CHAPTER – 1
INTRODUCTION

The functional performance of a machined component depends on static strength (load bearing capacity), fatigue strength, friction and wear resistance etc., which are principally controlled by surface characteristics, such as topography, hardness, nature of stress and strain induced on the surface region. About 90% of the energy supplied is lost in the friction of elements in relative motion, which largely depends on surface roughness. Roughness values less than 0.1 µm are required for good aesthetic appearance, easy mould release, good corrosion resistance and high fatigue strength. The surfaces of engineering components provide a link between manufacturing and their functional use.

Provision and long-term keeping of specified characteristics of machine parts greatly depend on their surface quality. The main cause of machine failures (over 80%) is wear of contact surfaces in mating part and the related contact/fretting fatigue. Wear resistance of rubbing parts can be improved by reducing the initial wear of components. In this line, it is a better practice to make the sliding surfaces with a roughness just equal to that of the worm-in parts. Surface roughness also affects the following:

- The strength of parts subjected to alternating cyclic stresses
- Impact strength of components.
- The contact rigidity of the joint face of mating parts.
• The strength of force fitted components.
• Corrosion in atmospheric ambience.
• Lubricating conditions.
• Heat conductivity and tightness of joints.
• Reflective power and absorbing capacity of surfaces.
• Resistance to gas and liquid flows in piping.
• Resistance to pitting in hydraulic machines.

Reduced wear can also be achieved by improving surface micro-hardness of components. Some reduction or increase in wear can result from induced compressive or tensile stresses at the surface layer, respectively. Hence, improved life of engineering components will be attained by providing appropriately better surface finish, surface hardness and induced residual stresses in the surface layer.

In a manufacturing plant a product may be shaped, turned, milled or drilled and left in that condition as being satisfactory for use. Surface has two important aspects that must be defined and controlled. The first, surface finish, which concerned with the geometric irregularities of the surface, and the second, surface integrity, concerning the metallurgical aspects of the surface. Both surface finish and surface integrity must be defined, measured, and maintained within specified limits in the processing of any product.
Surface finish has long been known to have an impact on the life of a component that undergoes cyclic loading in service. This is the principal reason that so much time and effort is spent on finish machining; finish grinding, honing, lapping, and polishing. The purpose of these processes is to produce a surface that is free of defects, such as gouges and scratches. A surface, free of such defects, will generally survive longer in cyclic loading conditions. However, finish actually has only a marginal influence on fatigue strength.

A great advancement in the present machine age has been possible due to the increased knowledge and constant improvement of the surface textures. Surface finish has long been known to have an impact on the life of component, its working efficiency and its physical, mechanical, chemical, metallurgical properties. Surface treatment is an important aspect of all manufacturing processes to impart specific physical, mechanical and tribological properties. The following section briefly describes various technical aspects of surface characterization and also the factors that control them.

1.1 Surface Characteristics

1.1.1. Surface finish

Surface finishing is a process of smoothening the surface by removing the surface irregularities made by manufacturing method. Surface finish, by definition, is the allowable deviation from a perfectly flat surface that is made by some manufacturing process. Whenever any process is used to manufacture a part, there will be some
roughness on the surface. This roughness can be caused by a cutting tool making tiny grooves on the surface or by the individual grains of the grinding wheel, each cutting its own groove on the surface. Surface finish is affected by the choice of tool, speed of the tool, environmental conditions, and definitely by what material you are working with. Even when there is no machining involved, as in casting/injection molding, the surface of the mold will have surface deviation. Even if you could create a mold which was perfectly flat, the cooling process and thermal properties of the material would cause surface imperfections.

1.1.2. Surface alterations

The types of surface alterations associated with metal removal practices are

*Mechanical:*

- Plastic deformations (as result of hot or cold working)
- Hardness alterations
- Cracks (macroscopic and microscopic)
- Voids, pits, burrs, or foreign material inclusions in surface

*Metallurgical:*

- Transformation of phases
- Grain size and distribution
- Foreign inclusions in material
- Twinning
- Recrystallization
Thermal:

• Heat-affected zone

• Re-solidified material

• Sputtered particles or re melted metal deposited on surface

Electrical:

• Conductivity change

• Magnetic change

• Resistive heating or overheating.

1.1.3 Factors affecting the surface finish

Whenever two machined surfaces come in contact with one another the quality of the mating parts plays an important role in the performance and wear of the mating parts. The height, shape, arrangement and direction of these surface irregularities on the work piece depend upon a number of factors such as:

A) The machining variables which include

   a) Cutting speed

   b) Feed

   c) Depth of cut

   d) Number of passes

B) The tool geometry

The design and geometry of the cutting tool also plays a vital role in determining the quality of the surface. Some geometric factors which affect achieved surface finish include:
a) Nose radius
b) Rake angle
c) Side cutting edge angle, and
d) Cutting edge.

C) Work piece and tool material combination and their mechanical properties
D) Quality and type of the machine tool used,
E) Auxiliary tooling, and lubricant used, and
F) Vibrations between the work piece, machine tool and cutting tool.

1.2. Surface Finishing Methods

1.2.1. Honing

Honing is a final finishing operation conducted on a surface, typically of an inside cylinder, such as of an automotive engine block. Abrasive stones are used to remove minute amounts of material in order to tighten the tolerance on cylindricity. Either type applies a slight, uniform pressure to a light abrasive that wipes over the entire surface. Honing is an abrading process for removing stock from metallic and non metallic surface. It is used to correct local irregularities such as ovality waviness of axis or non parallelism of cylindrical features and to develop a particular texture. Honing is the application of bonded abrasive stones (called hones) to a surface. The abrasive particles (Al$_2$O$_3$ or SiC) are held by proper bond in the form of sticks. Honing is employed for grinding internal or external surface
mostly honing is done on internal surface or holes such as automobile cylinders. However it cannot correct hole location or perpendicularity. Surface finishes of 0.05 \( \mu \)m Ra can be achieved. The hone rotates at 0.5-2.5 m/sec and reciprocates at 0.2-0.5 m/sec. The hole to be honed is flooded with a lubricant like paraffin while the honing sticks are removing metal. A honing machine rotates and reciprocates the hone inside holes being finished.

![Fig. 1.1: Honing process](image)

1.2.2. Lapping

Lapping is a machining operation, in which two surfaces are rubbed together with an abrasive between them, by hand movement or by way of a machine. A paste of abrasive is rubbed against the surface of the component with certain pressure and with a relative motion. This can take two forms: The first type of lapping (traditionally
called grinding), typically involves rubbing a brittle material such as glass against a surface such as iron or glass itself (also known as the "lap" or grinding tool) with an abrasive such as aluminum oxide, emery, silicon carbide, diamond, etc., in between them. This produces microscopically similar fractures as the abrasive rolls between the two surfaces and removes material from both. The other form of lapping involves a softer material for the lap, which is charged with the abrasive. The lap is then used to cut a harder material, which in most cases the work piece. The abrasive embeds within the softer material which holds it and permits it to score across and cut the harder material. Taken to the finer limit, this will produce a polished surface such as with a polishing cloth on an automobile, or a polishing cloth or polishing pitch upon glass or steel. With the aid of accurate interferometry and specialized polishing machines or skilled hand polishing can produce surfaces that are flat to better than 30 nanometers.

1.2.3. Buffing

Metal polishing, also termed buffing, it is the smoothing and brightening process of a surface by the rubbing action of fine abrasive in a lubricating binder applied intermittently to a moving wheel of wood cotton fabric felt or a cloth or a felt belt. Buffing is used to give a much more lustrous reflective finish that cannot be obtained by polishing. This gives a smooth finish by forming very thin lines that are not visible to the naked eye.
Buffing wheels are made of felt, pressed and glued layers of duck, or some select cloth and also of leather. The abrasive is mixed with a binder and is applied on either the buffing wheel or on the work. The buffing wheel rotates with a high peripheral speed up to 40 m/sec. The abrasive may consist of iron oxide, chromium oxide etc. The binder is a paste consisting of wax mixed with grease, paraffin and kerosene or turpentine and other liquids. The stone is given as oscillating motion in the axial direction and simultaneously the job is given a rotary motion about the axis.

Buffing is commonly used in metal polishing of pressure cookers, cookware, and kitchenware. Pipes which are used in pharmaceutical, dairy and water industries are buffed to maintain hygienic conditions and prevent corrosion.

1.2.4 Super finishing

Super finishing is a type of grinding also known as Micro finishing. An abrasive stick of very fine grit size (400-600 mesh) is retained in a suitable holder and held against the workplace surface under a high spring pressure. The stick is given a feeding and oscillatory motion. The work piece is rotated or reciprocated accordingly to the requirements of the shape being super finished. A lubricant is also fed into the contact surface. An extremely high quality surface with almost no defects is obtained. Holes can also be super-finished.
1.2.5. Grinding

Grinding is a finishing process used to improve surface finish, abrade hard materials, and tighten the tolerance on flat and cylindrical surfaces by removing a small amount of material. In grinding, an abrasive material rubs against the metal part and removes tiny pieces of material. The abrasive material is typically on the surface of a wheel or belt and abrades material in a way similar to sanding (or sand grinding). On a microscopic scale, the chip formation in grinding is the same as that found in other machining processes. The abrasive action of grinding generates excessive heat so that flooding of the cutting area with fluid is necessary.
Most of the processes, described in the present section involve removal of material with or without introducing or altering the surface stress/strain distribution and they also involve high costs. The only other technique which not only reduces surface roughness, but also introduces beneficial compressive residual stresses is *burnishing*, which process is described in detail in the next section.

### 1.3. Burnishing

#### 1.3.1. Burnishing process

Burnishing is considered as a cold-working finishing process, differing from other cold-working, surface treatment processes such as shot peening and sand blasting, etc. In that it produces a good surface finish and also induces residual compressive stresses at the metallic surface layers. Accordingly, burnishing distinguishes itself from chip-forming finishing processes such as grinding, honing, lapping and super-finishing which induce residual tensile stresses at the machined surface layers. Also, burnishing is economically desirable, because it
is a simple and economical process, requiring less time and skill to obtain a high-quality surface finish.

The burnishing process can be achieved by applying a highly polished and hard ball or roller onto a metallic surface under pressure. This will cause the peaks of the metallic surface to spread out permanently, when the applied burnishing pressure exceeds the yield strength of the metallic material, to fill the valleys.

Fig. 1.4: Burnishing process
The surface of the metallic material will be smoothed out and because of the plastic deformation the surface becomes work hardened, the material being left with a residual stress distribution that is compressive on the surface. The changes in surface characteristics due to burnishing will cause improvements in surface hardness, wear resistance, fatigue resistance, yield and tensile strength and corrosion resistance. It can be seen from this figure that the ball or roller rotates by the effect of frictional engagement between the surface of the ball or roller and the surface of the work piece. This process flattens the roughness peaks by causing plastic flow of the metal. It not only improves surface finish but also imposes favorable compressive residual stresses and raises hardness in functional surfaces, which can lead to long fatigue life and high load bearing capacity, surface finish, hardness, wear-resistance, and corrosion resistance.

The present work is an attempt to study the effects of roller burnishing on the surface roughness and hardness of Ferrous and Non-ferrous materials. The variable burnishing parameters selected for the experimental work were burnishing force, number of burnishing tool passes and other burnishing parameters such as feed-rate, speed, depth of cut etc.
1.3.2. Advantages of burnishing

The burnishing process gives many advantages in comparison with the chip-removal process, such as:

- Higher surface hardness
- Improved wear resistance.
- Increased corrosion resistance.
- Improved tensile strength.
- Higher dimensional stability.
- Improved tensile fatigue strength by inducing residual compressive stresses in the surface of the work piece.
- High load capacity
- Improved resistance to abrasive wear
- High durability of burnishing tools.
- Possibility to apply tools for burnishing on universal cutting machine tools and simplicity of operation.
- Elimination or limitation of labor consuming operations such as lapping horning, polishing, scarping and buffing.
- Possibility to eliminate heat treatment in certain cases.
- Possibility to achieve high shape-size precision.
- Decreases surface roughness to produce smooth brilliant surfaces.
• Burnishing actually work-hardens a part giving at longer life cycles and greater resistance to wear.

1.3.3. Applications of burnishing

There are many potential applications for the use of Burnishing:

• It has been used on the leading edges of Turbine Blades to improve resistance to foreign object damage (FOD) and crack growth.

• Bearing shafts up to 65 HRC have been processed to improve resistance to sapling and improve life.

• Many components with odd shapes or forms can be LPB processed.

• The ideal surface treatment system should emphasis affordability – low cost, and high process reliability.

• Employing surface enhancement by Burnishing to introduce a deep, stable layer of Compressive stress, thus eliminating tensile stresses and reducing susceptibility to high cycle fatigue (HCF) and corrosion related failure without altering either material or design.

• Burnishing introduces similar or even more applicable compressive residual stress than Laser shock peening (LSP).

• The Burnishing manufacturing process is highly controllable and operates at cycle times that greatly lower cost of production and provide processed parts in minutes, thus preventing production bottleneck constraints typical of LSP processing.
• Laser shock peening (LSP) is a surface enhancement Technology that is currently being developed to provide deep compressive residual stresses into a surface of a material to increase strength and fatigue life. However, development and application of LSP has proven to be very costly.

• Burnishing process can be used in standard CNC lathes and mills.

• Tooling and picturing can be developed for specific applications.

• The burnishing can be used for: GM / Bronze Bushes, Connecting Rod Small / Big End, Rocker Arm, Valve, Guide, Bearing Housing Motor End Cover, Piston G.P. Holes, Brake cylinders, Master Cylinders, Pneumatic Cylinders, Hydraulic Cylinders, Valve Rod, Long Holes, Pipes etc.

Apart from surface roughness, burnishing also affects the nature (distribution) and magnitude of residual stresses, microstructure and micro hardness. All these four characteristics greatly influence in service life of a machined part/component. The chapter 3 of the thesis dwells in detail on the means of measuring these influencing characteristics. A brief note is presented here on RESIDUAL STRESSES.

1.4. Residual Stresses

As we know, all manufacturing processes introduce residual stress into mechanical parts, which influence its fatigue behavior and breaking strength and even its corrosion resistance. Few metal
working methods exist which do not produce new stresses. The role of residual stress is therefore very important when designing mechanical parts. In fact, residual stress has a greater impact on service life than surface finish.

A surface in high tension, around a weld for example, will crack and fail quicker than if there were no stress at all. This is because the surface, which is already in tension, will be put in even higher tension during a loading cycle. This tension pulls at the surface of the material and weakens it. The oscillating tension eventually causes damage at some small point on the surface, usually at a flaw or stress concentration such as a sharp corner or fillet. This point is called the initiation or nucleation point. A crack develops at this location and begins to grow through the component until failure occurs. A surface that is in compression will experience less magnitude of tensile stresses during the tensile part of the loading cycle, if any at all. Because of this, it is more difficult to start a crack or for a crack to grow through a compressive layer. Therefore, the component lasts longer under cyclic loading conditions.

Residual stresses exist in particularly all rigid parts, whether metallic or non metallic (Wood, polymer, glass, ceramic, etc). It is the result of the metallurgical and mechanical history of each point in the part as a whole during its manufacture.
1.5 Scope of the Present work

Burnishing has been identified as one of the principal surface modification treatment and is the subject of present doctoral thesis. The effect of various burnishing parameters have been evaluated in the present work in case commercially important and widely used, low-to-medium criticality materials. These materials include EN series steels (EN 8, EN 24 and EN 31), aluminum alloy (AA6061) and Alpha-beta Brass. The reason for selecting these materials is to study the burnishing process as a function of surface as well as bulk hardness and generate an overall understanding on the burnishing process in different structural materials with an aim to propose BURNISHING MAP.

The burnishing parameters that include burnishing force, burnishing speed, depth of cut and number of passes and their effect on surface characteristics( surface roughness, residual stresses, micro structure and micro hardness have been evaluated systematically). The experimental procedure for these principle evaluations are outlined in the chapter 3. On the other hand the details of the materials and their chemical composition, micro structure are detailedly discussed in the chapters 5, 6 and 7 for EN series steels, aluminum alloy AA6061 and Alpha-Beta Brass. In the present thesis, the experiments for the optimization of burnishing parameters is accomplished by designing experiments based on experimental runs of burnishing by using the burnishing tool described in chapter 3 and
theoretical 2 and 3 level Taguchi method. It is deemed useful to design the experiments theoretically as most of the burnishing parameters affect simultaneously and differently on the surface characteristics which nature again varies differently for the five different materials studied in the present investigation.

1.6. Structure of the Thesis

Chapter 2: Various studies reported in literature regarding the surface modifications, the principles and the process of burnishing, residual stresses that result from surface modifications and surface roughness characteristics are detailed and discussed in this chapter.

Chapter 3: This chapter provides information about equipment used to find the various burnishing parameters.

Chapter 4: This chapter provides the theoretical Taguchi techniques to find the optimal burnishing parameters.

Chapter 5: The experimental results regarding surface characteristics, micro structure and micro hardness for EN Series steels were discussed in this chapter.

Chapter 6: In this chapter optimization of burnishing parameters and evolution of surface characteristics, micro structure and micro hardness for AA6061 alloy were evaluated.
Chapter 7: In this chapter optimal burnishing parameters were evaluated and discussed for Alpha-beta Brass.

Chapter 8: A summary of results obtained in the thesis, specific conclusions drawn and scope for further scientific work are given in this chapter. For the first time in the open literature an attempt is made to construct BURNISHGING MAPS and the burnishing maps thus proposed are presented in this Chapter.

1.7. Chapter Summary

Some of the important techniques of surface modifications and particularly the burnishing process and its parameters are described along with a brief note on the important surface characteristics that get altered by these surface modification techniques. Also a small note on burnishing advantages and limitations of burnishing is included.