JOMO KENYATTA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY

EMT 2540 Advanced Production Technology

Lecture Notes Compiled By: Ms Maurine N. Andanje

Students are reminded not to treat these lecture notes as a comprehensive and solely sufficient material for their studies since the purpose of the notes is not meant to be a substitute for regularly attending classes, reading relevant textbooks and recommended books. The notes are aimed at providing a quick reference and a brief guidance for the students.

May, 2021

Table of Contents

Title page i

Table of Contents ii

1 Powder Metallurgy **2**

1.1 The Basic Process 3

1.2 Powder Manufacture 4

1.2.1 Atomization 4

1.2.2 Chemical Methods 5

1.2.3 Electrolytic Process 6

1.2.4 Mechanical Pulverization (or) Comminution 6

1.3 Mixing and Blending 7

1.4 Powder Compaction 7

1.4.1 Classification of compacting 8

1.5 Sintering 14

1.5.1 Types of sintering 14

1.6 Hot Pressing 15

1.7 Secondary Operations / Finishing 16

1.7.1 Sizing 16

1.7.2 Coining 16

1.7.3 Infiltration 17

1.7.4 Impregnation 17

1.7.5 Heat treatment 17

1.8 Applications of Powder Metallurgy 17

1.9 Advantages of Powder Metallurgy 18

1.10 Disadvantages of Powder Metallurgy 19

2 Specialized machining processes 21

2.1 Ultrasonic Machining . . . 21

2.1.1 The machining system . . . 22

2.1.2 Factors affecting material removal rate . . . 23

2.1.3 Applications of Ultrasonic machining . . . 24

2.2 Abrasive Jet Machining . . . 27

2.2.1 Machining system . . . 27

2.2.2 Applications of abrasive jet machining . . . 28

2.3 Chemical Milling . . . 28

2.3.1 Tooling for CHM . . . 29

2.3.2 Process parameters . . . 30

2.3.3 Applications . . . 31

2.4 Electrochemical Machining . . . 31

2.4.1 Advantages of ECM . . . 32

2.4.2 Limitations of ECM . . . 32

2.4.3 Applications: . . . 33

2.5 Electrodischarge Machining (EDM) . . . 33

2.5.1 The machining system . . . 33

2.5.2 Application . . . 34

2.6 Laser Beam Machining . . . 35

2.6.1 Applications . . . 36

2.7 Electron beam machining (EBM) . . . 36

2.7.1 Basic equipment and removal mechanism . . . 36

2.8 Plasma Beam Machining . . . 38

2.8.1 Applications . . . 38

3 Welding and fabrication techniques 40

3.1 Forge welding . . . 41

3.1.1 Working . . . 41

3.1.2 Application . . . 41

3.1.3 Advantages and Disadvantages . . . 42

3.2 Tungsten Inert Gas Welding . . . 43

3.2.1 Advantages . . . 43

3.2.2 Disadvantages 44
3.2.3 Application 44
3.3 Plasma Arc Welding 44
3.3.1 Principle of PAW 45
3.3.2 Advantages of PAW 45
3.3.3 Disadvantages of PAW 45
3.3.4 Applications 46
3.4 Resistance Welding 46
3.4.1 Spot Welding 46
3.5 Electron beam welding 47
3.5.1 Principle of Operation 48
3.5.2 Advantages 48
3.5.3 Disadvantages 49
3.5.4 Applications 49
3.6 Laser Beam Welding 49
3.6.1 Principle of operation 49
3.6.2 Advantages 50
3.6.3 Disadvantages 50
3.7 Design for welding: Design recommendations 51
3.7.1 Cost Reduction 51
3.7.2 Minimizing Distortion 53
3.7.3 Weld Strength 55

4 Jigs and fixtures 58
4.1 Jigs 58
4.2 Fixtures 59
4.2.1 Differences between jigs and fixtures 60
4.2.2 Advantages of Jigs and fixtures 60
4.2.3 Fundamental principles of jigs and fixtures design 61
4.2.4 Essential features of jigs and fixtures 62
4.2.5 Materials used 63

5 Decorative and protective surface treatment 64

5.1 Mechanical hardening of the surface 64
5.2 Case hardening 65
5.3 Thermal spraying 65
5.4 Vapor deposition 65
5.5 Electroplating 66
5.6 Electroless plating 67
5.7 Anodizing 68
5.8 Painting 68

6 Mass production tools and techniques; machining centers 70

6.1 Machining Centers 72
6.1.1 General Structure and Types of Machining Centers 73
6.2 Job Production 75
6.3 Batch Production 75
6.4 Lean Production 76
6.5 Total Productive Maintenance as one of the tools of Lean Production 79
6.5.1 The Traditional TPM Model 79

7 Recent advances in production technology 83

7.1 Micro and nano manufacturing 83
7.2 Rapid Prototyping (Additive Manufacturing) 83

Course description

1. Powder metallurgy: Metal powders, pressing, sintering, pre-sintering, sizing and finishing. Properties of powder metallurgy products. Design of metal powder parts. Advantages and disadvantages of powder metallurgy.

2. Specialized machining processes: Electrochemical, electrodischarge, electrobeam, laser, chemical, ultrasonic, abrasive jet, plasma arc.

3. Welding and fabrication techniques: Forging, gas flame welding, resistance welding, other welding processes. Torch and arc cutting. Heat and design considerations in welding.

4. Jigs and fixtures.

5. Decorative and protective surface treatment.

6. Mass production tools and techniques; machining centers.

7. Practical exercises in powder metallurgy and specialized machining processes. Recent advances in production technology.

Course Textbooks

1. DeGarmo E.P. and Black J.T. (1996) Materials and Processes in Manufacturing, Wiley, John and Sons, Inc.

2. Larry J, Harold V.J, (2002) Welding: Principles and Application, Delmar Publishers, Inc.

References

1. Chapman W. A. J. (1986) Workshop Technology - Part 3, Arnold International, Students Ed.

2. Hindustani Machine Tools (HMT), (1980) Production Technology Tata McGraw-Hill Pub. Co, Bangalore India

3. International Journal of Production Research.

Mode of Examination: Continuous assessment and written University examination shall contribute 30% and 70%, respectively of the total marks.

Chapter 1

Powder Metallurgy

Powder metallurgy is the name given to the process by which fine powdered materials are blended, pressed into a desired shape (compacted), and then heated (sintered) in a controlled atmosphere to bond the contacting surfaces of the particles and establish desired properties. This process is one of the four major methods of shaping metals (machining, hot and cold plastic deformation, casting, and powder metallurgy). The process, commonly designated as P/M, readily lends itself to the mass production of small, intricate parts of high precision, often eliminating the need for additional machining or finishing. There is little material waste, unusual materials or mixtures can be utilized, and controlled degrees of porosity or permeability can be produced. Major areas of application tend to be those for which the P/M process has strong economical advantage or where the desired properties and characteristics would be difficult to obtain by any other method. Because of its level of manufacturing maturity, powder metallurgy should actually be considered as a possible means of manufacture for any part where the geometry and production quantity are appropriate.

Parts manufactured by the P/M process have found widespread applications in the automotive industry, household appliances, recreational equipment, hand and power tools, hardware items, office equipment, industrial motors, and hydraulics. Areas of rapid growth include aerospace applications, advanced composites, electronic components, magnetic materials, metalworking tools, and a variety of biomedical and dental applications.

1.1 The Basic Process

The powder metallurgy process generally consists of the following basic steps:

(a) Powder manufacture

(b) Mixing or blending

(c) Compacting

(d) Presintering

(e) Sintering

(f) Hot Pressing

(g) Secondary operations

Compaction is generally performed at room temperature, and the elevated-temperature process of sintering is usually conducted at atmospheric pressure. Optional secondary processing often follows to obtain special properties or enhanced precision. Figure 1.1.1 presents a simplified block diagram of the conventional die-compaction P/M process.

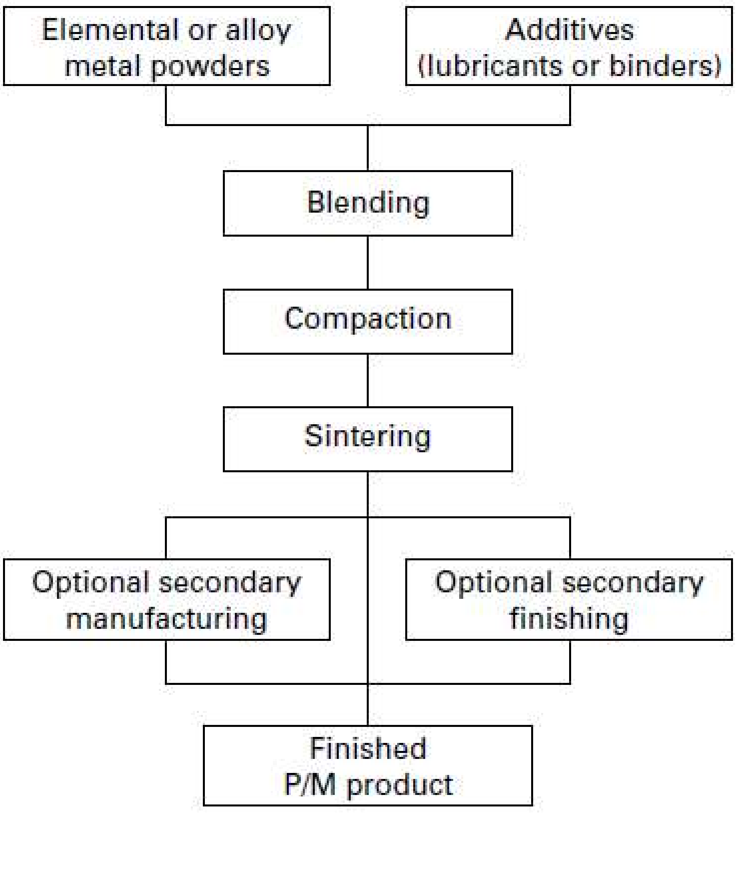

Figure 1.1.1: The basic powder metallurgy process

1.2 Powder Manufacture

A number of different metals and their alloys are used in P/M (e.g., iron, alloy steel, stainless steel, copper, tin, lead). The properties of powder metallurgy products are highly dependent on the characteristics of the starting powders. Some important properties and characteristics include *chemistry and purity, particle size, size distribution, particle shape, and the surface texture* of the particles. Several processes can be used to produce powdered material, with each imparting distinct properties and characteristics to the powder and hence to the final product. The particle size of the metal powder should be in the range of 10 to 100 microns. The three most important methods of producing metal powders are:

(a) atomization

(b) chemical methods

(c) electrolytic processes

1.2.1 Atomization

Over 80% of all commercial powder is produced by some form of melt *atomization*, where liquid material is fragmented into small droplets that cool and solidify into particles.

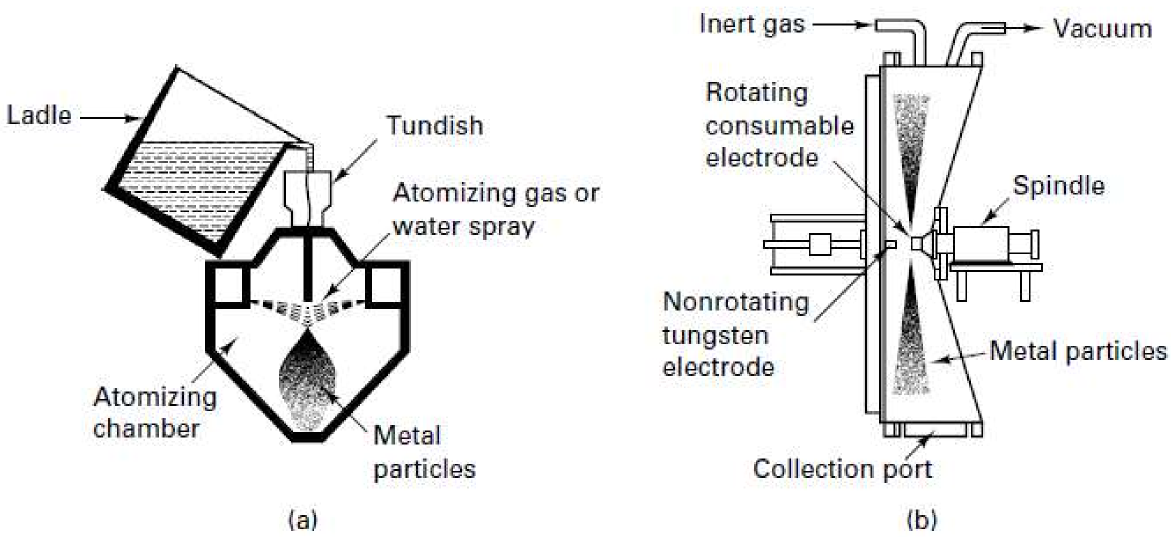

Figure 1.2.1: (a) melt atomization (b) atomization from a rotating consumable electrode.

Figure 1.2.1 illustrates two methods for producing metal powders: melt atomization and atomization from a rotating consumable electrode. Part (a) illustrates *gas atomization*, where jets of high-pressure gas (usually nitrogen, argon, or helium) strike a stream of liquid metal as it emerges from an orifice. Pressurized liquid (usually water) can replace the pressurized gas, converting the process to *liquid atomization* or *water atomization*. In part (b), an electric arc impinges on a rapidly rotating electrode. Centrifugal force causes the molten droplets to fly from the surface of the electrode and freeze in flight. Particle size is very uniform and can be varied by changing the speed of rotation.

Oxidation of the metal powder can be prevented by maintaining an inert atmosphere. This method is generally used for metals with low melting points such as: Zn, Pb, Sn, Al and Mg.

1.2.2 Chemical Methods

Chemical methods such as reduction, decomposition and condensation are used to produce metal powders.

a. **Reduction**

Chemical reduction is a process in which metal powders are formed by chemical reaction between metal oxides and reducing agents (e.g., hydrogen or carbon monoxide). Hydrogen or carbon monoxide reacts with oxygen in the metal oxide, producing pure metal. This method is used for metals with high melting points

Example: W, Mo powders are prepared by this method.

Tungsten powder is produced by the reduction of WO_3

$WO_3 + 3\ H_3 \rightarrow W + 3\ H_2O$

b. **Decomposition**

This method is specially used to produce metals from carbonyls. In this process, the gaseous metal carbonyls are decomposed thermally to get the corresponding metals. The powder so produced is spherical:

Example: Carbonyls of Ni & Fe i.e. $Ni(CO)_4$, $Fe(CO)_5$

$Ni(CO)_4 \rightarrow Ni + 4CO$

c. **Condensation**

In this process, a metal rod is vapourised by heating it to very high temperatures and the vapours are condensed.

Example:

Zn, Mg, Cd powders can be prepared by this method.

1.2.3 Electrolytic Process

The *electrolytic process* that is utilized to precipitate metal powders begins in the electrolytic cell where the source of desired metal is the anode. As the anode is dissolved, the desired metal is deposited on the cathode. After this step is complete, the metal deposit is removed from the cathode and is washed and dried.

Other methods of powder manufacture include:

- *Pulverization* or *grinding* of brittle materials (comminution).
- *Precipitation from solution.*
- *Shooting*

1.2.4 Mechanical Pulverization (or) Comminution

Mechanical pulverization is done using a mechanical pulverizer such as counter rotating blades or rapidly moving hammers. Due to the mechanical forces, it disintegrates the metal particles into fine powder. Pulverization is usually followed by ball milling. Brittle metals and alloys can be powdered by this method to a size of 0.001mm. Example of powders that can be produced by this method are: Mg, Zn, Pb.

In each process, the powders may be ground further to a desired fineness, usually in a ball mill. Metal powders are screened, and larger particles are returned for further crushing or grinding. The powders are classified according to particle size and shape in addition to other considerations such as chemical composition, impurity, density, and metallurgical condition of the grains. Particle diameters range from about 0.002 in. to less than 0.000 1 in. Test sieves are used to determine particle size. This method of testing has been standardized throughout the industry.

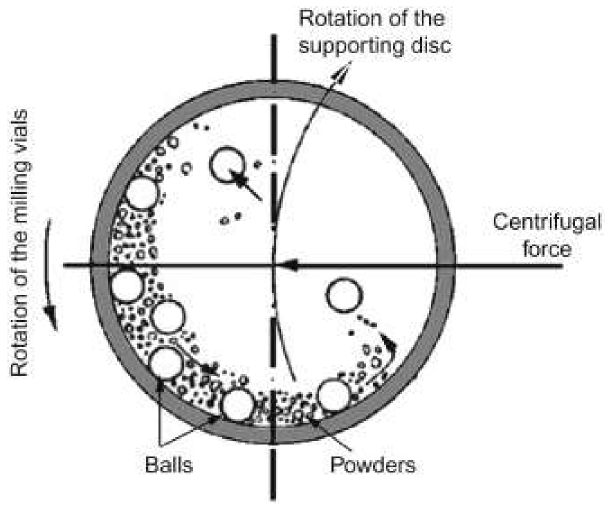

Figure 1.2.2: Ball milling process

Powders are often blended by tumbling or mixing. Lubricants (e.g., graphite) are added to improve flowability of material during feeding and pressing cycles. Deflocculants are also added to inhibit clumping and to improve powder flow during feeding.

1.3 Mixing and Blending

Mixing and blending of metal powders in desired proportions is done in order to get uniform and very good results especially when an alloy is to be manufactured. Lubricants and volatilizing agents are also added to give a desired amount of porosity and lubricity. The time of mixing may vary from a few minutes to several days depending upon the results desired. Overmixing should be avoided in many cases, since it may decrease particle size and work-harden the particles.

1.4 Powder Compaction

Powder compaction is the process of converting loose powder into the desired shape. Most compacting is done by cold pressing, but there are some specific applications, for which compacts are not pressed. The main purpose of compacting process is the forming of metal powders into compacts of desired shapes with sufficient strength to withstand ejection from the tools and handling it without breakage and damage.

1.4.1 Classification of compacting

Various methods of powder compaction are grouped into two types:

1. **Pressure shaping techniques**

   Pressure shaping techniques involves conversion of metal powder into desired article under pressure before sintering. It includes:

   i. Die compaction

   ii. Isostatic pressing

   iii. Powder extrusion

   iv. Powder forging

   v. High energy rate forming

   vi. Vibratory compaction

   vii. Continuous compaction

2. **Pressure-less shaping techniques** Pressure-less shaping techniques are those in which metal powder is converted into desired article without applying any external pressure. This technique includes:

   i. Slip casting

   ii. Gravity compaction

   iii. Continuous pressureless compaction

i. **Die compaction**

   About Die

   Dies are usually made of ground, hardened steels. The dies consists of two parts lower punch and upper punch. The lower punch is provided with shaping hole, in which metal powder is introduced.

   Process

   The metal powder is introduced into the cavity of the die. Required pressure is given by movement of upper and lower punches towards each other. After that, the green compact is ejected from the lower punch, see Figure 1.4.1. The pressures commonly employed range from 19 - 50 tons / sq. inch. It may be obtained by either mechanical or hydraulic presses.

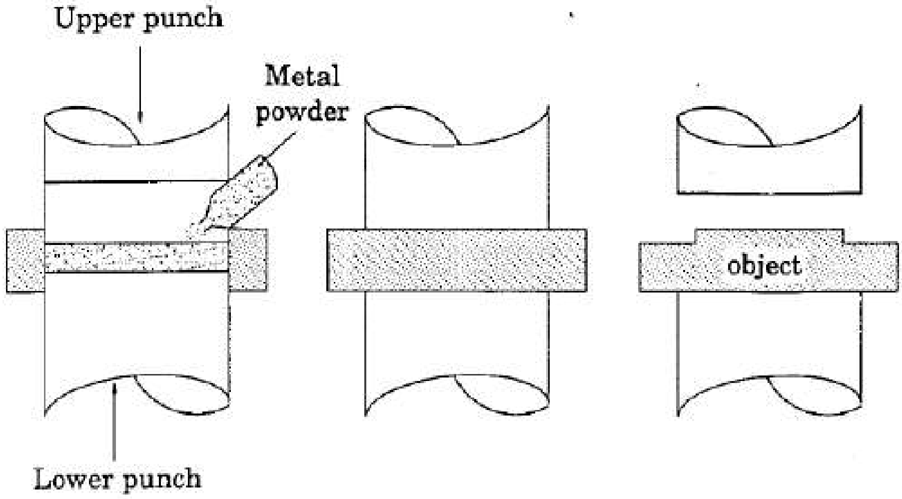

Figure 1.4.1: Shaping Dye

a. **Mechanical presses**

   Mechanical presses are available with pressure ratings of 10 - 50 tons and speeds of 6 - 150 strokes/min. The important features of which are high speed production rates, flexibility in design, simplicity, economy in operation, relatively low investment and maintenance costs.

b. **Hydraulic presses**

   Hydraulic presses are available with ratings upto 5,000 tons, but slower stroke speeds generally less than 20 strokes/min. These presses are used for higher pressure, more complicated metal parts.

ii. **Isostatic Pressing** Isostatic pressing is the consolidation of powdered metal contained in a tightly sealed flexible mould. The mould is then kept into shaped bodies in which a uniform pressure is applied simultaneously and equally in all directions thereby achieving uniform density and strength.

   a. **Hydrostatic Pressing** If the pressure transmitting medium is liquid such as water, water-soluble oil mixture, glycerine or various hydraulic oils, the process is referred to as "hydrostatic pressing".

b. **Isostatic Pressing** If the pressing media used are gases, powders, rubber or plastics, the process is referred to as "isostatic pressing".

Process of Isostatic Pressing

The powder is loaded in a shaped flexible mould (rubber) for the production of the desired shape and tightly sealed against leakage. The flexible mould is then placed in a pressure chamber where pressure is applied. The component shape is determined by the flexible mould and density is controlled by the amount of pressure used in the process.

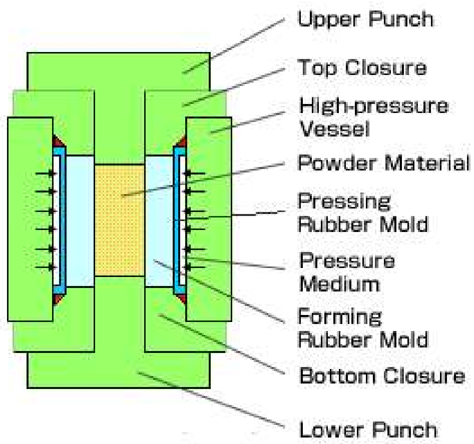

Figure 1.4.2: Isostatic pressing layout

The pressure required is generated either by a high pressure pump or by direct compression. Pressure is then released and the article is taken out from the pressure chamber after opening it. Figure 1.4.2 shows a layout of the isostatic pressing.

iii. **Powder Forging**

Forging is the working or forming of powder metal into a required shape by pressing.

Classification of forging process

Forging process can be classified into two types:

a. Hot forging or Hot working

b. Cold forging or Cold working

a **Hot forging**

If the temperature of the metal is increased to a certain degree in a protective atmosphere, new refined (recrystallised) grains are formed. The process of formation of these new refined grains is called recrystallisation. The temperature at which this process is completed is called recrystallisation temperature. The mechanical working of metal powder above the recrystallisation temperature is called "hot forging". After hot forging, the component is withdrawn from the die and is either quenched or cooled in protective atmosphere to minimise oxidation.

b **Cold forging**

The mechanical working of metal powders below the recrystallisation temperature is called "cold forging".

Example: Powder extrusion

iv. **Powder Extrusion**

The process consists of extruding the mixture of powder and materials at high pressures through the appropriate die. It is recommended to use pre-pressed mixture in order to attain the desired density. The extruded parts are then sintered.

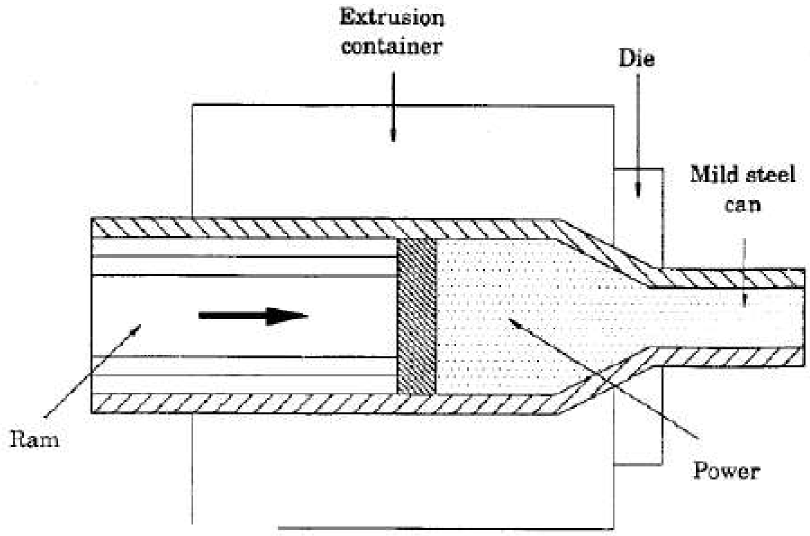

Figure 1.4.3: Powder extrusion

Figure 1.4.3 shows the operation of the powder extrusion process where the powder is placed in some kind of metal container. The sealed container is heated or evacuated and then extruded. After extrusion, the container material is then removed either mechanically or chemically.

v. **High-energy rate forming**

In this method, considerable work has been done on compacting parts using mechanical, explosive, spark-discharge and other high energy processes in order to produce high density parts. The machines used for the production of high energy parts are: Dynapak machine and Petro-forge machine.

vi. **Vibratory compaction**

Vibratory compaction involves the application of pressure and vibration simultaneously during pressing of a mass of powder within a rigid die. This method greatly enhances densification due to intensive mixing of particles and change in adjustment of their shapes. Both high frequency low-amplitude and low-frequency high-amplitude vibrations have been successfully applied for achieving the maximum densification.

vii. **Continuous compaction**

This method is applied primarily for simple shapes like rod, sheet, tube and plate. Roll compacting or powder rolling is the commonly used continuous compaction. Most of the commercial techniques involves flowing loose powder between a set of vertically oriented rolls as shown in Figure 1.4.4. In powder rolling, the rolls are set side by side so that the strip emerges vertically downwards as shown in Figure 1.4.4. When the channel rollers rotate, the powder is drawn into the gap between the rolls and is pressed into a strip. The continuous feeding of the powder produces the strip of infinite length. The strip is then sintered for a short time.

Pressure-less shaping techniques

i. **Slip casting**

Slip casting is commonly use for the production of ceramic articles, but only to a limited extent for metals. The slip for casting is first prepared by suspending a metal powder (finer than 5μ) in a liquid vehicle (suspending medium) and a small amount of suspension agent and binders. The slip is then placed in a mould which is made of fluid-absorbing material (like plaster of paris) to form the slip casting.

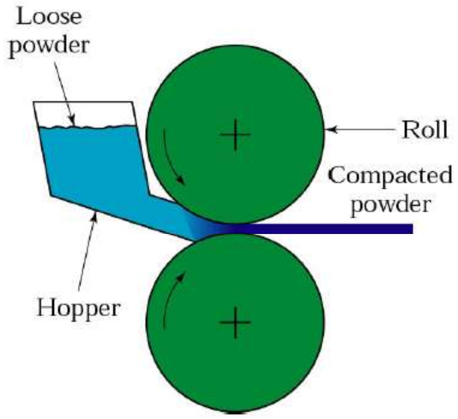

Figure 1.4.4: Roll compacting or powder rolling

The slip casting is then removed from the mould, dried and then sintered.

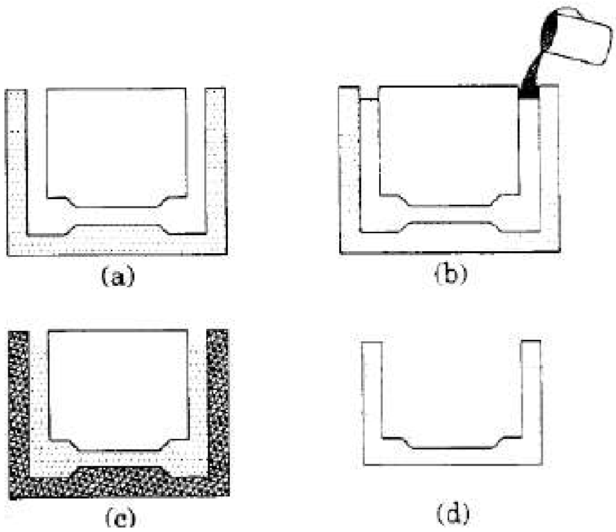

Figure 1.4.5: Principles of slip casting. (a.) Assembled mould (b.) Filling the mould (c.) Absorbing water from the slip (d.) Finished piece, removed from the mould and then trimmed

Figure 1.4.5 illustrates the principle stages of this method.

ii. **Gravity compaction**

The die is filled with loose powder and then heated to sintering temperature. The die is usually made of an inert material like graphite. Since pressure is not used during compacting, the parts produced are generally more porous. Commercially, this method is used for the production of P/M filters.

iii. **Continuous pressureless compaction**

In this process, the metal powder may be applied in the form of a slurry (similar to the slip in slip casting) to be coated on a metal screen or solid metal sheet for electrodes in nickel-cadmium rechargable batteries.

1.5 Sintering

Sintering is defined as the heating of loose or compact aggregate of metal powders below the melting point of the base metal with or without the application of external pressure in order to transform it to a more dense material by inter particle bonding. Sintering process is concerned with:

i. the diffusion of particle to particle

ii. the formation of grain boundary, and

iii. the closing of voids present in the green briquettes

In general density, mechanical strength, ductility, electrical and thermal conductivity increases with increased amount of sintering.

1.5.1 Types of sintering

Sintering is done in two different methods:

i. Solid phase sintering

ii. Liquid phase sintering

1. Solid phase sintering

This is the most widely used method. The sintering temperature is usually 60 - 80 % of the melting temperature of the lowest melting point constituent. Sintering is generally carried out in a controlled atmosphere furnace or occasionally in a vacuum furnace to prevent or reduce surface oxidation. A dry hydrogen atmosphere is used in the sintering of refractory carbides and electrical contacts. Nitrogen and methan are also used. The increased strength developed in the powder compact during sintering is due to the disappearance of the individual particle boundaries through solid state diffusion and recrystallisation. The rate of diffusion depends on:

i. The size of the particle

ii. The percentage of each metal present

iii. The temperature

The sintering process may increase rapidly above the recrystallisation temperature with an increase in strength and density ordinarily. The density of the compact is increased by sintering and shrinkage will occur. Shrinkage is associated with increase in areas of contact of the particle and reduction of the size of holes in the compact. Slow heating or degassing can be used to minimise problems associated with expansion.

2. Liquid phase sintering

Liquid phase sintering is carried out at a temperature at which a liquid phase exists. The sintering temperature may be above the melting point of one of the alloy constituents or above the melting point of an alloy formed during sintering. In the former case, liquid exists during the entire sintering operation, but in the latter case liquid is initially formed but disappears prior to completion of sintering. The density, strength and other properties of sintered compacts are dependent upon a number of factors like compacting pressure, sintering temperature and time.

Advantages of LPS

i. It produces very good density, because all the pores are filled by the liquid due to liquid-solid interfacial tensions.

ii. The rate of diffusion through the liquid phase and therefore the rate of alloying is greatly increased.

iii. It produces a more desirable metallurgical structure producing excellent mechanical properties.

1.6 Hot Pressing

In this method, the powder is placed into a die pressure and temperature is applied simultaneously. Moulding and sintering takes place at the same time, resulting into higher densities and greater productions.

Advantage

The advantage of hot pressing as compared with cold compacting and sintering are a reduction in gas content and shrinkage effects, along with higher strength, density, hardness and elongation.

Disadvantages

i. Hot pressing cannot be used for the production of very hard cemented-carbide parts.

ii. High cost of dies to withstand pressure at elevated temperatures.

1.7 Secondary Operations / Finishing

Powder metallurgy products are often ready to use when they emerge from the sintering furnace. Many P/M products, however, utilize one or more secondary operations to provide enhanced precision, improved properties, or special characteristics. Some finishing operations include:

(i) Sizing

(ii) Coining

(iii) Infiltration

(iv) Impregnation

(v) Heat treatment

1.7.1 Sizing

Sizing, which is a post-sintering operation, is used to correct size, distortion and other dimensional defects and improves surface finish and wear properties of the sized surface without producing large deformation and an appreciable increase in density. This is carried out by forcing the sintered components in a die of smaller dimensions, which plastically deforms and smoothens the faces in contact with the die.

1.7.2 Coining

The coining operation is carried out after sintering, produces the same results as the sizing operation and in addition, it improves density, hardness and strength and decreases the elongation of the part.

1.7.3 Infiltration

It involves preparing a porous metallic body or skeleton metal with high melting point and subsequently filling the pore of the skeleton with a molten metal (infiltrant) having lower melting point. In practice, this is done by immersing the porous skeleton metal in the molten infiltrant metal.

1.7.4 Impregnation

It is a process of completely filling or closing the voids and interconnected porosities in a P/M component. This is done for a variety of purposes such as lubrication, pressure tightness, plating, protection against corrosion.

1.7.5 Heat treatment

It involves heating and cooling a solid metal in such a way as to obtain desired conditions or properties like increased toughness, hardness, fatigue, strength, wear resistance. Heat treatment processes include carburizing and nitriding.

1.8 Applications of Powder Metallurgy

- Porous product (any degree of porosity can be provided. Eg filters flow regulators and bearing parts).
- Bearings for automobiles eg engine main bearing.
- Oil pump gears
- Cemented carbides (for cutting tools, wire drawing dies & deep drawing dies)
- Refractory metal composites. (jet engine nose cone crucible etc.)
- Diamond impregnated tools (e.g. glass cutter grinding wheel dressers etc.)
- Electrical contact materials (e.g. circuit breakers, resistance-welding electrodes, contact switches, carbon bushes etc.)
- Magnetic materials (e.g. pole piece of generators, motors transformer cores, computer memories hard discs etc.)

- Tungsten filaments used in incandescence bulbs.

1.9 Advantages of Powder Metallurgy

Like all other manufacturing processes, powder metallurgy has distinct advantages and disadvantages that should be considered if the technique is to be employed economically and successfully. Among the important advantages are these:

1. *Elimination or reduction of machining.* The dimensional accuracy and surface finish of P/M products are such that subsequent machining operations can be totally eliminated for many applications. If unusual dimensional accuracy is required, simple coining or sizing operations can often give accuracies equivalent to those of most production machining. Reduced machining is especially attractive for difficult-to-machine materials.

2. *High production rates.* All steps in the P/M process are simple and readily automated. Labour requirements are low, and product uniformity and reproducibility are among the highest in manufacturing.

3. *Complex shapes* can be produced such as combination gears, cams, and internal keys. It is often possible to produce parts by powder metallurgy that cannot be economically machined or cast.

4. *Wide variations in compositions are possible.* Parts of very high purity can be produced. Metals and ceramics can be intimately mixed. Immiscible materials can be combined, and solubility limits can be exceeded. Compositions are available that are virtually impossible with any other process. In most cases the chemical homogeneity of the product exceeds that of all competing techniques.

5. *Wide variations in properties are available.* Products can range from low-density parts with controlled permeability to high-density parts with properties that equal or exceed those of equivalent wrought counterparts. Damping of noise and vibration can be tailored into a P/M product. Magnetic properties, wear properties, friction characteristics, and others can all be designed to match the needs of a specific application.

6. *Scrap is eliminated or reduced.* Powder metallurgy is the only common manufacturing process in which no material is wasted. In casting, machining, and press forming, the scrap can often exceed 50% of the starting material. This is particularly important where expensive materials are involved, and powder metallurgy may make it possible to use more costly materials without increasing the overall cost of the product. An example of such a product would be the rare earth magnets.

1.10 Disadvantages of Powder Metallurgy

1. *Inferior strength properties.* Because of the residual porosity, powder metallurgy parts generally have mechanical properties that are inferior to wrought or cast products of the same material. Their use may be limited when high stresses are involved. The required strength and fracture resistance, however, can often be obtained by using different materials or by employing alternate or secondary processing techniques that are unique to powder metallurgy.

2. *Relatively high tooling cost.* Because of the high pressures and severe abrasion involved in the process, the P/M dies must be made of expensive materials and be relatively massive. Because of the need for part-specific tooling, production quantities of less than 10,000 identical parts are normally not practical.

3. *High material cost.* On a unit weight basis, powdered metals are considerably more expensive than wrought or cast stock. However, the absence of scrap and the elimination of machining can often offset the higher cost of the starting material. In addition, powder metallurgy is usually employed for rather small parts where the material cost per part is not very great.

4. *Size and shape limitations.* The powder metallurgy process is simply not feasible for many shapes. Parts must be able to be ejected from the die. The thickness/diameter (or thickness/width) ratio is limited. Thin vertical sections are difficult, and the overall size must be within the capacity of available presses.

5. *Dimensions change during sintering.* While the actual amount depends on a variety of factors, including as-pressed density, sintering temperature, and sintering time, dimensional change can often be predicted and controlled.

6. *Density variations produce property variations.* Any non-uniform product density that is produced during compacting generally results in property variations throughout the part. For some products, these variations may be unacceptable.

7. *Health and safety hazards.* Many metals, such as aluminium, titanium, magnesium, and iron, are pyrophoric they can ignite or explode when in particle form with large surface/volume ratios. Fine particles can also remain airborne for long times and can be inhaled by workers. To minimize the health and safety hazards, the handling of metal powders frequently requires the use of inert atmospheres, dry boxes, and hoods, as well as special cleanliness of the working environment

Chapter 2

Specialized machining processes

Traditional, also termed conventional, machining requires the presence of a tool that is harder than the workpiece to be machined. This tool should be penetrated in the workpiece to a certain depth. Moreover, a relative motion between the tool and workpiece is responsible for forming or generating the required shape. The absence of any of these elements in any machining process such as the absence of tool-workpiece contact or relative motion, makes the process a non-traditional one, also known as specialized machining process. Non-traditional manufacturing processes is therefore defined as a group of processes that remove excess material by various techniques involving mechanical, thermal, electrical or chemical energy or combinations of these energies but do not use a sharp cutting tools as it needs to be used for traditional manufacturing processes. Figure 2.0.1 shows the classification of material removal processes.

The non-traditional machining methods are classified according to the machining actions causing the removal of material from the workpiece. This is illustrated in Figure 2.0.2.

2.1 Ultrasonic Machining

Ultrasonic machining (USM) is the removal of hard and brittle materials using an axially oscillating tool at ultrasonic frequencies [18 - 20 kilohertz (kHz)]. During that oscillation, the abrasive slurry of B_4C or SiC is continuously fed into the machining

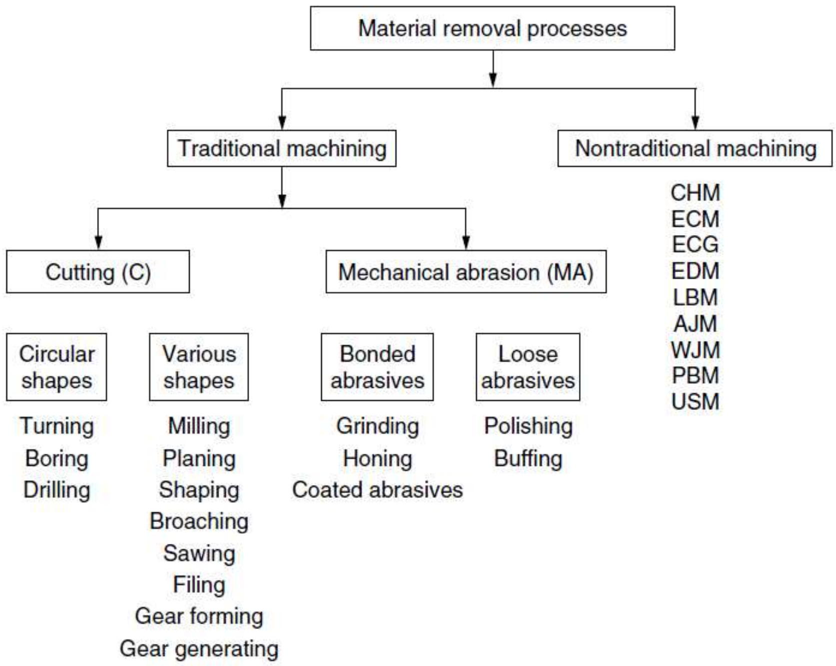

Figure 2.0.1: Material removal processes

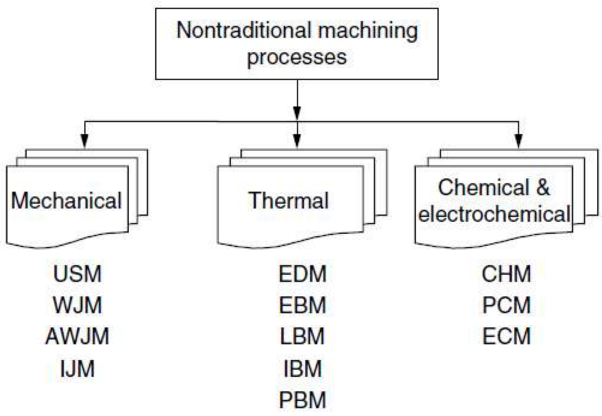

Figure 2.0.2: Non-traditional machining processes.

zone between a soft tool (brass or steel) and the workpiece. The abrasive particles are, therefore, hammered into the workpiece surface and cause chipping of fine particles from it. The oscillating tool, at amplitudes ranging from 10 to 40 μm, imposes a static pressure on the abrasive grains and feeds down as the material is removed to form the required tool shape.

2.1.1 The machining system

The machining system, shown in Figure 2.1.1 is composed mainly of the magnetostrictor, concentrator, tool, and slurry feeding arrangement. The magnetostrictor is energized at the ultrasonic frequency and produces small-amplitude vibrations. Such a small vibration is amplified using the concentrator (mechanical amplifier) that holds the tool. The abrasive slurry is pumped between the oscillating tool and the brittle workpiece. A static pressure is applied in the tool-workpiece interface that maintains the abrasive slurry.

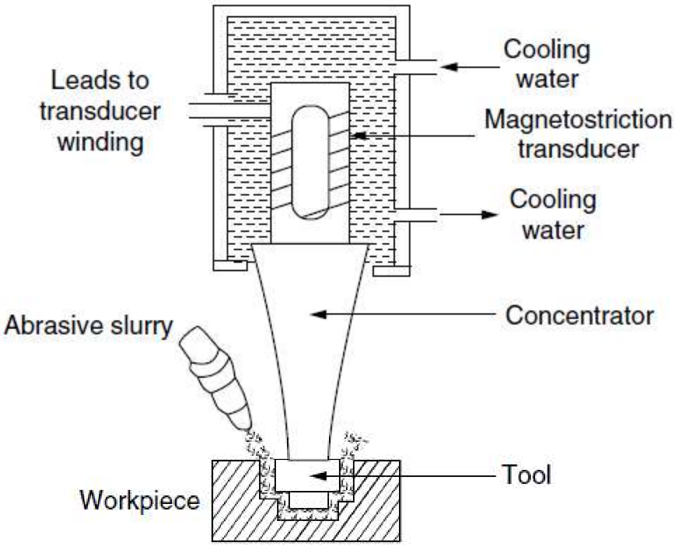

Figure 2.1.1: Main elements of an ultrasonic machining system.

Abrasive slurry is usually composed of 50 percent (by volume) fine abrasive grains (100-800 grit number) of boron carbide (B_4C), aluminum oxide (Al_2O_3), or silicon carbide (SiC) in 50 percent water. The abrasive slurry is circulated between the oscillating tool and workpiece.

2.1.2 Factors affecting material removal rate

i. **Tool oscillation**: The amplitude of the tool oscillation has the greatest effect of all the process variables. The material removal rate increases with a rise in the amplitude of the tool vibration. The vibration amplitude determines the velocity of the abrasive particles at the interface between the tool and workpiece. Under such circumstances the kinetic energy rises, at larger amplitudes, which enhances the mechanical chipping action and consequently increases the removal rate.

ii. **Abrasive grains**: Both the grain size and the vibration amplitude have a similar effect on the removal rate. The removal rate rises at greater grain sizes until the size reaches the vibration amplitude, at which stage, the material removal rate decreases. When the grain size is large compared to the vibration amplitude, there is a difficulty of abrasive renewal in the machining gap. Water is commonly used as the abrasive carrying liquid for the abrasive slurry while benzene, glycerol, and oils are alternatives. The increase of slurry viscosity reduces the removal rate. The improved flow of slurry results in an enhanced machining rate.

iii. **Workpiece impact-hardness**: The machining rate is affected by the ratio of the tool hardness to the workpiece hardness. In this regard, the higher the ratio, the lower will be the material removal rate. For this reason soft and tough materials are recommended for USM tools.

iv. **Tool shape**: The machining rate is affected by the tool shape and area. An increase in the tool area decreases the machining rate due to the problem of adequately distributing the abrasive slurry over the entire machining zone.

2.1.3 Applications of Ultrasonic machining

i. **Drilling and coring**

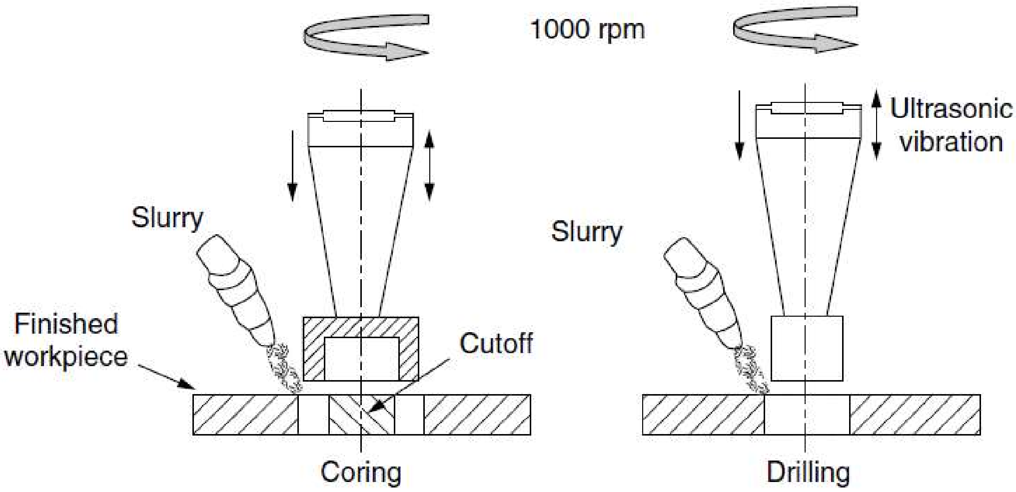

Figure 2.1.2: Rotary USM.

Figure 2.1.2 shows the rotary ultrasonic machining (RUM) where a tool bit is rotated against the workpiece in a similar fashion to conventional drilling. RUM ensures high removal rates, lower tool pressures for delicate parts, improved deep hole drilling, less breakout or through holes, and no core seizing during core drilling.

ii. **Ultrasonic sinking and contour machining**

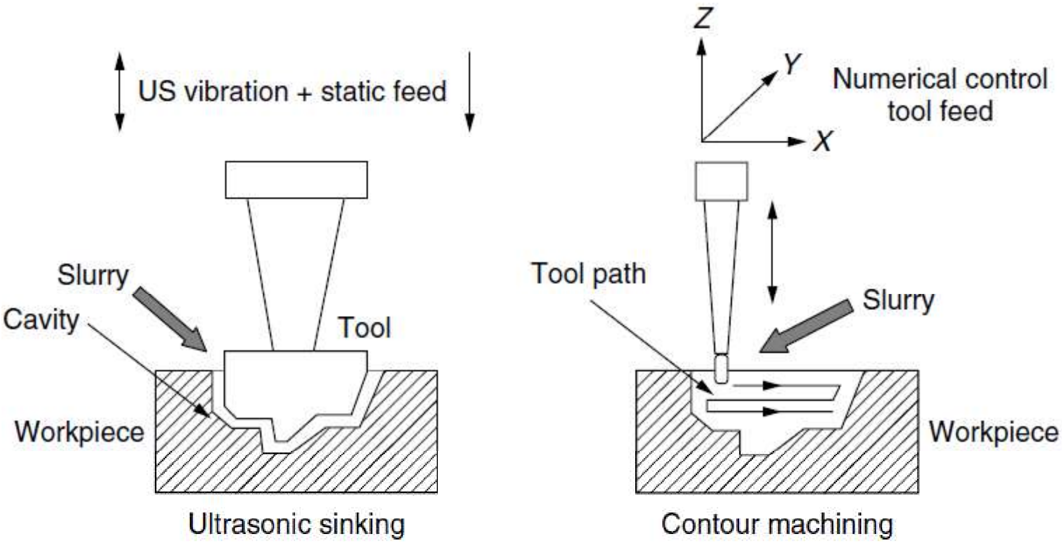

Figure 2.1.3: Ultrasonic sinking and contour machining

Figure 2.1.3 shows ultrasonic sinking and contour machining. During USM sinking, the material removal is difficult when the machined depth exceeds 5 to 7 mm, therefore the depth should not exceed 5 mm. Contouring USM employs simple tools that are moved in accordance to the contour required.

iii. **Production of EDM electrodes**

Figure 2.1.4: Graphite EDM electrodes machined by USM

USM is used to produce graphite EDM electrodes as shown in Figure 2.1.4. Typical ultrasonic machining speeds, in graphite, range from 0.4 to 1.4 centimeters per minute (cm/min). Small machining forces permit the manufacture of fragile graphite EDM electrodes.

iv. **Ultrasonic polishing**

Ultrasonic polishing occurs by vibrating a brittle tool material such as graphite or glass into the workpiece at an ultrasonic frequency and a relatively low vibration amplitude.

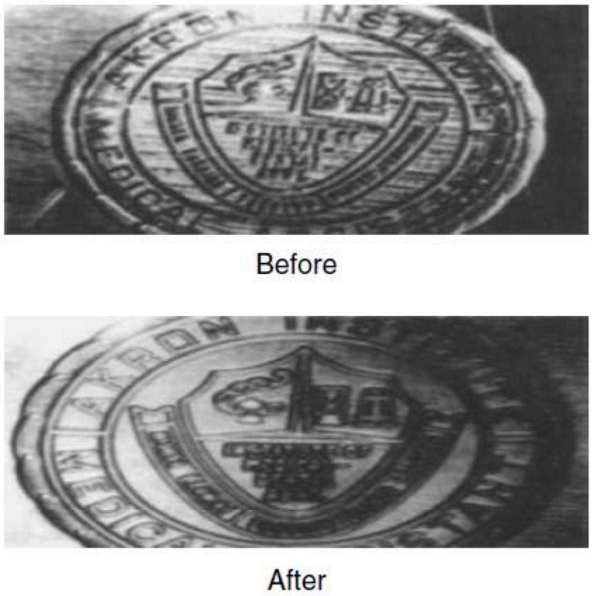

Figure 2.1.5: Ultrasonic polishing of CNC machined parts

v. **Micro-ultrasonic machining.** Micro-ultrasonic machining (MUSM) is a method that utilizes workpiece vibration. Using MUSM, microholes of 5 μm diameter on quartz, glass, and silicon have been produced using tungsten carbide (WC) alloy microtools.

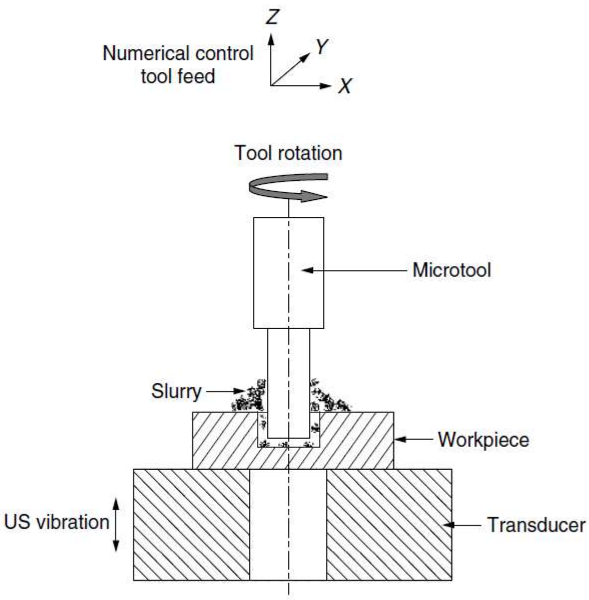

Figure 2.1.6: Micro-ultrasonic machining

2.2 Abrasive Jet Machining

In abrasive jet machining (AJM) a focused stream of abrasive grains of Al_2O_3 or SiC carried by high-pressure gas or air at a high velocity is made to impinge on the work surface through a nozzle of 0.3 - 0.5 mm diameter. The workpiece material is removed by the mechanical abrasion (MA) action of the high-velocity abrasive particles. AJM machining is best suited for machining holes in superhard materials. It is typically used to cut, clean, peen, deburr, deflash, and etch glass, ceramics, or hard metals.

2.2.1 Machining system

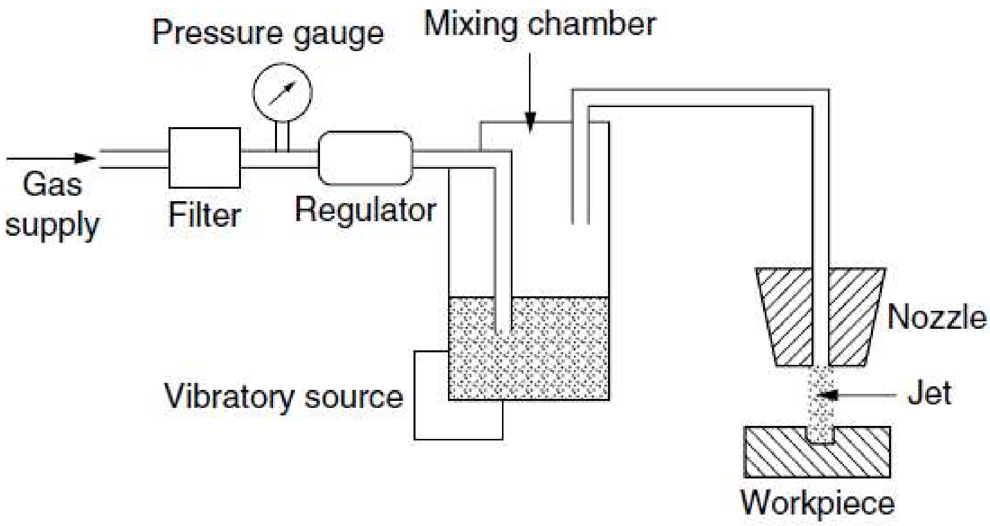

Figure 2.2.1: AJM system

In the machining system shown in Figure 2.2.1, a gas (nitrogen, CO_2, or air) is supplied under a pressure of 2 to 8 kg/cm^2. Oxygen should never be used because it causes a violent chemical reaction with workpiece chips or abrasives. After filtration and regulation, the gas is passed through a mixing chamber that contains abrasive particles and vibrates at 50 Hz. From the mixing chamber, the gas, along with the entrained abrasive particles (10 - 40 μm), passes through a 0.45 mm diameter tungsten carbide nozzle at a speed of 150 to 300 m/s. The abrasive powder feed rate is controlled by the amplitude of vibrations in the mixing chamber. The nozzle standoff distance is 0.81 mm. The relative motion between the workpiece and the nozzle is manually or automatically controlled using cam drives, pantographs, tracer mechanisms, or using computer control according to the cut geometry required.

The material removal rate, cut accuracy, surface roughness, and nozzle wear are influenced by the size and distance of the nozzle; composition, strength, size, and shape of abrasives; flow rate; and composition, pressure, and velocity of the carrier gas.

2.2.2 Applications of abrasive jet machining

1. Drilling holes, cutting slots, cleaning hard surfaces, deburring, polishing, and radiusing.

2. Machining intricate shapes or holes in sensitive, brittle, thin, or difficult-to-machine materials.

3. Insulation stripping and wire cleaning without affecting the conductor.

4. Micro-deburring of hypodermic needles.

5. Frosting glass and trimming of circuit boards, hybrid circuit resistors, capacitors, silicon, and gallium.

6. Removal of films and delicate cleaning of irregular surfaces because the abrasive stream is able to follow contours

2.3 Chemical Milling

Chemical milling (CHM) is the controlled chemical dissolution (CD) of the workpiece material by contact with a strong reagent. Special coatings called maskants protect areas from which the metal is not to be removed. The process is used to produce pockets and contours and to remove materials from parts having a high strength-to-weight ratio. CHM consists of the following steps:

1. Preparing and precleaning the workpiece surface to provides good adhesion of the masking material and assure the absence of contaminants.

2. Masking using readily strippable mask, which is chemically impregnable and adherent enough to stand chemical abrasion during etching.

3. Scribing of the mask, which is guided by templates to expose the areas that receive CHM.

4. The workpiece is then etched and rinsed, and the mask is removed before the part is finished.

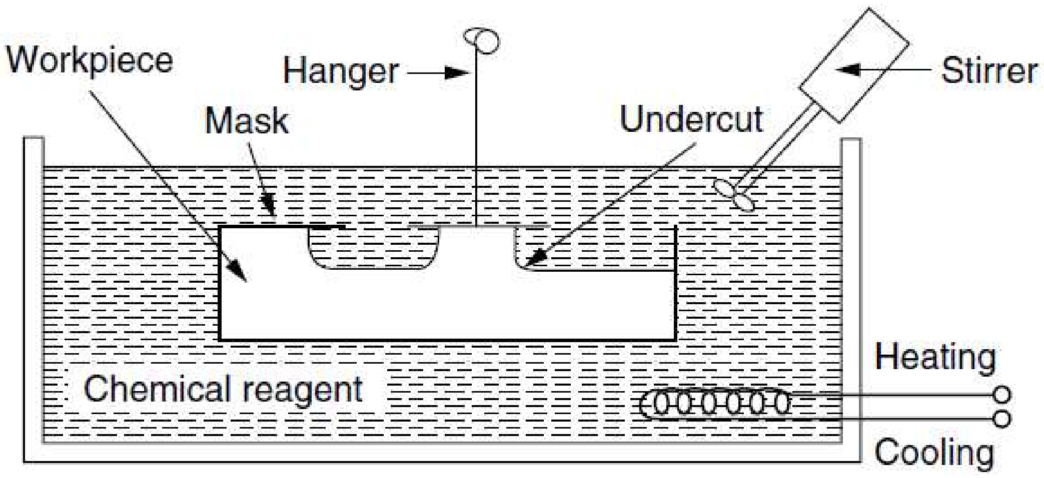

Figure 2.3.1: CHM setup

Figure 2.3.1 shows a set-up of the chemical milling process. The depth of the etch is controlled by the time of immersion. In order to avoid uneven machining, the chemicals that impinge on the surface being machined should be fresh. The chemicals used are very corrosive and, therefore, must be handled with adequate safety precautions.

2.3.1 Tooling for CHM

Tooling for CHM is relatively inexpensive and simple to modify. Four different types of tools are required: maskants, etchants, scribing templates, and accessories.

Maskants: Maskants are generally used to protect parts of the workpiece where CD action is not needed. Synthetic or rubber base materials are frequently used. Maskants should, however, possess the following properties:

1. Be tough enough to withstand handling

2. Adhere well to the workpiece surface

3. Scribe easily

4. Be inert to the chemical reagent used

5. Be able to withstand the heat generated by etching

6. Be removed easily and inexpensively after etching

Etchants: Etchants are acid or alkaline solutions maintained within a controlled range of chemical composition and temperature. Their main technical goals are to achieve the following:

1. Good surface finish
2. Uniformity of metal removal
3. Control of selective and inter-granular attack
4. Control of hydrogen absorption in the case of titanium alloys
5. Maintenance of personal safety
6. Best price and reliability for the materials to be used in the construction of the process tank.
7. Maintenance of air quality and avoidance of possible environmental problems.
8. Low cost per unit weight dissolved.
9. Ability to regenerate the etchant solution and/or readily neutralize and dispose of its waste products.

Scribing templates: Scribing templates are used to define the areas for exposure to the chemical machining action. The most common workpiece scribing method is to cut the mask with a sharp knife followed by careful peeling of the mask from the selected areas. Layout lines or simple templates of metal or fiberglass guide the scribing process.

Accessories: Accessories include tanks, hooks, brackets, racks, and fixtures. These are used for single - or multiple -piece handling into and out of the etchants and rinses.

2.3.2 Process parameters

CHM process parameters include the reagent solution type, concentration, properties, mixing, operating temperature, and circulation. The process is also affected by the maskant and its application. These parameters will have direct impacts on the workpiece regarding the following: etch factor (d/T), etching and machining rate, production tolerance and surface finish.

2.3.3 Applications

All the common metals including aluminium, copper, zinc, steel, lead, and nickel can be chemically machined. Many exotic metals such as titanium, molybdenum, and zirconium, as well as non-metallic materials including glass, ceramics, and some plastics, can also be used with the process. CHM applications range from large aluminium airplane wing parts to minute integrated circuit chips.

2.4 Electrochemical Machining

Electrochemical machining (ECM) is a modern machining process that relies on the removal of workpiece atoms by electrochemical dissolution (ECD) in accordance with the principles of Faraday. In this process, particles travel from the anodic material (workpiece) toward the cathodic material (machining tool). A current of electrolyte fluid carries away the deplated material before it has a chance to reach the machining tool. The cavity produced is the female mating image of the tool shape. The work-

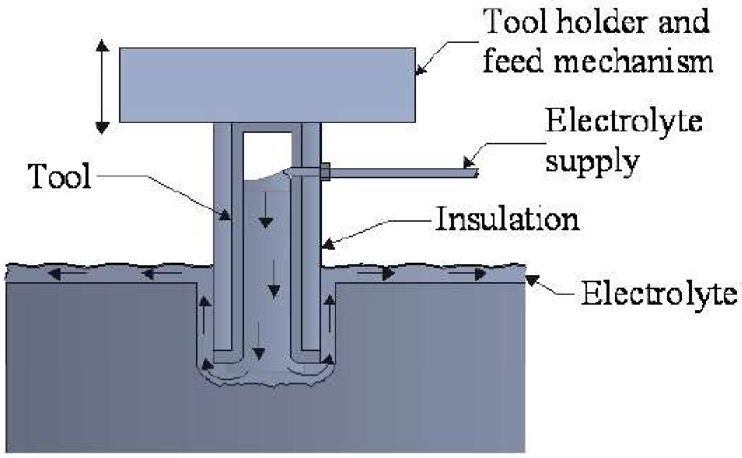

Figure 2.4.1: ECM process

piece hardness is not a factor, making ECM suitable for machining difficult-to-machine materials. A schematic representation of ECM process is shown in Figure 2.4.1. The ECM tool is positioned very close to the workpiece and a low voltage, high amperage DC current is passed between the workpiece and electrode. Some of the shapes made by ECM process are shown in Figure 2.4.2.

Figure 2.4.2: Parts made by ECM

2.4.1 Advantages of ECM

- The components are not subject to either thermal or mechanical stress.
- No tool wear during ECM process.
- Fragile parts can be machined easily as there is no stress involved.
- ECM deburring can debur difficult to access areas of parts.
- High surface finish (up to 25 μ m) can be achieved by ECM process.
- Complex geometrical shapes in high-strength materials particularly in the aerospace industry for the mass production of turbine blades, jet-engine parts and nozzles can be machined repeatedly and accurately.
- Deep holes can be made by this process.

2.4.2 Limitations of ECM

- ECM is not suitable to produce sharp square corners or flat bottoms because of the tendency for the electrolyte to erode away sharp profiles.
- ECM can be applied to most metals but, due to the high equipment costs, is usually used primarily for highly specialised applications.

Material removal rate, MRR, in electrochemical machining:

MRR = C .I. h (cm^3/min) C: specific (material) removal rate (e.g., 0.2052 cm^3/amp-min for nickel);

I: current (amp);

h: current efficiency (90 - 100%).

The rates at which metal can be electrochemically removed are in proportion to the current passed through the electrolyte and the elapsed time for that operation. Many factors other than current influence the rate of machining. These involve electrolyte type, rate of electrolyte flow and some other process conditions.

2.4.3 Applications:

ECM has been used in a wide variety of industrial applications ranging from cavity sinking to deburring. The ability to machine high-strength alloys and hardened steel has led to many cost-saving applications where other processes are impractical. Typical applicators for the ECM process are shown in Figure 2.4.2.

2.5 Electrodischarge Machining (EDM)

In EDM, the removal of material is based upon the electrodischarge erosion (EDE) effect of electric sparks occurring between two electrodes that are separated by a dielectric liquid. Metal removal takes place as a result of the generation of extremely high temperatures generated by the high-intensity discharges that melt and evaporate the two electrodes.

2.5.1 The machining system

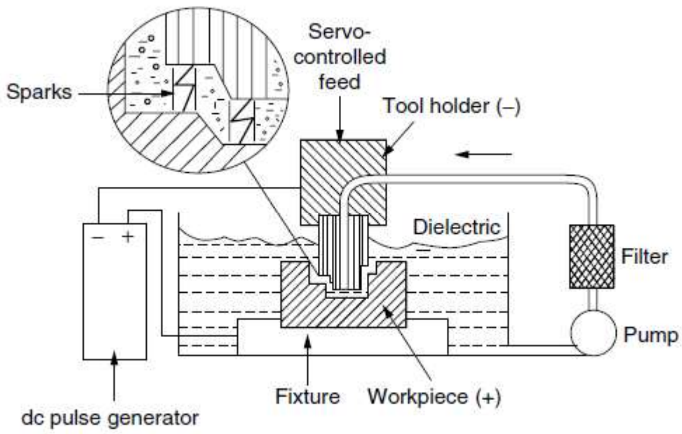

Figure 2.5.1: EDM schematic

Figure 2.5.1 shows the main components of the EDM system. These components include the tool feed servo-controlled unit, which maintains a constant machining gap that ensures the occurrence of active discharges between the two electrodes. The power supply is responsible for supplying pulses at a certain voltage, current, on time and off time. The dielectric circulation unit flushes the dielectric fluid to the inter-electrode gap after being filtered from the machining debris.

EDM Electrodes: Metals with a high melting point and good electrical conductivity are usually chosen as tool materials for EDM. Common materials used are: Graphite, copper, copper tungsten, silver tungsten, steel, brass etc.

Dielectric fluids: The main functions of the dielectric fluid are to:

1. Flush the eroded particles from the machining gap.

2. Provide insulation between the electrode and the workpiece.

3. Cool the section that was heated by the discharging effect.

Process Parameters: The performance of EDM is determined by three main properties, i.e., material removal rate, surface quality and accuracy. These are determined by the process parameters such as: pulse characteristics, workpiece thermal properties (melting and boiling point, conductivity), dielectric properties, tool electrode (material, movement, wear).

2.5.2 Application

EDM has become an indispensable process in the modern manufacturing industry. It produces complex shapes to a high degree of accuracy in difficult-to-machine materials such as heat-resistant alloys, superalloys, and carbides. The incorporation of EDM within a computer integrated manufacturing (CIM) system reduces the length of time that the unit operates without stops for maintenance. Typical applications include:

- Micro-EDM: Micromachining of holes, slots, and dies.
- EDM drilling such as the creation of cooling channels in turbine blades made of hard alloys.
- ED sawing where billets and bars are created.

- Machining of spheres, dies and molds
- Wire EDM a special form of EDM which uses a continuously moving conductive wire electrode. It is used in the machining of superhard materials such as polycrystalline diamond (PCD) and cubic boron nitride (CBN) blanks, and other matrix composites.
- EDM of insulating ceramics.
- Texturing: Texturing is applied to the steel sheets during the final stages of cold rolling

2.6 Laser Beam Machining

Laser is the abbreviation of light amplification by stimulated emission of radiation. A highly collimated, monochromatic, and coherent light beam is generated and focused to a small spot. High power densities (10^6 W/mm^2) are then obtained. Laser beam machining (LBM) uses the light energy from a laser to remove material by vaporization and ablation.

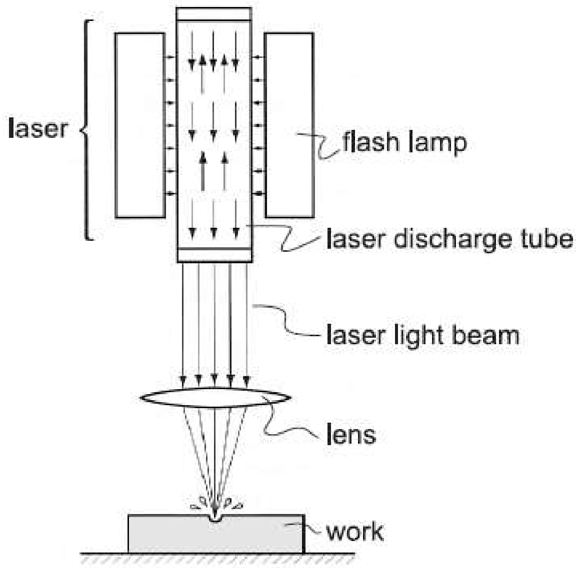

Figure 2.6.1: The set-up of laser beam machining process.

The types of lasers used in LBM are basically the carbon dioxide (CO_2) gas lasers. Lasers produce collimated monochromatic light with constant wavelength. In the laser beam, all of the light rays are parallel, which allows the light not to diffuse quickly like normal light. The light produced by the laser has significantly less power than a normal white light, but it can be highly focused, thus delivering a significantly higher light intensity and respectively temperature in a very localized area.

Materials: The range of work materials that can be machined by LBM is virtually unlimited including metals with high hardness and strength, soft metals, ceramics, glass, plastics, rubber, cloth, and wood.

2.6.1 Applications

Lasers are being used for a variety of industrial applications, including heat treatment, welding, and measurement, as well as a number of cutting operations such as drilling, slitting, slotting, and marking operations. Drilling small-diameter holes is possible, down to 0.025 mm. For larger holes, the laser beam is controlled to cut the outline of the hole.

LBM can be used for 2D or 3D workspace. The LBM machines typically have a laser mounted, and the beam is directed to the end of the arm using mirrors. Mirrors are often cooled (water is common) because of high laser powers.

2.7 Electron beam machining (EBM)

Electron beam machining uses a high-velocity stream of electrons focused on the workpiece surface to remove material by melting and vaporization.

2.7.1 Basic equipment and removal mechanism

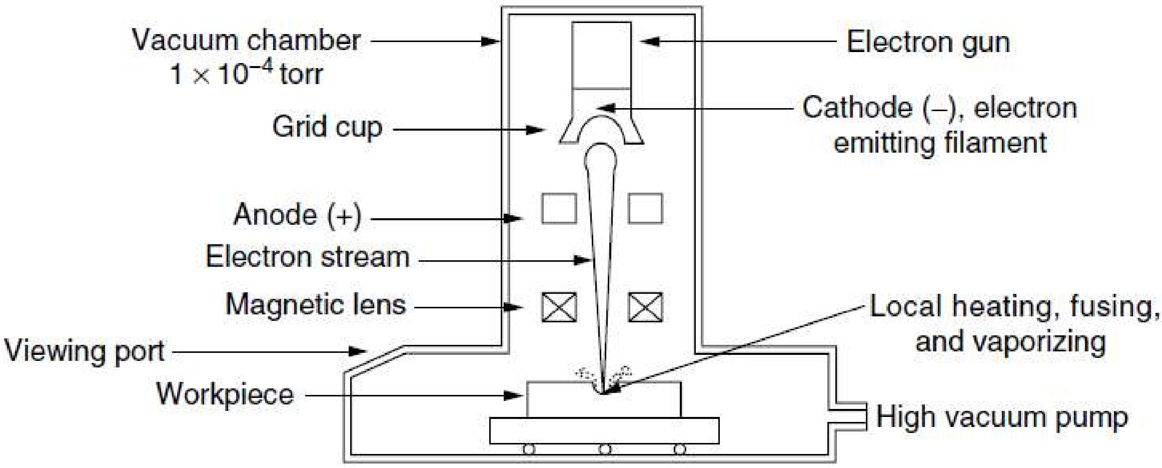

Figure 2.7.1: Components of an EBM system.

An electron beam gun generates a continuous stream of electrons that are focused through an electromagnetic lens on the work surface. The electrons are accelerated with voltages of approx. 150,000 V to create velocities over 200,000 km/s. The lens is capable of reducing the area of the beam to a diameter as small as 0.025 mm. On impinging the surface, the kinetic energy of the electrons is converted into thermal energy of extremely high density, which vaporizes the material in a very localized area. EBM must be carried out in a vacuum chamber to eliminate collision of the electrons with gas molecules.

Electron beam machining is used for a variety of high-precision cutting applications on any known material. Applications include drilling of extremely small diameter holes, down to 0.05 mm diameter, drilling of holes with very high depth-to-diameter ratios, more than 100:1, and cutting of slots that are only about 0.025 mm wide. Besides machining, other applications of the technology include heat treating, integrated circuit fabrication and welding.

The process is generally limited to thin parts in the range from 0.2 to 6 mm thick. Other limitations of EBM are the need to perform the process in a vacuum, the high energy required, and the expensive equipment.

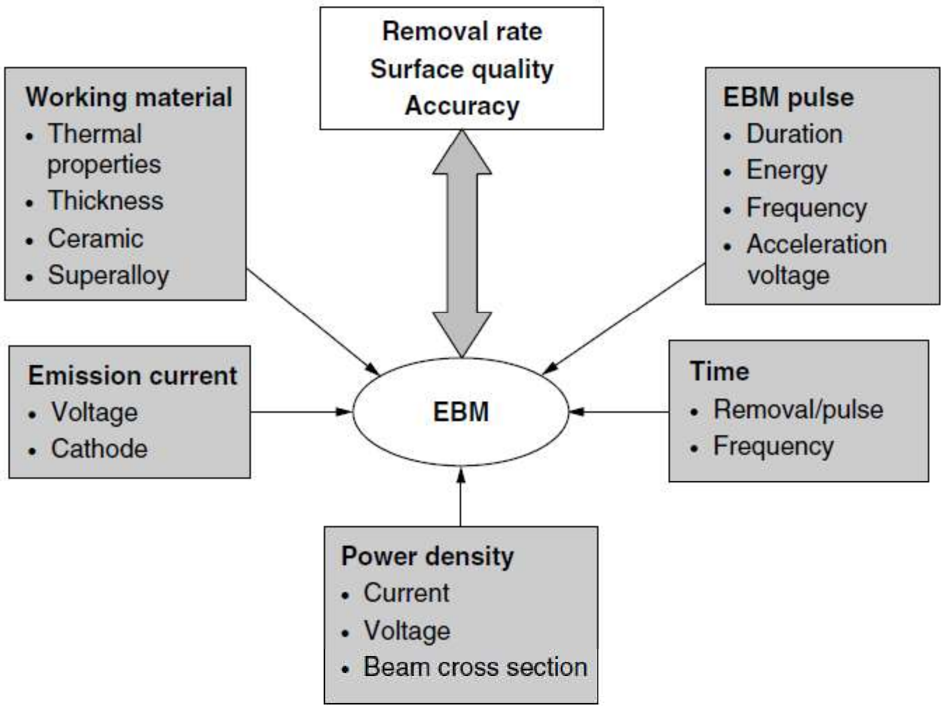

Figure 2.7.2: Parameters affecting EBM performance.

2.8 Plasma Beam Machining

When the temperature of a gas is raised to about 2000 °C, the gas molecules become dissociated into separate atoms. At higher temperatures, 30,000 °C, these atoms become ionized. The gas in this stage is termed plasma.

In plasma machining a continuous arc is generated between a hot tungsten cathode and the water-cooled copper anode. A gas is introduced around the cathode and flows through the anode. The temperature, in the narrow orifice around the cathode, reaches 28,000 °C, which is enough to produce a high-temperature plasma arc. Under these conditions, the metal being machined is very rapidly melted and vaporized. The stream of ionized gases flushes away the machining debris as a fine spray creating flow lines on the machined surface.

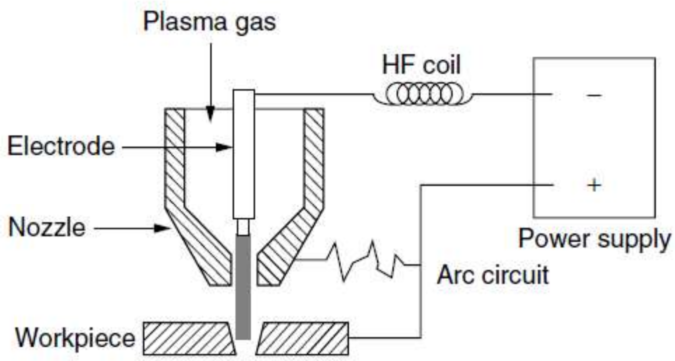

Figure 2.8.1: Transferred plasma arc system

2.8.1 Applications

1. PBM is an attractive turning method for difficult-to-machine materials by conventional methods.

2. Computer numerical controlled PBM is used for profile cutting of metals that are difficult to tackle by oxyacetylene gas technique such as stainless steel and aluminium.

3. PBM can cut 1.5-mm-deep, 12.5-mm-wide grooves in stainless steel at 80 mm3/min, using 50 kW as the cutting power. Such a high machining rate is 10 times the rate of grinding and chipping methods.

4. The process is recommended for parts that have subsequent welding operations.

5. A plasma arc can cut tubes of wall thickness of up to 50 mm. In this case no deburring is required before tube welding.
6. Underwater NC plasma cutting can achieve machining accuracy of $\pm$ 0.2 mm in 9 m at low cutting speeds.

Chapter 3

Welding and fabrication techniques

Welding is a process for joining two similar or dissimilar metals by fusion. It joins different metals/alloys, with or without the application of pressure and with or without the use of filler metal. The fusion of metal takes place by means of heat. The heat may be generated either from combustion of gases, electric arc, electric resistance, chemical reaction, frictional heat, or by sound and light energy. The gas flame welding which was first known to the welding engineer is no longer satisfactory and hence scientist invented advance method such as TIG, MIG,PAW,EBW,LBW.

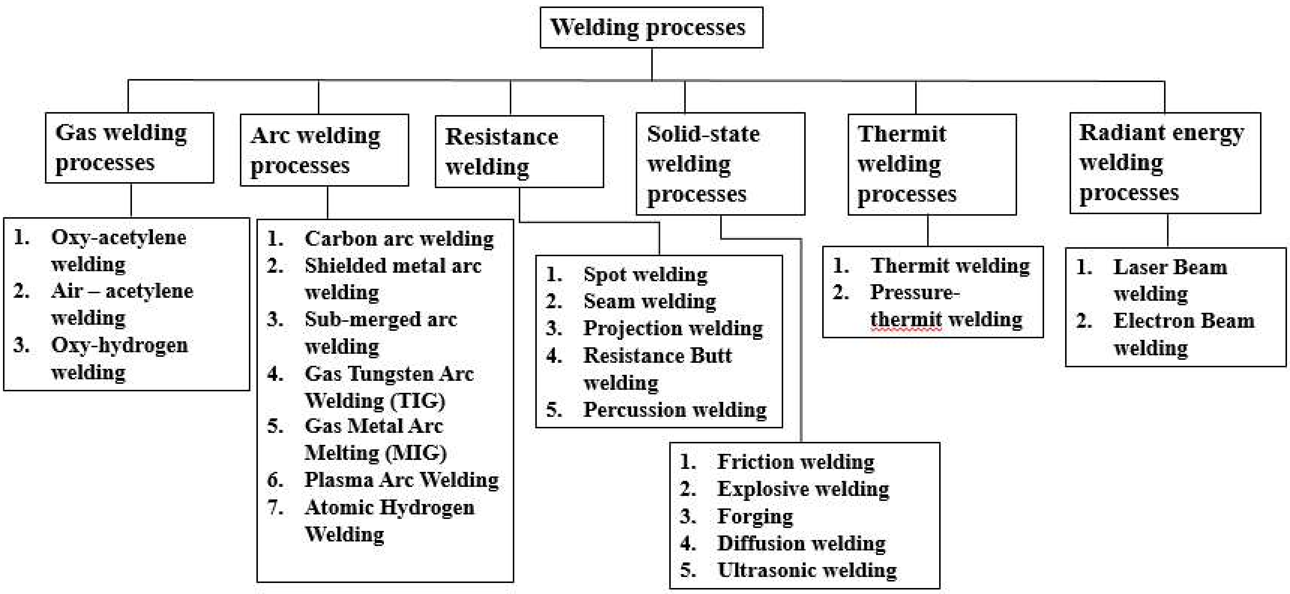

Figure 3.0.1: Welding processes

3.1 Forge welding

Forge welding is a solid state welding process in which two pieces of metal are joined by heating them to a high temperature and then hammering them together. This heating deforms the work pieces plastically. Now a repeated hammering or high pressurize load is applied on these plates together. Due to this high pressure and temperature, inter-molecular diffusion takes place at the interface surface of the plates which make a strong weld joint. One of the basic requirement of this types of welding, is clean interface surface which should be free from oxide or other contaminant particles. To prevent the welding surface from oxidation, flux is used which mixes with the oxide and lower down its melting temperature and viscosity. This allow to flow out the oxide layer during heating and hammering process.

3.1.1 Working

Forge welding was one of the most applied welding method in ancient time. This is a fundamental welding process of all solid state welding. Its working can be summarized as follow:

- First both the work plates are heated together. The heating temperature is about 50 to 90% of its melting temperature. Both the plates are coated with flux.
- Manual hammering is then done by a blacksmith hammer on an anvil for making a joint. This process is repeated until a proper joint is created.
- For welding large work pieces, mechanical hammering is used which is either driven by electric motor or by using hydraulic means. Sometime dies are used which provides finished surface.

3.1.2 Application

- It is used to join steel or iron.
- It is used to manufacture gates, prison cells etc.
- It is widely used in cookware.
- It was used to join boiler plates before introduction of other welding process.

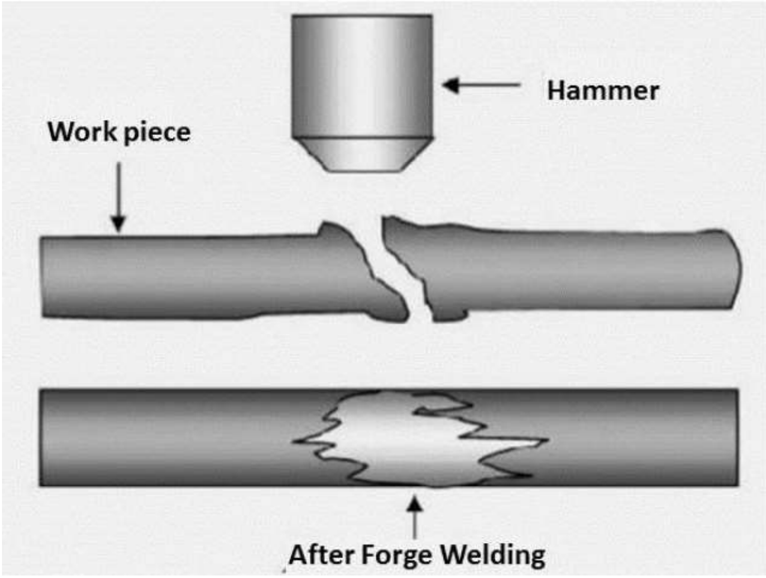

Figure 3.1.1: Schematic representation of forge welding using hammer

- It was used to weld weapons like swords etc.
- Used to weld shotgun barrels.

3.1.3 Advantages and Disadvantages

Advantages

- It is a simple and easy joining process.
- It does not require any costly equipment for welding small pieces.
- It can weld both similar and dissimilar metals.
- Properties of weld joint are similar to those of the base material.
- No filler material is required.

Disadvantages

- Only small objects can be welded. Large objects will require large pressing machines and heating furnaces.
- High skill is required because excessive hammering can damage the welding plates.
- High welding defects involved.
- It is a slow welding process therefore not suitable for mass production.

3.2 Tungsten Inert Gas Welding

Tungsten Inert Gas (TIG) or Gas Tungsten Arc (GTA) welding is the arc welding process in which arc is generated between non consumable tungsten electrode and work piece. The tungsten electrode and the weld pool are shielded by an inert gas normally argon and helium.

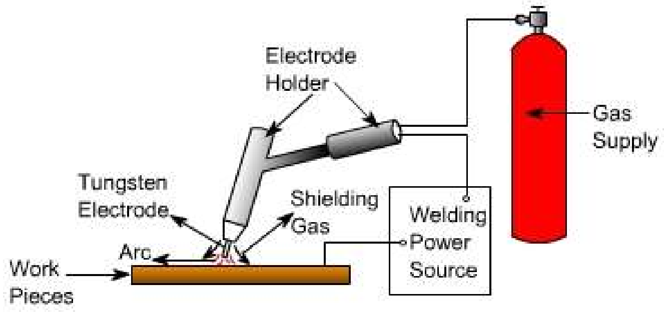

Figure 3.2.1: Schematic diagram of TIG welding system

Argon is most widely than helium because it is a heavier gas, producing better shielding at lower flow rate. The shielding gas displaces the air surrounding the arc and weld pool. This prevents the contamination of weld metal by oxygen and nitrogen in the air. Filler metal may or may not be used. When a filler metal rod is used, it is usually fed manually into the weld pool. Electrode used in this process are made up of tungsten and tungsten alloys. The tungsten electrode is used only to generate an arc. The arc does not melt the tungsten, which has melting point above 3300 °C.

The TIG torch is moved along the groove steadily to effect the welding and complete the joint. The TIG process is used for welding aluminum and its alloy, stainless steel, magnesium alloy nickel base alloy, copper base alloy, carbon steel and low alloy steel.

3.2.1 Advantages

1. It produces high quality weld in nonferrous metals.

2. Practically no weld cleaning is necessary.

3. The arc and weld pool are clearly visible to the welder.

3.2.2 Disadvantages

1. Deposition rates are lower and hence completion time for weld joint is longer than in other process.
2. The welding cost is more because it uses argon gas for shielding.
3. Skill is required.

3.2.3 Application

1. The aerospace industry is one of the primary users of gas tungsten arc welding.
2. Many industries use GTAW for welding thin work pieces, especially nonferrous metals.
3. It is used extensively in the manufacture of space vehicles, and is also frequently employed to weld small-diameter, thin-wall tubing such as those used in the bicycle industry.

3.3 Plasma Arc Welding

Plasma arc welding (PAW) is an arc welding process in which welding heat is obtained from a constricted arc set up between a tungsten electrode and the job. The process employs two inert gases, one forms the arc plasma and the second shields the arc plasma. Filler metal may or may not be added.

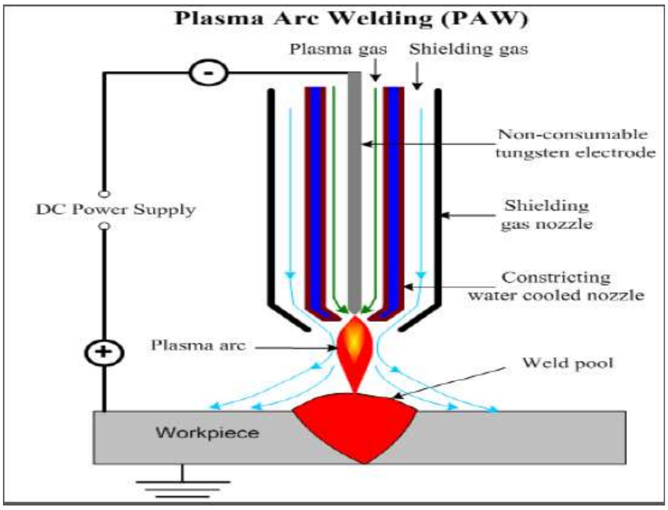

Figure 3.3.1: Schematic diagram of plasma arc welding system

3.3.1 Principle of PAW

A small amount of pure argon gas flow is allowed through the inner orifice surrounding the tungsten electrode to form the plasma gas. Because of the squeezing action of the constricting nozzle, the arc is concentrated and straight. This increases the heat contained per unit volume of the arc plasma so arc temperature of the order of 11000 °C can be obtained.

Plasma arc welding process can be divided into two basic types:

1. **Non-transferred arc process:** The arc is formed between the electrode (-ve) and water cooled constricting nozzle (+ve). Arc plasma comes out of the nozzle as a flame.
2. **Transferred arc process:** The arc is formed between the electrode (-ve) and the workpiece (+ve). In other words the arc is transferred from electrode to the workpiece.

3.3.2 Advantages of PAW

- Stability of arc
- Uniform penetration
- Simplified fixture
- Excellent weld quality
- Rewelding of the root of the joint saved

3.3.3 Disadvantages of PAW

- Welders need ear plugs because of unpleasant, disturbing and damaging noise.
- Risk of electrical hazards
- Inert gas consumption is high
- Skilled welder required.

3.3.4 Applications

- Tube mill application
- Welding of stainless steel tubes
- For welding high melting point metals

3.4 Resistance Welding

Resistance welding processes are pressure welding processes in which heavy current is passed for short time through the area of interface of metals to be joined. These processes differ from other welding processes in the respect that no fluxes are used, and filler metal rarely used. Heat is generated in localized area which is enough to heat the metal to sufficient temperature, so that the parts can be joined with the application of pressure. Pressure is applied through the electrodes.

The heat generated during resistance welding is given by following expression:

$$H = I^2RT \tag{3.4.1}$$

Where:

H is heat generated, I is current in amperes, R is resistance of area being welded, T is time for the flow of current.

3.4.1 Spot Welding

Spot welding is the resistance welding process in which overlapping sheet are joined by fusion at one or more spots by the heat generated by resistance to the flow of electric current through work piece that are held together under force by two electrode. It essentially consists of two electrodes, out of which one is fixed. The other electrode is fixed to a rocker arm for transmitting the mechanical force from a pneumatic cylinder.

Principle of operation

When the current is turned on, the pieces are heated at their point of contact to a welding temperature. The current is cut-off and mechanical pressure is then applied by the electrodes to forge the welds, finally the electrodes open. Current usually range from 3000 A to 40000 A , depending on the material being welded and their thickness. This may be used to weld steel and other metal parts up to a total thickness of 12 mm.

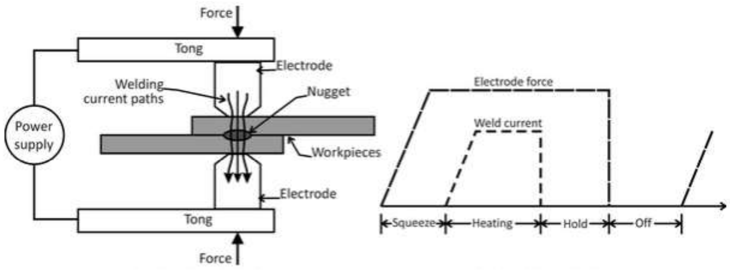

Figure 3.4.1: Schematic diagram of resistance spot welding system

Advantages

- High production rate
- Dissimilar metal can be welded
- High skill not required
- Most suitable for welding sheet metal

Disadvantages

- Suitable for thin sheet only
- High equipment cost

Applications of Spot Welding

- It has applications in automobile and aircraft industries.
- Spot welding of two 12.5 mm thick steel plates has been done satisfactorily as a replacement for riveting.
- Containers and boxes frequently are spot welded.

3.5 Electron beam welding

Electron beam welding is a process in which the heat is generated when the electron beam impinges on work piece. As the high velocity electron beam strikes the surfaces to be welded, their kinetic energy changes to thermal energy and hence causes the workpiece metal to melt and fuse. The beam is created in a high vacuum (10^{-3} to 10^{-5} mm of Hg).

3.5.1 Principle of Operation

This process employs an electron gun in which the cathode in form of hot filament of tungsten or tantalum is the source of a stream of electrons. The electrons emitted from filament accelerated to a high velocity to the anode because of the large potential difference that exists between them. The electron beam is focused by a magnetic lens system on the workpiece to be welded.

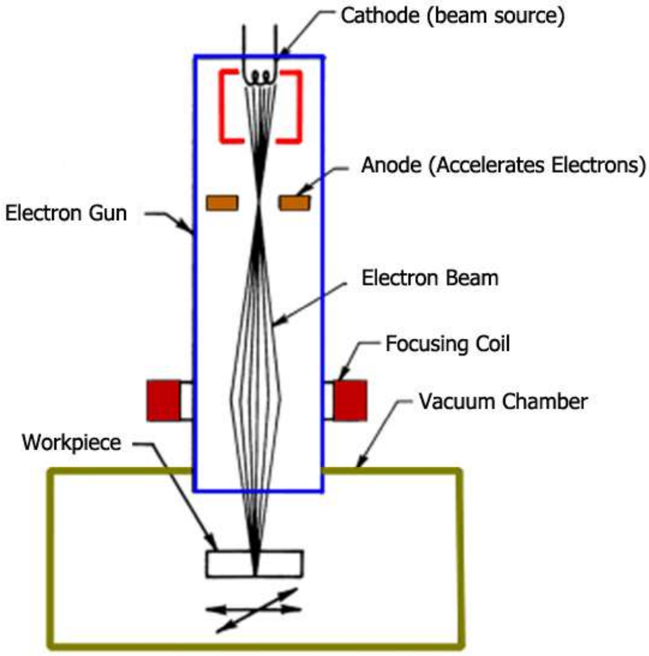

Figure 3.5.1: Schematic diagram of electron beam welding system

The depth of penetration of the weld depends on the electron speed which in turn is dependent upon the accelerating voltage. When the high velocity electron beam strikes the work-piece all the kinetic energy is converted to heat. As these electrons penetrate the metal, the material that is directly in the path is melted which when solidifies, forms the joint.

3.5.2 Advantages

- The penetration of the beam is high.

- The process can be used at higher welding speeds typically between 125 and 200 mm/sec.
- No filler metal or flux needs to be used in this process.
- The heat liberated is in a narrow zone, thus the heat affected zone is minimal as well as weld distortions are virtually eliminated.
- It can weld or cut any metal or ceramic, diamond, sometimes as thick as 150 mm.

3.5.3 Disadvantages

- High operating cost
- Expensive equipment
- Work size is limited by the size of the chamber

3.5.4 Applications

Automobile, airplane, aerospace, farm and other type of equipment are being welded by the electron beam process.

3.6 Laser Beam Welding

Laser is a abbreviation of light amplification by stimulated emission of radiation. The laser beam welding process is the focusing of a monochromatic light into extremely concentrated beams. It employs a carefully focused beam of light that concentrates tremendous amount of energy on a small area to produce fusion.

3.6.1 Principle of operation

The laser beam welding consist of electrical storage unit, capacitor tank , triggering device , flash tube wrapped with a wire , focusing lens mechanism and work table. When capacitor bank is triggered, energy is injected into the wire that surrounds the flash tube. The flash tube or lamp are designed for the operation at a rate of thousand of flashes per second. The lamp become a efficient device for converting electrical energy into light energy, the process of pumping the laser. The laser is then activated.

The beam is emitted through the coated end of the lasing material. The beam goes through a focusing device where it is pin-pointed on the workpiece. Fusion takes place and the weld is accomplished.

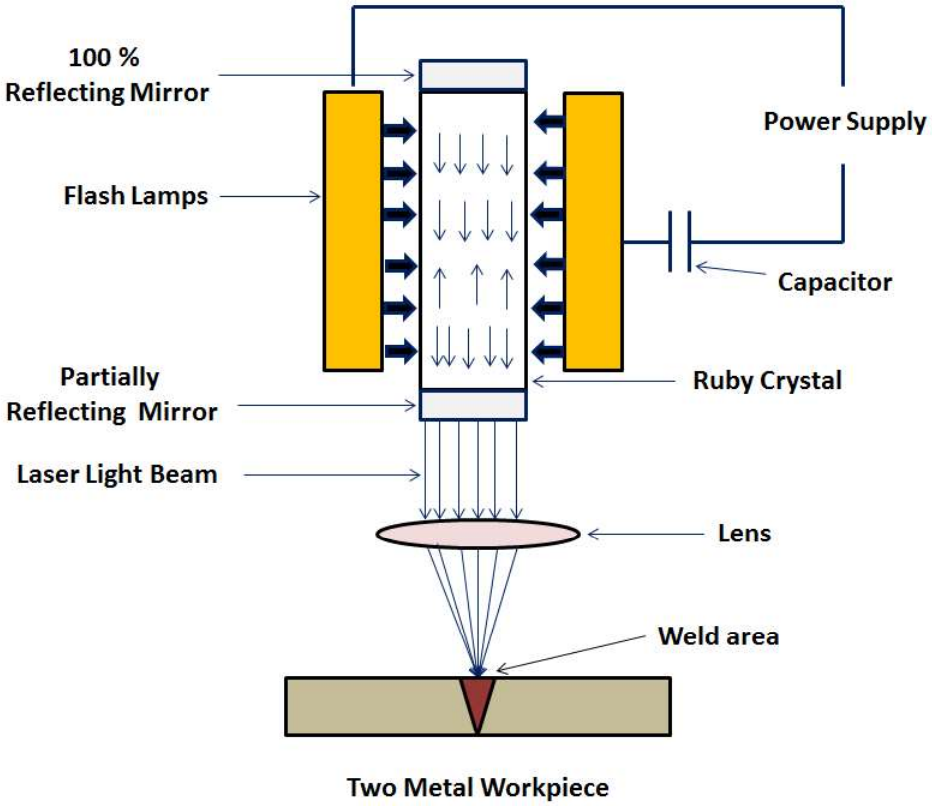

Figure 3.6.1: Schematic diagram of laser beam welding system

3.6.2 Advantages

- This process can be used to weld dissimilar metals with widely varying physical properties.
- Laser welding holds thermal distortion and shrinkage to a minimum.
- High production rate.
- Weld can be made with a high degree of precision

3.6.3 Disadvantages

- High energy losses.

- Highly skilled operation.
- High equipment cost.
- Eye protection required

3.7 Design for welding: Design recommendations

Arc welding can be used to weld almost any kind of assembly, including even complex structures. Commonly produced devices by arc welding are tube fittings, storage tanks, pressure vessels, machine frames, structures for industrial equipment, railroad cars etc.

If well designed, welded components exhibit excellent strength characteristics equal to or even stronger than the base components. Other benefits include light weight, economical and pleasing appearance. However, it is a bit difficult to attain the long sweeping curves, rounded contours, and relatively smooth surfaces as those exhibited by castings and forgings.

The most common classes of weld joints are: butt joints, lap joints, T-joints, corner joints, and edge joints, which are shown in Figure 3.7.1. In this figure, butt, lap, T, and corner joints are shown with two fillets, though use of one fillets is also quite common.

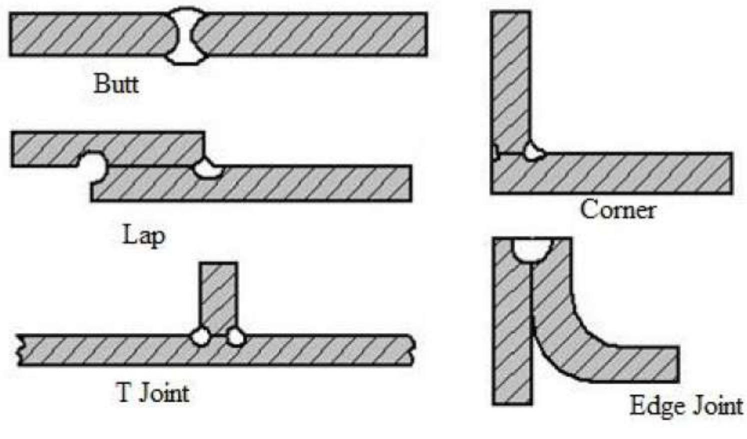

Figure 3.7.1: Common types of welded joints

Some design recommendations include:

3.7.1 Cost Reduction

Following are some design recommendations to reduce costs:

1. Welded assemblies should have few parts.

2. Weld joints should be placed in such a way that there is easy access of the welding nozzle. If the nozzle is close to the welding point, the molten metal will be well shielded.

3. Provide minimum amount of weld filler, with respect to both fillet size and length that meets functional requirements of the assembly.

4. Whenever possible, welding should be done horizontally, with the stick or electrode holder pointing downward during welding. This position is the most rapid and convenient with all welding methods.

5. The designer should be aware of poor and good fit-up of parts (shown in Figure 3.7.2) at the weld joint. It is essential not only for welding speed but also for minimizing distortion of the finished weldment.

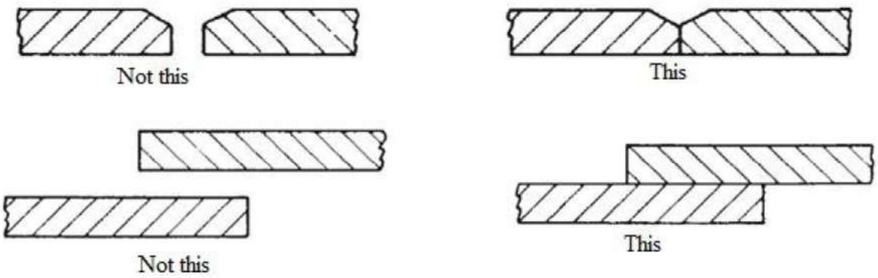

Figure 3.7.2: Poor and good fit-up of weld joints.

6. The buildup of weld fillets should be kept to a minimum as it doesn't add significant strength to the joint, see Figure 3.7.3.

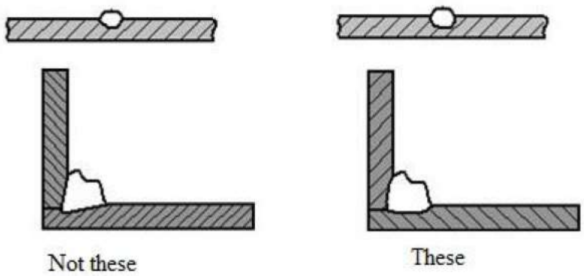

Figure 3.7.3: A buildup of filler material in weld joints does not add materially to joint strength.

7. Locating welds out of sight is better; rather than in locations where special finishing operations are required for the sake of appearance.

8. The joint should be designed so that it requires minimal edge preparation. For this, one should use slip or lap joints in welded assemblies to avoid the cost of close edge preparation and to simplify fit-up problems.

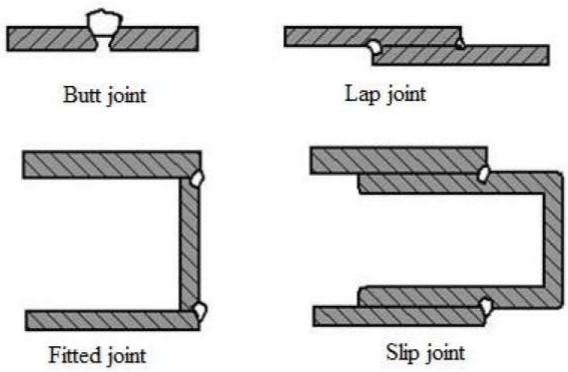

Figure 3.7.4: Joints on the right require less edge preparation

9. If machining after welding is required, it is advisable to place welds away from the material to be machined to avoid machining problems.

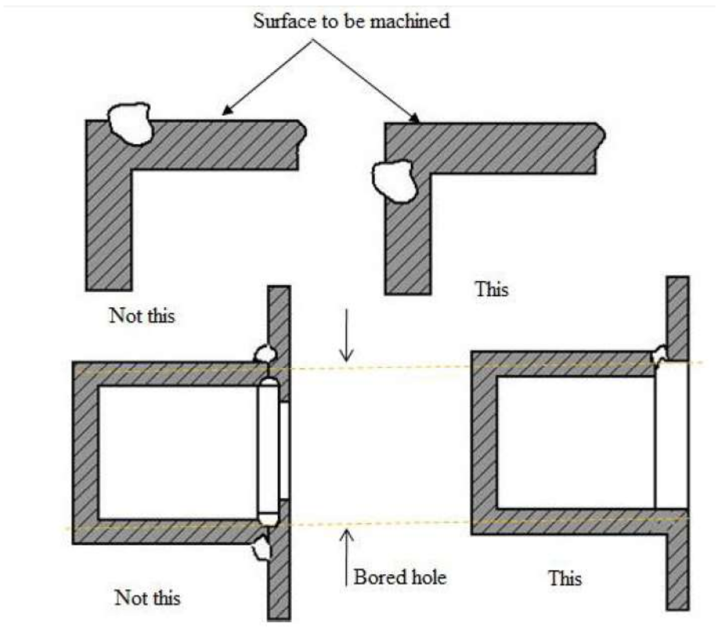

Figure 3.7.5: Weld metal outside the portion of the weldment to be machined

10. Sometimes it is advantageous to include a weld backup strip as an integral part of one of the component to be welded.

3.7.2 Minimizing Distortion

Distortion can be minimized by the following design recommendations:

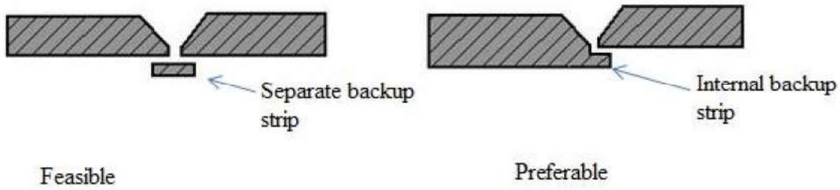

Figure 3.7.6: Backup strip as internal parts

1. Good fit of parts minimizes welding time and controls the distortion. It is better to have maximum contact of mating surface as evident in Figure 3.7.2. The more gaps to fill, the greater the possible weldment distortion.

2. Use thicker, rigid components to reduce distortion from welding.

3. Short flanged butt joints are preferable to join thin materials. Unless joints have good supports long sections of thinner material, when welded together, are apt to distort and buckle.

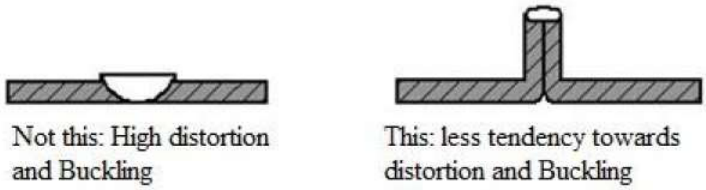

Figure 3.7.7: A short-flanged butt joint is often preferable for joining thin material

4. If possible, place welds opposite one another to reduce distortion. This balances the shrinkage forces in the weld fillets as they tend to offset one another. Figure 3.7.8 shows some examples.

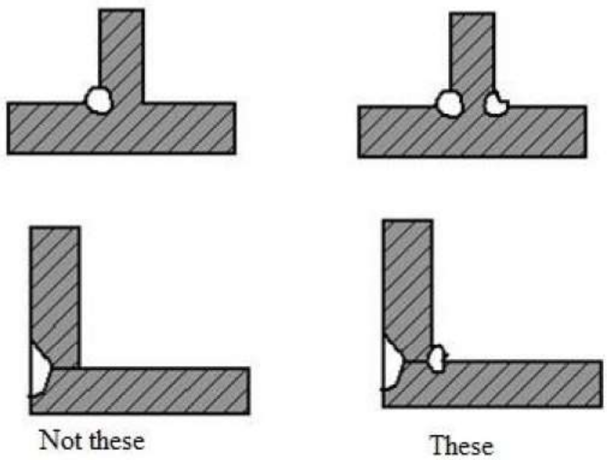

Figure 3.7.8: Use opposing welds to reduce angular distortion

5. If sections of unequal thickness are to be welded, distortion can be reduced by equalizing wall thickness at the joint by machining a groove in the thicker piece adjacent to the weld joint. This is shown in Figure 3.7.9.

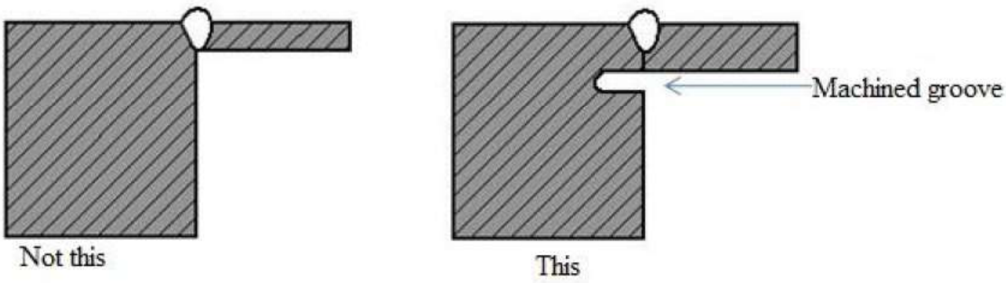

Figure 3.7.9: Use of a machined groove to equalize wall thickness to reduce distortion.

6. Consideration should be given to shrinkage inherent in each weld while dimensioning welded assemblies.

3.7.3 Weld Strength

The following design recommendations need to be followed for strengthening of welds.

1. Butt joints are most efficient. For deep-penetration welding or for thin stocks, the square-edged butt joint can be employed and edge-preparation time can therefore be saved.

2. Welds should be placed to minimise stress concentration in the fillet. This is shown in Figure 3.7.10.

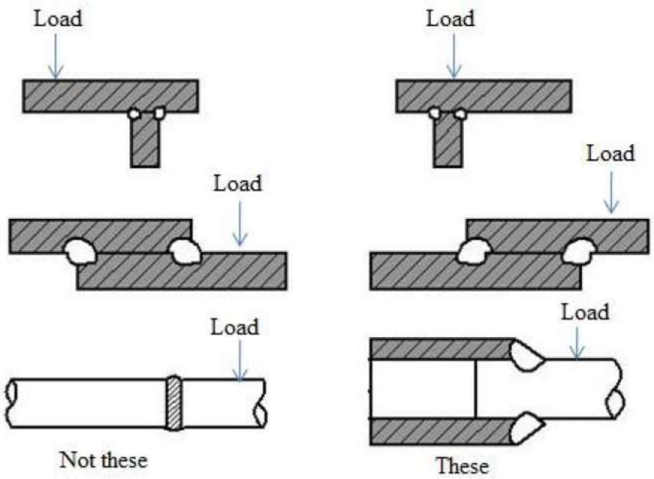

Figure 3.7.10: Design of weldments to minimize stress concentration in the weld fillet

3. Groove welds should be designed to be in either compression or tension but fillet welds should be designed for shear only as shown in Figure 3.7.11 and 3.7.12.

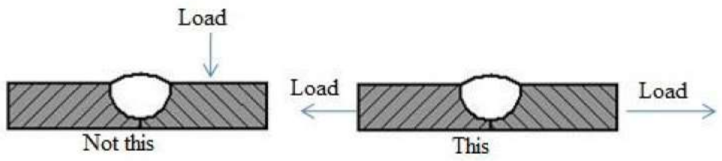

Figure 3.7.11: Groove welds either in tension or compression.

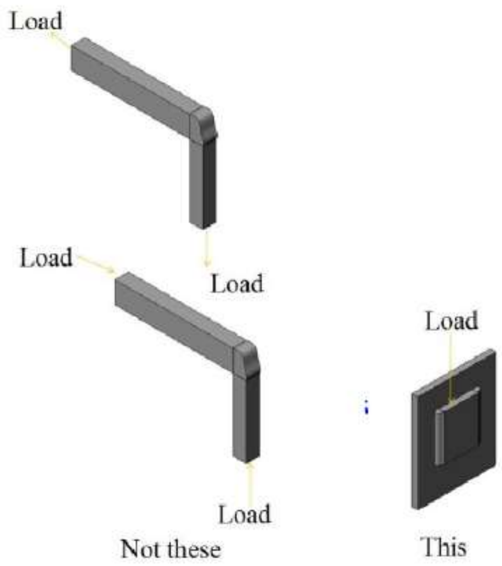

Figure 3.7.12: Fillet welds should be designed to be in shear only

4. If intermittent welds are used in place of continuous welds for reducing cost, the length of each fillet should be at least 4 times the fillet thickness and should not be less than 40 mm. If the joint is in compression, the spacing of the welds should not exceed 16 times the joint thickness; for the case of tension, the spacing may be as much as 32 times the thickness but not over 300 mm.

Electron and Laser Beam Weldments

The following are some design recommendations for electron and laser beam weldments:

1. Butt joints are preferred to lap joints as the process uses narrow width of the ray and deep penetration
2. Good fit up of the mating surface is essential because of the narrow beam.
3. Electron-beam weldments need to be processed in vacuum chambers and so they should be self-fixturing to permit batches of assemblies to be placed in the welding

chamber with minimum space occupancy. This also reduces the cost of multiple fixtures.

Weldments and Heat Treatment

Designers should note the following rules concerning the use of heat treatment in weldments:

1. Carburized or hardened steels should not be welded as they require controlled conditions and proper equipment and supplies.
2. Welding reduces or removes the hardness of carburized or nitride mild (low-carbon) steels in the welded area.
3. Carbon in welded areas will affect the physical and chemical characteristics of the weld bead, resulting in possible cracking or weld failure in or adjacent to the weld.
4. Any straightening operation on carburized and hardened parts may result in some surface cracking in the welded area because of the possible distortion from stress relief and heat treatment.

Chapter 4

Jigs and fixtures

The successful running of any mass production depends upon the interchangeability to facilitate easy assembly and reduction of unit cost. Mass production methods demand a fast and easy method of positioning work for accurate operations on it.

Jigs and fixtures are production tools used to accurately manufacture duplicate and interchangeable parts. Jigs and fixtures are specially designed so that large numbers of components can be machined or assembled identically, and to ensure interchangeability of components.

Jigs and fixtures are so closely related that the terms are sometimes confused or used interchangeably. The difference is in the way the tool is guided to the work piece. Fixture locates, holds and supports the work securely so the required machining operation can be performed. Jig not only locates and supports the workpiece but also guides the cutting tool.

4.1 Jigs

It is a work holding device that holds, supports and locates the workpiece and guides the cutting tool for a specific operation. The term jig should be used only for devices employed while drilling, boring, reaming or tapping holes. It is not fastened to the machine on which it is used. So it may be moved around on the table of the drilling machine to bring each bushing under the drill.

Jigs make it possible to drill, ream and tap holes at much greater speeds and with greater accuracy. Jigs physically limit and control the path of the cutting tool with the help of bushings.

An example of a jig is when a key is duplicated, the original is used as a jig so the new key can have the same path as the old one.

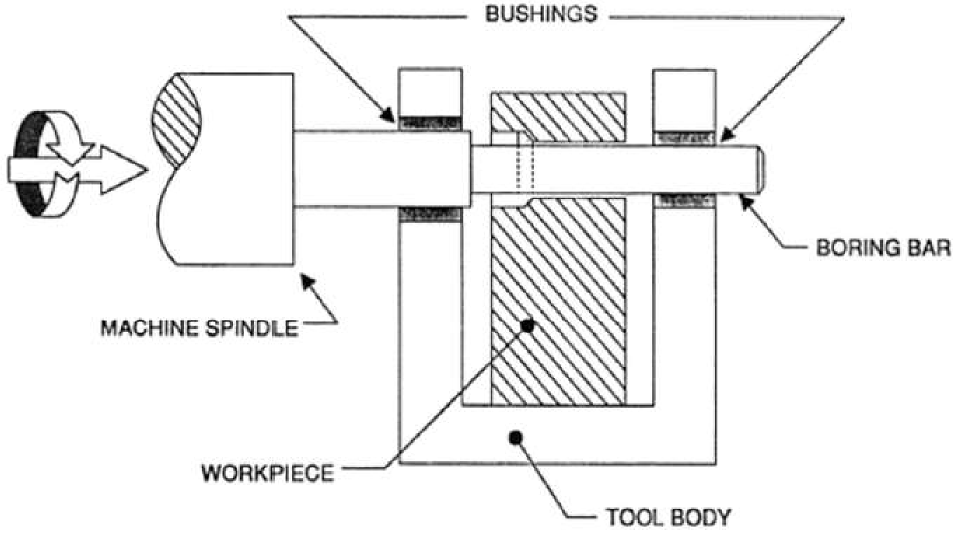

Figure 4.1.1: Boring jig

4.2 Fixtures

It is a work holding device that holds, supports and locates the workpiece for a specific operation but does not guide the cutting tool. Fixtures are used for machining operations like milling, shaping, turning, broaching, etc. A fixture is also fixed to the machine on which its is used. The accuracy of machining depends upon the operator and construction of machine tool.

Examples: Vises, chucks

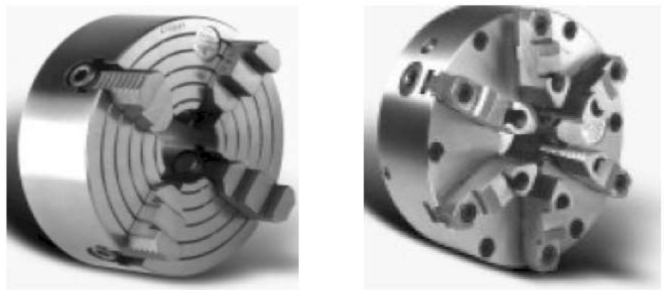

Figure 4.2.1: 4-jaw and 6-jaw chucks

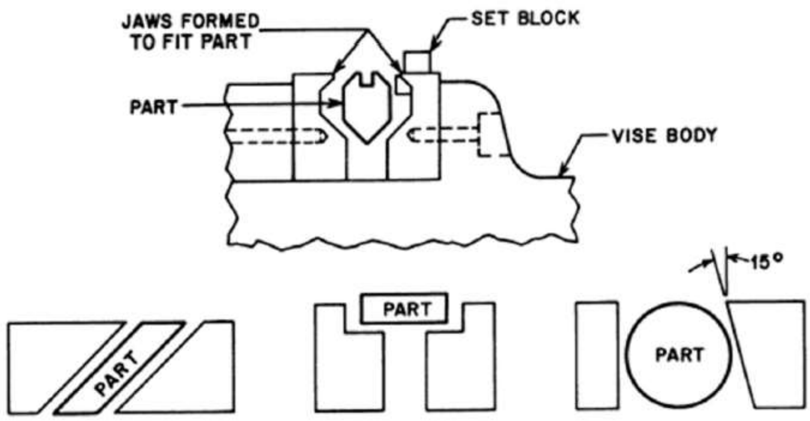

Figure 4.2.2: Vise-jaw fixture

4.2.1 Differences between jigs and fixtures

JIGS	FIXTURES
1. It is a work holding device that holds, supports and locates the workpiece and guides the cutting tool for a specific operation	1. It is a work holding device that holds, supports and locates the workpiece for a specific operation but does not guide the cutting tool
2. Jigs are not clamped to the drill press table unless large diameters to be drilled and there is a necessity to move the jig to bring one each bush directly under the drill.	2. Fixtures should be securely clamped to the table of the machine upon which the work is done.
3. The jigs are special tools particularly in drilling, reaming, tapping and boring operation.	3. Fixtures are specific tools used particularly in milling machine, shapers and slotting machine.
4. Gauge blocks are not necessary.	4. Gauge blocks may be provided for effective handling.
5. Lighter in construction.	5. Heavier in construction.

Figure 4.2.3: Differences between jigs and fixtures

4.2.2 Advantages of Jigs and fixtures

1. **Productivity:** Jigs and fixtures increases the productivity by eliminating the individual marking, positioning and frequent checking. The operation time is also reduced due to increase in speed, feed and depth of cut because of high clamping rigidity.

2. **Interchangeability and quality:** Jigs and fixtures facilitate the production of articles in large quantities with high degree of accuracy, uniform quality and interchangeability at a competitive cost.

3. **Skill reduction**: There is no need for skillful setting of work on tool. Jigs and fixtures makes possible to employ unskilled or semi skilled machine operator to make savings in labour cost.

4. **Cost reduction:** Higher production, reduction in scrap, easy assembly and savings in labour cost results in ultimate reduction in unit cost.

4.2.3 Fundamental principles of jigs and fixtures design

1. **Locating points:** Good facilities should be provided for locating the work. The article to be machined must be easily and quickly taken out from the jig so that no time is wasted in placing the workpiece in position to perform operations. The position of workpiece should be accurate with respect to tool guiding in the jig or setting elements in fixture.

2. **Fool Proof:** The design of jigs and fixtures should be such that it would not permit the workpiece or the tool to inserted in any position other than the correct one.

3. **Reduction of idle time:** Design of jigs and fixtures should be such that the process, loading, clamping and unloading time of the workpiece takes minimum as far as possible.

4. **Weight of jigs and fixtures:** It should be easy to handle, smaller in size and low cost in regard to amount of material used without sacrificing rigidity and stiffness.

5. **Jigs provided with feet:** Jigs sometimes are provided with feet so that it can be placed on the table of the machine.

6. **Materials for jigs and fixtures:** Usually made of hardened materials to avoid frequent damage and to resist wear. Example- MS, Cast iron, Diesteel, CS, HSS.

7. **Clamping device:** It should be as simple as possible without sacrificing effectiveness. The strength of clamp should be such that not only to hold the workpiece firmly in place but also to take the strain of the cutting tool without springing when designing the jigs and fixtures.

4.2.4 Essential features of jigs and fixtures

- Reduction of idle time Should enable easy clamping and unloading such that idle time is minimum.
- Cleanliness of machining process Design must be such that not much time is wasted in cleaning of scarfs, burrs, chips etc.
- Replaceable part or standardization The locating and supporting surfaces as far as possible should be replaceable, should be standardized so that their interchangeable manufacture is possible.
- Provision for coolant Provision should be there so that the tool is cooled and the swarfs and chips are washed away.
- Hardened surfaces All locating and supporting surfaces should be hardened materials as far as conditions permit so that they are not quickly worn out and accuracy is retained for a long time.
- Inserts and pads Should always be riveted to those faces of the clamps which will come in contact with finished surfaces of the workpiece so that they are not spoilt.
- Fool-proofing Pins and other devices of simple nature incorporated in such a position that they will always spoil the placement of the component or hinder the fitting of the cutting tool until the latter are in correct position.
- Economic soundness Equipment should be economically sound, cost of design and manufacture should be in proportion to the quantity and price of producer.
- Easy manipulation It should be as light in weight as possible and easy to handle so that workman is not subjected to fatigue, should be provided with adequate lift aids.
- Initial location Should be ensured that workpiece is not located on more than 3 points in any plane. Tests to avoid rocking, spring loading should be done.
- Position of clamps Clamping should occur directly above the points supporting the workpiece to avoid distortion and springing.

- Ejecting devices Proper ejecting devices should be incorporated in the body to push the workpiece out after operation.
- The design should assure perfect safety of the operator.

4.2.5 Materials used

Jigs and fixtures are made of variety of materials, some of which can be hardened to resist wear. Materials generally used:

1. High speed steel: Cutting tools like drills, reamers and milling cutters.
2. Die steels: Used for press tools, contain 1% carbon, 0.5 to 1% tungsten and less quantities of silicon and manganese.
3. Carbon steels: Used for standard cutting tools.
4. Collet steels: Spring steels containing 1% carbon, 0.5% manganese and less of silicon.
5. Non shrinking tool steels: High carbon or high chromium, very little distortion during heat treatment,
6. Nickel chrome steels: Used for gears.
7. High tensile steels: Used for fasteners like high tensile screws.
8. Used in most part of Jigs and Fixtures. Cheapest material, Contains less than 0.3% carbon.
9. Cast Iron: Used for odd shapes to some machining and laborious fabrication.
10. Nylon and Fiber: Used for soft lining for clamps to damage to workpiece due to clamping pressure.
11. Phospher bronze: Used for nuts due to high tensile strength.

Chapter 5

Decorative and protective surface treatment

These processes are sometimes referred to as post-processing. They play a very important role in the appearance, function and life of the product. Broadly, these are processes that affect either a thin layer on the surface of the part itself, or add a thin layer on top of the surface of the part. There are different coating and surface treatments processes, with different applications, uses, etc. The important uses include:

- Improving the hardness
- Improving the wear resistance
- Controlling friction, Reduction of adhesion, improving the lubrication, etc.
- Improving corrosion resistance
- Improving aesthetics

5.1 Mechanical hardening of the surface

These methods apply mechanical impulses (e.g. light hammering) on the surface of a metallic part. This hammering action causes tiny amount of plastic flow on the surface, resulting in the work-hardening of the surface layer due to the introduction of compressive residual stresses. Examples of these processes include ***Shot peening*** (uses tiny balls of metal or ceramic), ***Water-jet peening*** (uses a jet of water at high pressures, e.g. 400 MPa), or ***Laser peening*** (surface is hit by tiny impulses from a laser) an expensive process used to improve fatigue strength of jet fan blades and turbine impellers.

Another method is ***explosive hardening***, where a layer of explosive coated on the surface is blasted the resulting impact results in tremendous increase in the surface hardness. This method is used to harden the surface of train rails.

5.2 Case hardening

This is a very common process that is used to harden the outer surface of parts such as gear teeth, cams, shafts, bearings, fasteners, pins, tools, molds, dies etc. In most of these types of components, the use involves dynamic forces, occasional impacts, and constant friction. Therefore the surface needs to be hard to prevent wear, but the bulk of the part should be tough (not brittle); this is achieved best by case hardening. In most cases, the chemical structure of the metal is changed by diffusing atoms of an alternate element which results in alterations to the micro-structure on the crystals on the surface.

The metal parts are put in an oven, and heated with the atmosphere containing excess of a gaseous/liquid form of the doping substance. This causes the dopant to diffuse into the surface. The duration and temperature control the concentration and depth of the doping. Most of these processes are used to case harden steel and other iron alloys, including low carbon steels, alloy steels, tool steels etc.

5.3 Thermal spraying

Metal is melted in a specially designed spray gun (using oxy-fuel, plasma, or other means to heat the sprayed metal till it melts). High pressure gas then sprays the liquid metal, depositing a layer on top the part similar to a painting process. This is illustrated in Figure 5.3.1.

5.4 Vapor deposition

In these processes, the layer of deposited material is very thin only a few microns. In the vacuum evaporation process, the metal to be deposited is heated in an enclosed

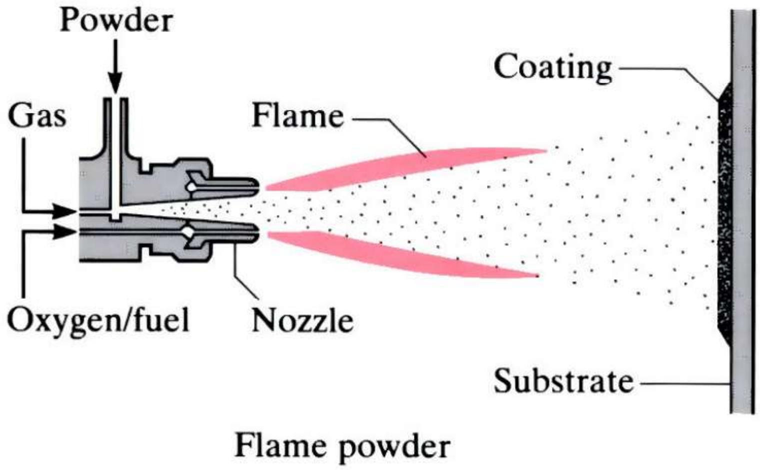

Figure 5.3.1: Thermal spraying

oven at high temperature and very low pressure; some of the metal vapor deposits as a thin layer on the part. The surface can be coated not only with metal, but also with some carbides, nitrides, or ceramics. Typical applications include surface coating of cutting tools, e.g. drills, reamers, punches, dies etc.

A very important coating process is ***sputtering*** - it is important because of its extensive use in production of electronic chips.

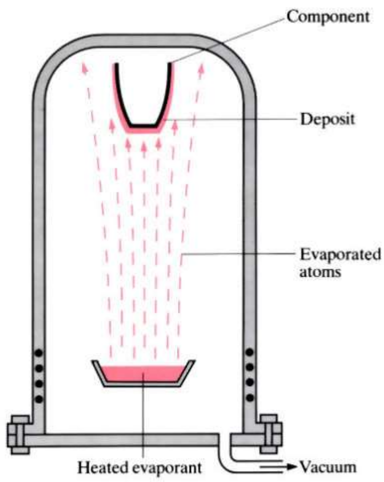

Figure 5.4.1: Physical vapour deposition

5.5 Electroplating

This is a process by which a thin layer of metal is deposited on the surface of an electrically conducting part. The part is used as a cathode, and the depositing material forms the anode. The electrodes are dipped in a solution of the appropriate salt, such that on application of voltage, the metal from the anode is dissolved into the solution, and deposited on the cathode. A simple example of this process is copper plating using $CuSO_4$ solution, using Copper anodes. This is illustrated in Figure 5.5.1.

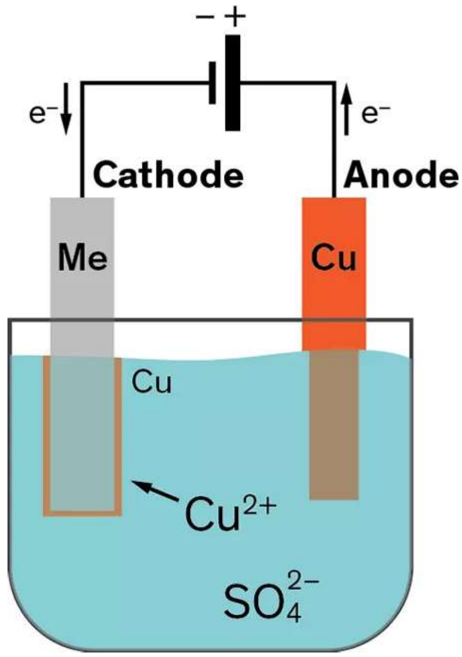

Figure 5.5.1: copper plating

5.6 Electroless plating

In this case, the plating is achieved by a purely chemical reaction in the solution that causes the metal to be deposited. This process can be used to plate non-conducting parts with a layer of metal. The most common use of this process is deposition of Nickel - the reduction of Nickel chloride in solution by Sodium hypophosphite, which causes Ni metal to be deposited on the part. The deposited metal is not in crystalline form, so this process is followed by heat-treatment and quenching. Ni-coating using this method is used for making tool coatings that are quite hard (up to 1000 HV).

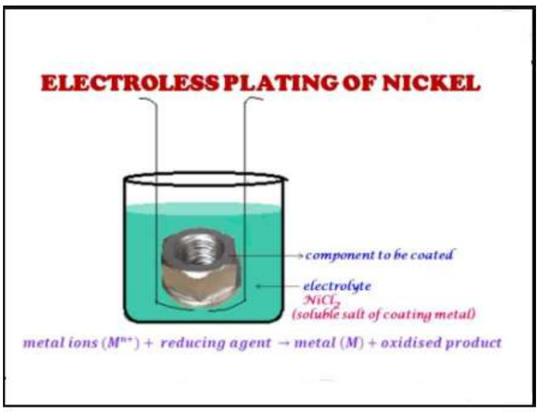

Figure 5.6.1: Nickel electroless plating

5.7 Anodizing

This is a very common process - many common Aluminium parts are surface treated by anodizing to give them a different colour (usually black, red, blue, etc.). The process uses the metal part as an anode; using electrolytic process, a layer of hard metal oxide is formed at the anode (i.e. on the surface of the part). Common examples include aluminium parts, such as picture frames, car-body parts, door-knobs and other building fixtures, bathroom fixtures and racks, sporting goods, e.g. baseball bats, and so on.

5.8 Painting

This is the most common surface treatment is painting. Examples of its functional value include:

(i.) Car body paints are corrosion resistant

(ii.) Boats are painted with anti-corrosion paint with (toxic) chemicals to avoid growth of barnacles, seaweed etc.

(iii.) Examples of aesthetic or decorative value are too numerous.

Paints are of three types:

(a.) ***Enamel:*** Oil-based paints that produce a smooth surface and glossy appearance

(b.) ***Lacquers:*** These are resin based paints that dry to a thin coat after the solvent evaporates out. Common examples are varnish used in painting wood.

(c.) ***Water-based paints:*** common examples include several wall paints and home-interior paints.

The most common methods of paint application include:

(i) Dip coating: part is dipped into a container of paint, and pulled out.

(ii) Spray coating: one or more spray guns move along the surface of the part to give a uniform coat of paint; this is the method most commonly used in painting auto bodies, home appliances, e.g. fridge doors, etc.

(iii) Electrostatic spraying: Here the paint particles are given an electrostatic charge and the spray is achieved by applying a voltage difference across the paint particles and the part.

(iv) Silk-screening: Used in painting patterns, text, etc on top of most products. Tiny holes are made in a thin (silk-like) sheet, corresponding to the pattern that needs to be painted. The screen is kept on top of the part in the correct position, and the paint is poured on top of the screen. A roller (or squeegee brush) is used to squeeze the paint out through the holes in the silk screen and onto the part. The screen is removed and the part is sent to dry in an oven. Uses:

1. It is used in the textile industry to create colored patterns on textiles (e.g. logos on T-shirts).
2. It is used to paint almost all text and patterns on all electronics products - e.g. all numbers, text and symbols on your mobile phone.
3. It is used to deposit patterns of solder-paste on top of printed circuit boards.

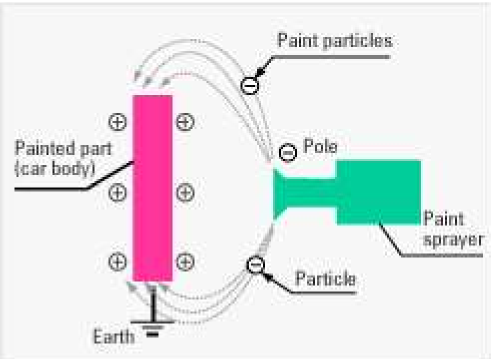

Figure 5.8.1: Schematic of an Electrostatic Spray Painting process

Figure 5.8.2: Automated spray painting of a car body in a BMW plant

Chapter 6

Mass production tools and techniques; machining centers

Mass production is the manufacturing of large quantities of standardized products, often using assembly lines or automation technology. Manufacturers who use mass production techniques must establish highly organized methods of production. The main characteristics of mass production are:

- Specialized machines
- Interchangeable parts
- Division of labor

An early example of mass production is when Henry Ford installed the first moving assembly line in 1913. Fords assembly line enabled him to mass produce entire automobiles. As a result, Fords Model T was available at a lower cost because they were built more efficiently. Initially, Ford broke his assembly line into 84 steps and trained each worker to work on just one step. In 1914, he added a mechanized belt to accelerate the process. Eventually, Fords method of mass production reduced the time it took to build a car from over 12 hours to two and a half hours.

Advantages of mass production

1. **Increased productivity:** Mass production makes it possible to manufacture large volumes in less time. There's no need for workers to run around to gather supplies

or tools when manufacturers use mass production techniques.

2. **Uniformity:** Mass production helps ensure each product is the same. As a result, manufacturers have greater control over quality, and consumers know what to expect.

3. **Lower cost:** Mass production enables companies to produce larger quantities with fewer workers. Instead of having to pay several workers to complete a task by hand, manufacturers use machines to produce goods much faster. This allows companies to sell their products at a lower cost without losing profit.

4. **Higher quality of life:** Due to mass production, more people can afford products that make life easier and more comfortable. Consumers can afford new shoes, clothes, household items and other goods when they need them.

5. **Faster production:** When companies use machinery and mass production techniques, they can develop and produce products much faster.

6. **Less error:** Machines are designed to perform specific tasks, and they are less likely to make mistakes than humans during production. Consider how a machine doesn't get distracted or won't perform poorly due to lack of sleep.

7. **Increased worker safety:** Manufacturers who mass produce goods often employ automation technology to complete strenuous or dangerous tasks. For example, robots used in mass production can safely handle and assemble large and heavy parts. This helps keep employees safe from accidents or injuries.

8. **Job specialities:** With mass production, factory workers are trained to perform highly specialized tasks. Employers benefit from skilled and efficient employees, and employees develop marketable skill sets.

Disadvantages of mass production

1. **Initial costs:** It takes a lot of capital and time to build a factory equipped with specialized machinery. Specialized machinery costs a lot of money, and so does the factory floor space needed to hold assembly-line machinery.

2. **Less flexibility:** Specialized machinery used in mass production are designed to do specific jobs. This level of inflexibility can sometimes be problematic.

3. **High energy consumption:** Factories that mass produce goods use powerful machinery which require substantial amounts of energy.

4. **Pollution:** Simply said, factories cause pollution. The most common forms of pollution are air, water and noise pollution.

5. **Affects employees' well-being:** Mass production and assembly lines involve repetitive work. Factory employees may spend their entire shift standing in the same spot, doing the same tasks over and over. This can leave employees feeling unmotivated, bored or isolated. Repetitive motions can also lead to conditions like carpal tunnel syndrome.

6. **Lack of product uniqueness:** Mass-produced goods lack uniqueness. In todays world, many consumers want customized products that feel personal and express their identity. Some manufacturers offer customized products, while others do not have the capabilities to mass produce custom goods.

7. **Unhealthy habits:** Mass production has reduced the need to perform labour-intensive tasks. As machines do the grunt work, fewer people need to engage in physical activity. More people now drive to work instead of walking; consumption of mass-produced food, which is often high in fat and salt, has become part of unhealthy diets for many consumers.

8. **Inventory buildup:** Mass production creates large quantities at once. As a result, products may build up before they can be sold. Excess inventory requires a large amount of warehouse space which costs money and energy to maintain.

9. **Loss of jobs for unskilled workers:** Mass production fosters innovation and has led to the development of advanced machinery which require special skills and knowledge. This means that manufacturers are hiring highly skilled workers, such as engineers and computer programmers, leaving low-skilled workers jobless.

6.1 Machining Centers

A machining center is an advance machine tool capable of turning, milling and drilling a workpiece, usually metal, in a single operation. Certain models have other capabilities, such as molding non-metallic pieces. Today, machining centers are widely used in manufacturing sites. As an example, machining centers in the automobile industry are used for efficient grinding and drilling of engine parts as well as for making dies for body components. Many other products commonly used in daily life and in industrial settings are manufactured in machining centers.

Machining centers feature a computerized automatic tool change function, that automatically retrieves and exchanges tools from a tool magazine where the tools are stored during the machining of workpieces. This saves time and effort required for standard tool changeovers, and consequentially enables automated and power-saving operations while reducing costs.

Machining centers can continuously perform several types of machining at the same time on different surfaces of a workpiece, greatly improving production efficiency.

6.1.1 General Structure and Types of Machining Centers

Machining centers can be broadly classified into three types based on their structure: horizontal, vertical, and gantry types. The horizontal type - the first to be developed can be defined simply as a machine where the spindle to which the cutting tool is attached is mounted horizontally (or parallel to the floor). In contrast, vertical types have the spindle set upright. Gantry types, on the other hand, have a gate - like structure with the spindle mounted on the ceiling of the gate, facing downward.

Using the horizontal type as an example, the general structure of a machining center consists of a base part called a bed at the bottom, a saddle that moves on the bed, a table attached on top of the saddle for placing the raw material, a column installed perpendicularly to the bed, and a spindle head where the cutting tools are attached.

Differences Between Horizontal and Vertical Types

Horizontal machining centers have a blade - mounted spindle that comes out sideways, which machines workpieces in the horizontal direction. The column moves along the X axis, the saddle along the Y axis, and table along the Z axis, and this combination enables three-dimensional machining. Additionally, some models have a B axis that rotates the table horizontally, making it possible to machine materials using a total of four axes.

One advantage of horizontal types is the capability to machine four surfaces of a workpiece - when using a four-axis machining center with B axis - all at once. This eliminates the need for operators to manually switch the four sides of the workpiece, and thus also contributes to higher machining precision. Moreover, machining from the horizontal direction allows chips to fall down, which helps prevent the chips from accumulating on the workpiece and digging into the blade.

Conversely, vertical machining centers have the spindle in a vertical position, and workpieces are machined from above. Generally, the table travels horizontally on the X and Y axes, and the spindle moves vertically, enabling triaxial machining.

Compared with horizontal types where the spindle is situated to the side of the workpiece, vertical types take up less installation space, making them a popular choice. In addition, machining from above the workpiece allows operators to work while comparing the machining to the design drawings. However, machining on the top of the workpiece causes chips to accumulate on the workpiece, creating the need for a blower that uses compressed air, or rinsing with lubricant to remove the chips appropriately.

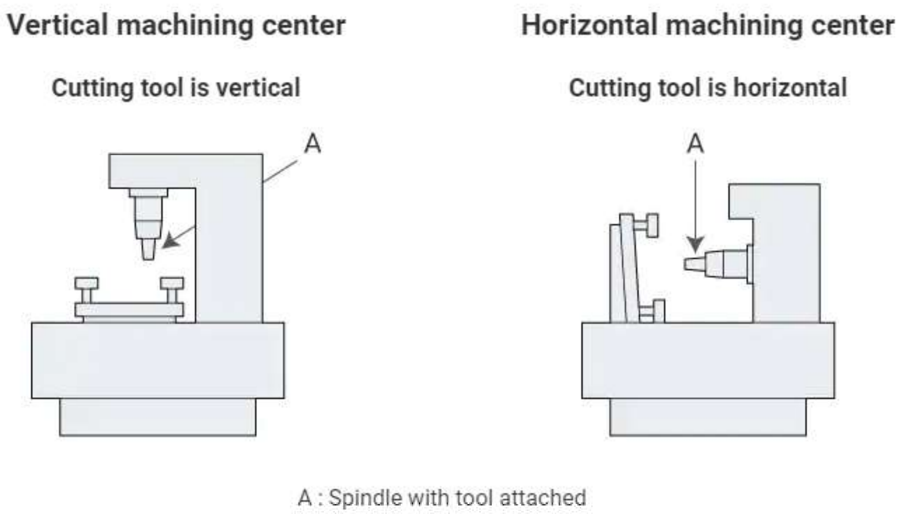

Figure 6.1.1: Vertical and horizontal machining centers

Other types of production apart from mass production include job production, batch production and lean production.

6.2 Job Production

Job production (one off production) is where one single item is designed and made at a time. These items are most often produced to suit a customers individual requirements. Each of these products is unique and, more often than not, a long time would have been spent designing and making it. For this reason, items produced by this method are expensive to buy.

Job production would not be suitable for factories and is more likely to be found in smaller establishments where the emphasis is placed on the hand made and quality aspects of a product.

Advantages

- Each piece is made to the exact customer requirements.
- Job Satisfaction for workers is high
- Quality of products is very high

Disadvantages

- The products are very expensive
- The work is very time consuming

Example: wedding cakes, draperies

6.3 Batch Production

Batch production is used where several of the same product are made. When the required number has been produced, production stops. Another batch of the same product can be made at a later date if the demand for the product is there.

All items made in a batch are the same. Therefore production is speeded up and the cost of labour is reduced. This results in the final product being less expensive for the customer.

Advantages

- Workers may specialise to some degree.

- Labour costs are reduced resulting in cheaper products.
- Production is faster.

Disadvantages

- The work less interesting and repetitive
- More space required for working and storage
- Quantities of raw material must be stored

Example: bread rolls, uniforms

6.4 Lean Production

Lean is about doing more with less: less time, inventory, space, labor, and money. 'Lean manufacturing' is a shorthand for a commitment to eliminating waste, simplifying procedures and speeding up production. Lean Manufacturing (Toyota Production System) is, in its most basic form, the systematic elimination of waste.

Five areas that drive lean manufacturing/production:

1. cost
2. quality
3. delivery
4. safety, and
5. morale

Just as mass production is recognized as the production system of the 20th century, lean production is viewed as the production system of the 21st century.

Benefits of Lean Production

Establishment and mastering of a lean production system would allow you to achieve the following benefits:

- Waste reduction
- Production cost reduction

- Manufacturing cycle times decreased
- Labor reduction while maintaining or increasing throughput
- Inventory reduction while increasing customer service levels
- Capacity increase in current facilities
- Higher quality
- Higher profits
- Higher system flexibility in reacting to changes in requirements improved.
- More strategic focus
- Improved cash flow through increasing shipping and billing frequencies

Removal of waste activities

In Lean Manufacturing, waste is any activity that consumes time, resources, or space but does not add any value to the product or service. Lean manufacturing is, in its most basic form, the systematic elimination of 7 wastes - overproduction, waiting, transportation, inventory, motion, over-processing, defective units - and the implementation of the concepts of continuous flow and customer pull.

The seven wastes to be eliminated:

1. Overproduction and early production producing over customer requirements, producing unnecessary materials / products
2. Waiting time delays, idle time (time during which value is not added to the product)
3. Transportation multiple handling, delay in materials handling, unnecessary handling
4. Inventory holding or purchasing unnecessary raw materials, work in process, and finished goods
5. Motion actions of people or equipment that do not add value to the product.
6. Over-processing unnecessary steps or work elements / procedures (non added value work)

7. Defective units production of a part that is scrapped or requires rework.

Difference between Lean Production and Mass Production

Mass production refers to a manufacturing process in which products are manufactured on a mass scale. Lean production refers to a manufacturing process in which items are produced based on current demand trends.

Here is how lean and mass production differ:

1. A mass production process focuses on manufacturing in large-sized lots. The idea is to manufacture the maximum number of products in one lot. A lean production process focuses on producing as per the latest market demand. For example, a high-end car that is priced at several millions may be produced on an order basis.

2. The mass production process requires the company to stock the manufactured products in a warehouse. These products are dispatched to market intermediaries (distributors). These distributors then supply these products to retailers. A lean production process generally supplies direct to the customer. Stocking of products is not required however, a market intermediary may be required (for example, a car dealer in the case of a custom-built car).

3. Planning for mass production is based on a variety of complex factors like market price, competition, inventory levels, time taken for distribution, extra production that is required because an advertisement is released, etc. Such planning is complex and requires enterprise-level tools. Lean production is easy to plan because it is based on market demand. Figures and statistics are known and the production schedules are easy to plan.

4. The manufacturing cycle and the sales cycle are separate issues in the mass production process. In a lean production process, these two are closely intertwined because the products are manufactured based on the latest demand numbers.

5. Mass production is a push type of process - push the products to the market. Lean production is a pull process - let the customer pull the product based on its demand.

6. It logically follows that mass production is supply-oriented, while lean production is demand-oriented.

7. Huge volume of waste is generated in a mass production facility; a lean production facility produces minimal waste.

8. Mass production facilities are equipped with heavy machinery. These facilities typically work in 3 shifts. Lean production facilities may not be equipped with bulky machinery. The machinery used in lean production is compact and movable, and can be easily set up.

6.5 Total Productive Maintenance as one of the tools of Lean Production

TPM (Total Productive Maintenance) is a holistic approach to equipment maintenance that strives to achieve perfect production:

- No Breakdowns
- No Small Stops or Slow Running
- No Defects
- No Accidents

TPM emphasizes proactive and preventative maintenance to maximize the operational efficiency of equipment. It blurs the distinction between the roles of production and maintenance by placing a strong emphasis on empowering operators to help maintain their equipment.

The implementation of a TPM program creates a shared responsibility for equipment that encourages greater involvement by plant floor workers. In the right environment this can be very effective in improving productivity (increasing up-time, reducing cycle times, and eliminating defects).

6.5.1 The Traditional TPM Model

The traditional approach to TPM was developed in the 1960s and consists of 5S as a foundation and eight supporting activities (sometimes referred to as pillars).

The eight pillars

Figure 6.5.1: The traditional TPM model

The eight pillars of TPM are mostly focused on proactive and preventative techniques for improving equipment reliability.

1. Autonomous Maintenance: Places responsibility for routine maintenance, such as cleaning, lubricating, and inspection, in the hands of operators.
    - Gives operators greater ownership of their equipment.
    - Increases operators' knowledge of their equipment.
    - Ensures equipment is well-cleaned and lubricated.
    - Identifies emergent issues before they become failures.
    - Frees maintenance personnel for higher-level tasks.
2. Planned Maintenance: Schedules maintenance tasks based on predicted and/or measured failure rates.
    - Significantly reduces instances of unplanned down time.
    - Enables most maintenance to be planned for times when equipment is not scheduled for production.
    - Reduces inventory through better control of wear-prone and failure-prone parts.
3. Quality Maintenance: Design error detection and prevention into production processes. Apply root cause analysis to eliminate recurring sources of quality defects.

- Specifically targets quality issues with improvement projects focused on removing root sources of defects.
- Reduces number of defects.
- Reduces cost by catching defects early (it is expensive and unreliable to find defects through inspection).

4. Focused Improvement: Have small groups of employees work together proactively to achieve regular, incremental improvements in equipment operation.
   - Recurring problems are identified and resolved by cross-functional teams.
   - Combines the collective talents of a company to create an engine for continuous improvement.
5. Early Equipment Management: Directs practical knowledge and understanding of manufacturing equipment gained through TPM towards improving the design of new equipment.
   - New equipment reaches planned performance levels much faster due to fewer start-up issues.
   - Maintenance is simpler and more robust due to practical review and employee involvement prior to installation.
6. Training and Education: Fill in knowledge gaps necessary to achieve TPM goals. Applies to operators, maintenance personnel and managers.
   - Operators develop skills to routinely maintain equipment and identify emerging problems.
   - Maintenance personnel learn techniques for proactive and preventative maintenance.
   - Managers are trained on TPM principles as well as on employee coaching and development.
7. Safety, Health, Environment: Maintain a safe and healthy working environment.
   - Eliminates potential health and safety risks, resulting in a safer workplace.

- Specifically targets the goal of an accident-free workplace.

8. TPM in Administration: Apply TPM techniques to administrative functions.

    - Extends TPM benefits beyond the plant floor by addressing waste in administrative functions.
    - Supports production through improved administrative operations (e.g. order processing, procurement, and scheduling)

Chapter 7

Recent advances in production technology

7.1 Micro and nano manufacturing

Manufacturing industry has witnessed a rapid increase in demand for micro products and micro components in diverse sectors such as electronics, optics, medicine, biotechnology and automotive. Examples of applications include medical implants, diagnostic devices, micro fluidic systems, micro nozzles and micro moulds. This current trend for product miniaturisation can only be met to some extend by micro electromechanical systems (MEMS) fabrication technologies that followed the silicon-based microelectronics revolution of the late twentieth century.

7.2 Rapid Prototyping (Additive Manufacturing)

Additive manufacturing (AM) refers to a group of technologies that build physical objects directly from three dimensional CAD data. AM adds liquid, sheet, wire or powdered materials, layer by layer, to form component parts with little or no subsequent processing requirements. This approach provides a number of advantages including near 100% material utilisation, short lead times and flexibility in product design. The common processes are Stereolithography (SLA), Liquid Polymerization (LP), Fused Deposition Modelling (FDM), Ballistic Particle Manufacturing (BPM), Selective Laser Melting (SLM), Laser-Engineered Net-Shaping (LENS) and Binder Jet

Printing (BJP).

Other recent advancements include:

- Production Automation and Control (PAC)
- Innovative Design Technologies such as: Intelligent Conceptual Design, Automatic Feature Recognition (AFR)
- Production Organisation and Management (POM)