Chapter 1: Introduction

1. Introduction

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Introduction

Technological revolution in the recent years increased in the expectation from the manufacturing industry. The expected service-life of the components has taken a long-leap, without increasing the production cost. So the engineers had to come up with improvised and versatile manufacturing processes that address these expectations. The service behavior and life of the components depend mostly on the surface properties. For this reason, significant attention has been paid to the post-machining operations, because the conventional machining processes like turning, milling etc produce surfaces with inherent irregularities and imperfections. So there is need for a surface finishing operation that nullifies these irregularities and also improves other surface properties like hardness, corrosion resistance, wear resistance and fatigue life. These properties can be increased by utilizing surface plastic deformation (SPD) process, which does not involve material removal, but improves the surface properties by deforming the surface plastically, under compressive loads. Under this external load, the surface of the component is subjected to cold working. One such SPD process that has gained increasing acceptability in the manufacturing industry is burnishing.
1.1 Introduction to burnishing

Burnishing is a surface modification process which produces a very smooth surface finish by the planetary rotation of a tool over a bored or turned surface. The tool may consist of one or more ball or roller. This process does not involve the removal of material from the work pieces. All machined or other processed metal surfaces consist of a series of peaks and valleys which constitute the surface irregularities. The force applied by the burnishing tool forces the material from the peaks to flow into the valleys. This reduces the height of the peaks and depth of the valleys, thereby reducing the surface roughness. This is shown in figure 1.1.

![Figure 1.1: Basic operation of burnishing](Workpiece surface irregularities exaggerated)

Burnishing was first developed in American industry in 1930s, to impart residual compressive stress to the surface layers of the metal parts, in order to increase the fatigue life of the rail road car axels and the rotating machinery shafts. By 1960s it was applied more widely, particularly in automotive industry of Japan and USSR. Compressive stresses could also be produced by other processes like
shot peening, laser shock peening. But these stresses were found to be relaxed when exposed to heat. This thermal relaxation of compressive stresses shortens the component life and reduces its performance. So burnishing came up as a process that could impart thermally stable surface compressive stresses.

In 1996, Lambda Technologies developed and patented ‘Low Plasticity Burnishing (LPB™)’ which differed slightly from the conventional burnishing. It makes use of very minimal amount of plastic deformation or cold working, to create the residual stresses, which improve the surface properties like fatigue life and corrosion resistance. LPB™ uses a constant volume hydrostatic tool design as shown in figure 1.2, which is patented by Lambda Technologies, to float the ball continuously during the operation, irrespective of the applied force. This eliminates the dragging of the ball and damaging the surface, which is bound to happen in conventional burnishing, if not performed by taking enough care and precautions.

Figure 1.2: Low plasticity burnishing (© Lambda Technologies)
1.1.1 Principle of burnishing operation

Burnishing is a versatile process that improves the surface finish and dimensions of the turned parts, without the usage of extensive tooling. A conventional lathe, on which the workpieces were turned, can be used for burnishing, thereby eliminating the time and effort for remounting the workpiece. The tool used for burnishing consists of one or more ball or roller, held in a casing. This tool can be mounted on the tool post of the lathe. When the tool is made to come in contact with the rotating workpiece, the friction force rotates the balls or rollers of the tool, in a planetary motion.

Burnishing process is considered as a cold working process, because the surface of the workpiece is subjected to severe stress due to the planetary motion between the tool & workpiece and the pressure applied by the tool. When this stress exceeds the yield strength of the material, it results in the plastic flow of the material from the peaks of the surface irregularities into the valleys, thereby reducing the surface roughness. This also induces thermally stable and long-lasting compressive residual stresses.

1.1.2 Types of burnishing

Burnishing process can be classified into various types based on the type of the tools used, geometry of the workpieces being worked on, etc. In this section a brief discussion about this classification of burnishing process based on various schemes is presented.
1.1.2.1. **Classification based on tool:**

Burnishing process can be broadly classified into two types based on the geometry of the tool. They are

1. Ball burnishing
2. Roller burnishing

**Ball Burnishing:** In this type of burnishing, the tool consists of one or more spherical balls, supported in shank by the hydraulic pressure of the fluid or a spring and the reactive force of the work piece. Schematic of ball burnishing is shown in figure 1.3. Fluid is circulated constantly, using a hydraulic pump, through the recesses around the ball to keep it in contact with the work piece. When the tool is fed along the work piece, the ball is pressed against the work piece, resulting in the burnishing operation. The force of burnishing can be controlled by varying the hydraulic pressure of the fluid. In some ball burnishing tools, the hydraulic fluid will be replaced by a spring to control the positioning of the ball and the force applied on the workpiece.

![Figure 1.3: Schematic of ball burnishing process](image)
**Roller Burnishing:** Roller burnishing, as the name suggests, employs a tool with single or multiple rollers. For a multiple rollers tools, the rollers are present around the circumference of a supporting shank. Figure 1.4 shows the schematic of burnishing operation with single roller burnishing tool. The shank will be connected to the machine, which can be a drilling machine or milling machine or even a lathe. When the tool is made to come in contact with the work piece, the rollers around the shank also rotate, resulting in the burnishing of the work piece.

![Figure 1.4: Schematic of roller burnishing process](image)

Roller burnishing tool with single roller is called universal burnishing tool. In these types of tools the roller is supported using a bolt and nut assembly in a fork (figure 1.5). These tools can be used for burnishing flat, tapered and cylindrical surfaces.
Apart from these two basic types of burnishing tools, many other types of burnishing tools are being used in the industries. They are:

**Ballizing tool:** This is a metal displacement process in which an oversized ball is pushed through an undersized hole, as shown in figure 1.6. The ball enlarges the hole by displacing an amount of material equal to the interference fit. The ball displaces the material by plastic flow, leaving a layer of dense and hardened surface, with improved surface finish.
In many situations ball burnishing and ballizing would be used synonymously. Though the mechanism of operation of both these processes is the same, they differ in the applicability. Ballizing is applied only when working with bores; whereas ball burnishing can be applied on a wider range of workpiece geometries, which include inner surfaces, outer surfaces, flat surfaces, etc.

**Burnishing drills:** This tool combines the drilling operation with burnishing. The forward end of the tool includes a pair of cutting edges inclined radially from the forwardmost central end of the drill body. The shank, which starts after the cutting edges, is of higher diameter, a few microns more than the cutting tool diameter. This shank creates a burnishing effect on the drilled surface. The design of the burnishing drill should include provision for the removal of chips before the burnishing operation becomes active. Figure 1.7 shows the burnishing drill tool. The design of the burnishing drill looks similar to the conventional drill, the only difference being the shank size.

![Burnishing drill](Figure 1.7: Burnishing drill)

**Diamond burnishing tool:** Diamond burnishing tools are designed to produce mirror-like surface on a wide variety of ferrous and non-ferrous parts. These tools have a diamond insert in a tool holder which can be
mounted on most of the conventional and CNC lathes. The premium quality diamond burnishing insert is polished and contoured to provide superior finishes and excellent tool life. Figure 1.8 shows commercially available diamond burnishing tool, with holder and diamond insert.

Bearingizing Tool: Bearingizing tool combines roller burnishing with peening action. The tool consists of rollers, which rise and fall over a cammed arbor, when the tool is rotated at very high speeds. This generates up to 2 lakh rapid blows per minute on the workpiece surface. This results in the flattening of the surface irregularities, resulting in very fine surface finish. Figure 1.9 shows a bearingizing tool.
1.1.2.2 Classification based on work surface geometry:

Roller burnishing has more number of applications when compared to the other types. This is because of its capability to burnish various types of surfaces, which are listed below and discussed.

**Internal cylindrical surface:** Internal surfaces formed by drilling or any other metal forming process can be burnished. Roller burnishing tool with multiple rollers can be used for this purpose. Figure 1.10 (a) shows the schematic representation of the burnishing operation of internal cylindrical surface. Figure 1.11 shows the commercially available roller burnishing tool for inner cylindrical surfaces.

**Taper surface:** Roller burnishing can be applied on internal and external tapered surfaces. The tools used of this purpose generally have the facility to adjust the taper angle, as per requirement. Figure 1.10 (b) shows the schematic diagram of the burnishing operation of
internal taper surface. Commercially available roller burnishing tool for internal tapered surface is shown in figure 1.12.

**Flat surface:** Flat surfaces can be burnished using the technique similar to milling operation. The tool rotates along the vertical axis and the rollers rotate in the horizontal axis, parallel to the work piece surface, thereby improving the surface finish of the work piece. Figure 1.10 (c) shows the schematic representation of burnishing a flat surface. Figure 1.13 shows the tool available commercially for burnishing flat surfaces.

**Contour surface:** Roller burnishing tools need to be manufactured with the required contours, like concave, convex etc, to meet the requirements. But the limitation is that the contour has to be symmetrical over a rotational axis and any modification in the contour might result in the manufacture of a fresh tool. The schematic diagram of burnishing a concave surface is shown in figure 1.10 (d)

**External cylindrical surface** : Universal burnishing tool with single roller is best suited for burnishing the external cylindrical surfaces. This operation can be carried out on conventional or CNC lathes. Figure 1.10 (e) shows the schematic representation of this process and figure 1.5 shows the tool used commercially.

Versatility, ease of operation and adaptability of roller burnishing made it suitable for adoption in most of the industries for improving the surface finish and other properties.
Figure 1.10: Types of roller burnishing tools

(a) Internal cylindrical surface
(b) Taper surface
(c) Flat surface
(d) Contour surface
(e) External cylindrical surface
1.1.2.3 Classification based on starting position and feed rate of burnishing:

Burnishing can be classified into two types based on the starting position and feed rate with respect to the preceded turning operation. They are:

1. Homothetic burnishing: In this type, the starting position on the work piece and feed rate of both turning and burnishing will be
the same. It means that the starting point of burnishing is right at the valley of the surface profile formed by turning. Figure 1.14(a) shows the schematic diagram of the surface roughness obtained by homothetic burnishing.

2. **Heterosteric burnishing:** In this type of burnishing, either or both – starting position and feed rate of turning and burnishing will not be the same. It means that the starting point of burnishing is in front of the valley. Better surface finish can be obtained from heterosteric burnishing, when both starting point and feed rate of burnishing are different from turning. Figure 1.14(b) shows heterosteric burnishing with same feed rate for turning and burnishing, but with different starting point. Figure 1.14(c) shows
heterosteric burnishing with different feed rates and starting points for turning and burnishing.

From the figure 1.14, it is obvious that the surface finish is highest in heterosteric burnishing when the starting point and feed rate are different for turning and burnishing.

1.1.3 Advantages and disadvantages

Every manufacturing process has its own merits and demerits, which control their applicability in the industries. Burnishing also has merits and demerits, which are discussed in this section.

**Advantages:**

1. Accurate size: Parts can be produced by burnishing with high control over the dimensions. Hence very close tolerances can be achieved

2. Superfine surface finish: Very smooth surfaces finish, as high as 0.05 μm Ra is possible with burnishing. The surface finish obtained is comparable with any of the other conventional surface finish operations like grinding, peening etc.

3. Improves physical properties: Burnishing produces hard, wear and corrosion resistant surface because of the cold rolling. It also induces compressive stresses which increase the fatigue life of the components that are subjected to cyclic loads.

4. More economical: Burnishing eliminates grinding and honing, which are expensive and time consuming processes. Burnishing can be done on any standard lathe or drill machine, which eliminates initial investment. Skilled labor is not needed for this process. Any
worker who has experience in operating lathe or drilling machine can work on burnishing process.

5. Saves time: Work piece loaded on a lathe, milling or drilling machine need not be re-mounted for burnishing. The previous tool can be replaced with burnishing tool and process can be done on the same mount. Thus the cycle time is reduced, which increases the throughput.

6. Adjustable settings: Most of the commercially available burnishing tools have adjustable settings, which increases their scope of work. This reduces the cost, when any change takes place in the component design.

7. Replaceable wear parts: Wear parts such as roller, balls, guide rollers etc can be easily replaced, which helps in prolonging the tool life with less maintenance cost.

8. Wide variety of work pieces geometries, like flat, tapered, cylindrical, free-form surfaces can be processed by burnishing.

**Disadvantages:**

1. The initial cost of the burnishing tool is high.

2. Burnishing cannot be applied on miniature work pieces.

3. Components with thinner walls, which do not have enough strength, cannot be burnished, because the forces applied during burnishing are generally high.

4. Burnishing of intricate shapes and contours require dedicated tools and high skilled workmen. If the design or shapes of
the contours change, new set of tools have to be designed and manufactured. This increases the cost and time.

1.1.4 Process parameters of burnishing

There are many process parameters that control the operation and outcome of burnishing process. Each of these parameters has to be optimized and controlled to get the best possible results. The most important parameters are:

1. Burnishing force
2. Speed
3. Feed
4. Number of tool passes
5. Tool diameter and material
6. Lubricant

The details of these parameters and their effect on burnishing process are discussed below.

1. **Burnishing force:** The force with which the tool is pressed against the workpieces is termed as burnishing force. This force acts normally on the workpiece surface. The amount of force is controlled by the depth of penetration of the tool. Burnishing force is the most important and critical parameter of the burnishing process, because the surface roughness obtained depends on the force with which the tool is pressed against the workpiece. The applied force should be high enough to deform or yield the surface asperities and make the material flow from the peaks into the valleys of the surface
irregularities. The amount of force required to burnish a material largely depends on its yield strength.

2. **Speed:** The speed with which the work piece is rotated during burnishing is called speed. In flat surface burnishing, where the work piece is static and the tool is rotated, the speed is referred to the rotational speed of the tool. Speed is generally measured in revolutions per minute (rpm) or meters per minute (m/min). Speed of rotation should be chosen based on the strength and dimensions of the work piece.

3. **Feed:** It is the velocity at which the tool is fed or advanced along the work piece. It is expressed in the units of distance per one revolution of the work piece. Feed rate is dependent on the surface finish required. Lesser the feed rate more will be the surface finish, up to certain limit. So the feed rate should be optimized to obtain better surface finish.

4. **Number of tool passes:** It is the number of times burnishing process is repeated on the same work piece, at the same set of parameters. In many cases repeated burnishing may be needed to improve the surface finish. In some cases, the number of tool passes may go up to 5, depending on the strength of the work piece material.

5. **Tool diameter and material:** The size and material of the tool (roller or ball) also has effect on the surface finish of the burnished work piece. The material of the tool should be chosen such
that it has higher hardness and toughness than the workpiece material.

6. Lubricant: As burnishing is a chip-less operation and the amount of heat generated is also less, the influence of lubricant on the process outcome is also very less. In some cases burnishing can be done even in the absence of lubricant. But it is advisable to use any less viscous lubricant, for ease of movement of the bearings and rollers.

1.2 Characteristics of burnished components

Burnishing process has gained higher acceptability in the industries not just because of its surface finishing capabilities, but due to many other surface characteristics that are enhanced by burnishing. Most of these improvements are desirable from engineering perspective, which made burnishing an outstanding surface modification process. In this section the effect of burnishing on surface and material characteristics are listed and discussed in details.

1.2.1 Surface finish

Burnishing is primarily a surface finishing process. By application of burnishing the height of the surface irregularities can be reduced. When the pressure applied by the burnishing tool exceeds the yield strength of the work piece material, plastic flow of material occurs from peaks into the valleys, thereby reducing the surface roughness. Figure 1.15 shows the reduction in surface roughness by burnishing.
1.2.2 Surface hardness:

The material on the surface of the burnished component undergoes plastic flow because of the applied pressure. Because of this cold working, the hardness of the component’s surface increases. This increase in the hardness is confined only to the surface layers of the workpiece. Further heat treatment of the workpiece can be eliminated to increase its hardness, as the surface of the workpiece has already undergone case hardening.

1.2.3 Compressive stresses:

Compressive stress has a beneficial effect on the fatigue life and stress corrosion cracking of the material because it delays crack initiation and propagation. Tensile stresses on the contrary reduce the mechanical performance of the components. So it is always desirable to have compressive stresses induced in the components.

Under the immense force of the burnishing tool, the material of the component undergoes compression, thereby inducing residual compressive stresses. These compressive stresses are very long lasting.
and do not dissipate under normal working conditions. But when the component is subjected to heat treatment or used at elevated temperatures, these compressive stresses get relaxed. So the temperate of operation of the burnished components has to be monitored and controlled to extend the life of the compressive stresses.

Conventional metal forming processes like turning, milling etc induce tensile stresses in the component. So the components have inferior mechanical properties. When these components are burnished, the tensile stresses are relaxed and compressive stresses are induced in the components. Figure 1.16 shows the distribution of stresses in components before and after burnishing.

From the above schematic representation of the stress distribution, it is very clear that the tensile stress in the components can be relieved and compressive stresses can be induced upto certain depth, by burnishing.
1.2.4 Microstructure:

Cold working processes have the inherent ability of refining the grain size of the components surface. The grains are also aligned in the direction of working. This refinement and realignment of grains improve the strength and other metallurgical properties of the components. The surface of the burnished component is subjected to cold working, which results in the refinement and realignment of the grains of the surface layers. So by decreasing the grain size the strength and toughness of the materials can be increased. This enhancement in the strength is because of the increase in the area of grain boundary. The area of grain boundary increases because of increase in the number of grains per unit volume. Figure 1.17 shows the refinement in the grain size by burnishing.

![Before Burnishing](image1.jpg)

![After Burnishing](image2.jpg)

Figure 1.17: Refinement in grain size

1.2.5 Corrosion resistance:

Corrosion is a phenomenon, in which the material of the component reacts with the environment surrounding it. This results in the removal or addition of material to the exposed surface. In most of the cases this event is undesirable, as it reduces the life of the component and results in premature failures. Corrosion resistance of the components can be improved by subjecting them to additional
processes like painting, doping etc. But these processes involve addition cost and time. Burnishing process, apart from improving the surface finish also improve the corrosion resistance. The main reason for this is enhanced hardness, refined grain size and induced compressive stresses. The induced compressive stresses also hinder the stress corrosion cracking phenomenon, which is quite common when components have to operate under cyclic loads in corrosive environment. The current work includes extensive study of improvement in corrosion resistance of roller burnished components.

1.2.6 Wear resistance:

Wear is a very common phenomenon in mating parts. Though the life of the component subjected to wear can be assessed accurately, based on the working conditions, it is always desirable to have components with high wear resistance. This reduces the running cost and down time of the machinery. Burnishing process provides a very good advantage by improving the wear resistance. The case hardening of the surface of the burnished components is one of the primary reasons for this improvement in wear resistance.

1.2.7 Fatigue Life:

The fatigue life of the component subjected to cyclic loads is mostly governed by the stresses induced in the components. Conventional machining and finishing processes like turning, milling grinding induce tensile stresses in the components. These stresses deteriorate the fatigue performance. So the components which are subjected to cyclic loads are generally processes by secondary
operation which relaxes these tensile stresses and induces compressive stresses. Burnishing is one such operation, which induces compressive stresses of considerable magnitude, which do not get relaxed under working conditions, except high temperatures.

1.2.8 Electrical Conductivity:

The electrical conductivity is the measure of how well material conduct electricity. Most of the good electrical conductors are metals, in which closely linked atomic structures allow the free movement of electrons. This particular factor of electrical conductivity is not constant and varies from material to material. However there are some general factors as well, that commonly affect the conductivity in a significant manner. Some of these factors are temperature, impurities, porosity etc. When the other factors are maintained constant, the reduction in porosity can improve the electrical conductivity of materials.

Due to the high force applied by the burnishing tool, the material of the component’s surface gets closely compacted. This results in reduced porosity of the burnished component. This reduction in the porosity results in the improvement of electrical conductivity. In the current study, the electrical conductivity of burnished and unburnished components of copper and aluminium is determined to study the effect of burnishing in improving the electrical conductivity. It should be noted here that the effect of burnishing in reducing the porosity is limited only to the outer surface layers on which burnishing is applied and not on the bulk of the material. So
the improvement in the electrical conductivity of components of larger radius will only be marginal.

1.2.9 Bearing Ratio and Bearing Ratio Curve:

Bearing ratio ($t_p$) is the length of the bearing surface expressed as a percentage of the assessment length at a depth from the highest peak. The value of the bearing ratio can be used to determine the wear behavior of the surface in working condition. The calculation of the bearing ratio is described in figure 1.18.

![Figure 1.18: calculation of bearing ratio ($t_p$)](image)

The bearing ratio is calculated at various depths and the data is sorted in descending order and plotted from 0% to 100%. This curve is called bearing ratio curve or Abbott-Firestone curve. A sample curve is shown in figure 1.19.
Bearing ratio curve can be used to determine various parameters ($R_k$, $R_{pk}$, $R_{vk}$, $MR_1$, $MR_2$ etc), which describe the surface texture of the component and its behavior when subjected to wear. In the current thesis, the bearing ratio curves are developed for the burnished and unburnished surfaces. From this data, the bearing parameters are determined, which can be used to assess the improvement in the bearing performance of burnished components.