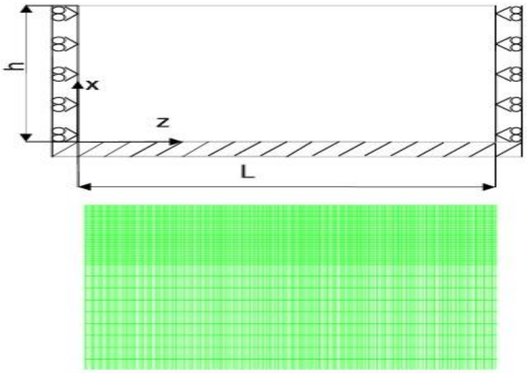

Fig 3.Mesh and boundary conditions of the work piece in the 2D ball burnishing simulation [15]

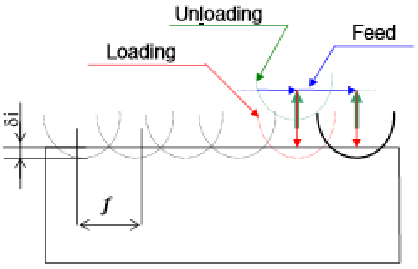

Fig 4.The ball tool loading in the 2D simulation[15]

3.1 Development of 2D FEM

To model the ball burnishing process in the 2D condition, the study was restricted to the cross-sections sliced along the longitudinal direction of the cylindrical workpiece. In fact, compared to the transverse cross-section, simulation of the longitudinal object takes into account more primordial parameters, such as feed rate and surface roughness profile. Since the diameter of the workpiece is considerably larger than the diameter of the ball tool, the treated workpiece is modelled by a rectangle fixed on its lower edge and with no horizontal displacement on its side edges (Fig. 3). In ABAQUS CPE8, eight-node biquadratic 2D solid plane strain elements are used to mesh the workpiece. The ball is considered circular in the 2D model. In the simulation, the cycle of load imposed on the ball can be controlled by using two different ball movement controls, that is, displacement control and force control. In the force control, the ball presses on the workpiece until the maximum applied load is reached for every indentation cycle. This type of loading does not strictly reflect the real load applied to the part during cylindrical rolling. Indeed, the real contact is a sphere/cylinder one, whereas the 2D model simulates a cylinder/plane contact. For these reasons, it is interesting to use the displacement control method in the 2D FEM. This load is a succession of three repetitive movements[15](Fig. 4):

-A vertical displacement δ (loading), which corresponds to the phase of penetration into the material;

– A phase of unloading, where the ball returns to its original position;

– After unloading, the ball is moved in a horizontal direction over a distance equal to the value of the feed rate per revolution (f)[15].

This method would require information on the ball penetration depth for the given process settings. This depth value, involving plastic deformation, changes from one cycle to another. It cannot be solved analytically due to the nonlinearity of the workpiece properties and is usually very difficult to measure during ball burnishing experiments. One solution is to consider the depth constant and use the 3Dsphere/ cylinder indentation simulation to assume the relationship between ball burnishing force and ball penetration depth under various conditions[15].

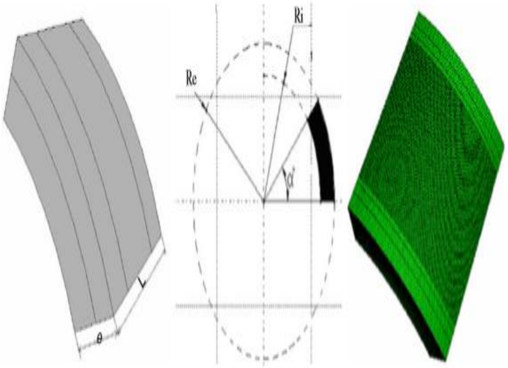

Fig 5. Geometric model and mesh of the workpiece in the 3D simulation[15]

3.2 Development of 3D FEM

Figure 5 shows the geometric workpiece model considered in the 3D FEM simulations. The workpiece is modelled by a portion of a cylindrical part. The choice of workpiece size in 3D FEM simulations takes into account the real dimensions of the treated piece, the presented boundary conditions and the optimization of computational time. The external radius is equal to the rod bar radius which is utilised in experimental work. The length L, the angle α and the thickness e are chosen in order to eliminate the effects of boundary conditions imposed on the workpiece and to obtain a homogeneous zone where these results are established. Sensitivity analysis of the workpiece size effect on the inelastic components led to the choice of the following values[15]:

L=7mm; a = 50°; e=2mm;and Re = 7:5mm

Several FE meshes were prepared and studied for the 3D model to find the effect of the mesh density on computational accuracy, computer time and program convergence. Finally, an FE model with 283,550 eight-node C3D8R elements and 300,456 nodes was prepared with increased mesh density in the area close to the surface, as shown in Fig. 5. The following velocity boundary conditions were applied to the nodes on these surfaces[15]:

At $\theta = 0$ and $\theta = 50$; $v_\theta = 0$
At $R = R_i$; $v_x = v_y = v_z = 0$
At $z = 0$ and $z = L$; these planes were considered free.

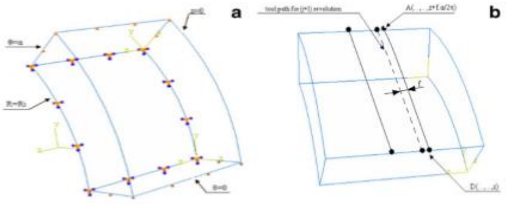

Fig 6. a) Boundary conditions imposed on the workpiece; b) ball boundary conditions[15]

For the 3D ball burnishing modelling, the displacement control method was used. The controlled ball penetration depth is determined by the ball burnishing force F_b. For every revolution simulation, the loading is done in two steps. The first is the indentation phase. In the second step, the ball is free on rotation and moves along the path presented in Fig. 6. The depth penetration of the tool is determined by the ball burnishing force. For the j_{th} simulation revolution, the tool centre is maintained in the $\alpha=0$ plane at z=1.8 mm. For the $(j+n)_{th}$ revolution, the tool begins its motion from $z=1.8+n\times f$[15].

V. CONCLUSIONS:

- Speeds, Feed & Depth of penetration are most affecting parameters on Surface Roughness[1].
- High Burnishing Pressure increases the surface hardness[7].
- A reduction in burnishing speed resulted in a better surface finish[4].
- The increase in the ball burnishing pressure increases the compressive residual stress layer and the maximum residual stress[15].
- Using high pressure increases the cold work dramatically and may consequently increase surface damage[15].
- At the same pressure and feed rate, the use of a large ball diameter is more effective[15].
- The burnishing force and burnishing speed play a major role and their effects are significant[10].

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