STUDY MATERIAL ON

ADVANCE MANUFACTURING PROCESSES

6TH SEMESTER

Prepared by

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PROGRAMME: MECHANICAL ENGINEERING

COURSE: ADVANCE MANUFACTURING PROCESSES **(TH4), 6TH SEM**

COURSE OUTCOMES:

At the end of this subject Students will be able to:

CO1. Explain the working of unconventional machining processes.
CO2. Explain the various processes in making of plastic components for engineering / domestic applications.
CO3. Explain the additive manufacturing process and other related technologies.
CO4. Understand the concepts of Special Purpose Machines.
CO5. Summarize the Maintenance of various Machine Tools.

MAPPING OF COURSE OUTCOMES WITH PROGRAM OUTCOMES AND PROGRAM SPECIFIC OUTCOMES

CO-PO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PSO1	PSO2
CO.1	3	2	3	1	2	2	2	2	3
CO.2	2	2	3	1	2	2	1	2	3
CO.3	3	3	3	1	3	2	2	2	3
CO.4	2	2	3	1	3	2	2	2	3
CO.5	3	2		1	2	2	1	2	

SYLLABUS

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1.0 Modern Machining Processes: 1.1 Introduction – comparison with traditional machining. 1.2 Ultrasonic Machining: principle, Description of equipment, applications. 1.3 Electric Discharge Machining: Principle, Description of equipment, Dielectric fluid, tools (electrodes), Process parameters, Output characteristics, applications. 1.4 Wire cut EDM: Principle, Description of equipment, controlling parameters; applications. 1.5 Abrasive Jet Machining: principle, description of equipment, Material removal rate, application. 1.5 Laser Beam Machining: principle, description of equipment, Material removal rate, application. 1.6 Electro Chemical Machining: principle, description of equipment, Material removal rate, application. 1.7 Plasma Arc Machining – principle, description of equipment, Material removal rate, Process parameters, performance characterization, Applications. 1.8 Electron Beam Machining - principle, description of equipment, Material removal rate, Process parameters, performance characterization, Applications.

2.0 Plastic Processing: 2.1 Processing of plastics. 2.2 Moulding processes: Injection moulding, Compression moulding, Transfer moulding. 2.3 Extruding; Casting; Calendering. 2.4 Fabrication methods-Sheet forming, Blow moulding, Laminating plastics (sheets, rods & tubes), Reinforcing. 2.5 Applications of Plastics.

3.0 Additive Manufacturing Process: 3.1 Introduction, Need for Additive Manufacturing 3.2 Fundamentals of Additive Manufacturing, AM Process Chain 3.3 Advantages and Limitations of AM, Commonly used Terms 3.4 Classification of AM process, Fundamental Automated Processes, Distinction between AM and CNC, other related technologies. 3.5 Application –Application in Design, Aerospace Industry, Automotive Industry, Jewelry Industry, Arts and Architecture. RP Medical and Bioengineering Applications. 3.6 Web Based Rapid Prototyping Systems. 3.7 Concept of Flexible manufacturing process, concurrent engineering, production tools like capstan and turret lathes, rapid prototyping processes.

4.0 Special Purpose Machines (SPM): 4.1 Concept, General elements of SPM, Productivity improvement by SPM, Principles of SPM design.

5.0 Maintenance of Machine Tools: 5.1 Types of maintenance, Repair cycle analysis, Repair complexity, Maintenance manual, Maintenance records, Housekeeping. Introduction to Total Productive Maintenance (TPM).

CHAPTER 1

UNCONVENTIONAL MACHINING PROCESSES

The recent increase in the use of hard, high strength and temperature resistant materials in engineering has necessitated the development of newer machining techniques. With the exception of grinding, conventional methods of removing material from a workpiece are not readily applicable to these new materials.

New materials such as hastalloy, nitralloy, waspalloy, nimonics, carbides etc., are difficult to machine and find applications in aircrafts, nuclear reactors, turbines, special cutting tools etc.

Conventional machining processes when applied to these newer materials:

(i) Are uneconomical,
(ii) Produce poor degree of accuracy and surface finish
(iii) Produce some stress in the metal being cut whereas newer machining techniques are essentially stress free.
(iv) Are slow and highly insufficient.

Although most of the new machining processes have been developed specifically for newer materials that are difficult to machine, some of them (processes) have found use in the production of complex shapes and cavities in softer, more readily machined materials.

CLASSIFICATION

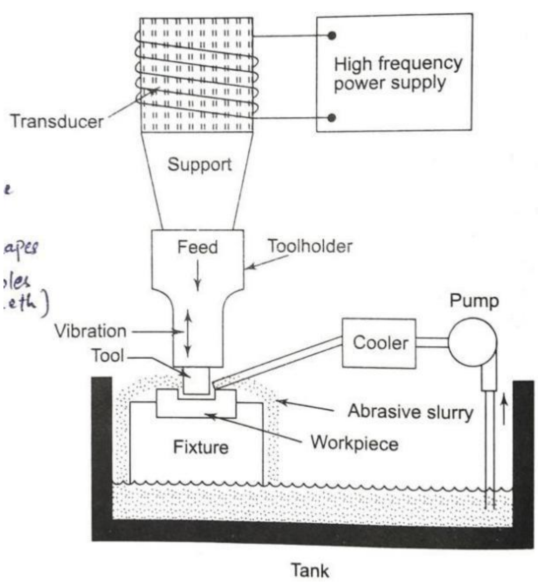
Type of Energy	*Newer Machining Processes*
(*a*) Mechanical	1. Ultrasonic machining (USM) 2. Abrasive jet machining (AJM) 3. Water jet machining (WJM)
(*b*) Chemical	1. Chemical machining (CHM)
(*c*) Electro-chemical	1. Electro-chemical machining (ECM) 2. Electrolytic grinding (ECG)
(*d*) Electro-thermal	1. Electrical discharge machining (EDM) 2. Electron beam machining (EBM) 3. Plasma arc machining (PAM) 4. Laser beam machining (LBM)

Type of Energy	*Mechanism of Metal removal*	*Energy Transfer media*	*Energy Source*	*Process*
(*a*) Mechanical	Erosion	High velocity particles	Pneumatic/hydraulic pressure	AJM, USM, WJM
	Shear	Physical contact	Cutting tool	Conventional machining
(*b*) Chemical	Ablative reaction	Reactive environment	Corrosive agent	CHM
(*c*) Electrochemical	Ion-displacement	Electrolyte	High current	ECM, ECG
(*d*) Electrothermal	Fusion	Hot gases	Ionized material	EBM
	Fusion	Electrons	High voltage	EDM
	Vaporization	Radiation	Amplified light	LBM
	Vaporization	Ion stream	Ionized gas	PAM

ULTRASONIC MACHINING

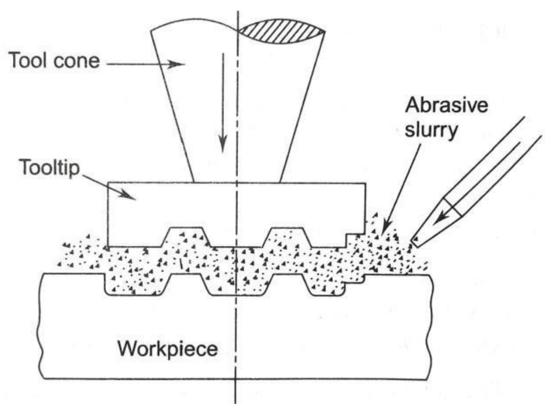
Ultrasonic machining (USM) is a mechanical metal-removal process for brittle materials by using high frequency oscillations of a shaped tool using abrasive slurry. The term ultrasonic refers to the frequency range above the audible range and is above 16 kHz.

A schematic of the ultrasonic machining set-up is shown in Fig. The transducer generates the high frequency vibrations of the order of 20 to 30 kHz with amplitude of the order of 0.02 mm. This vibration is transmitted to the tool made of soft material, through a mechanical coupler known as tool holder. The tool shape is a close complementary shape of the final surface to be generated.



The tool while oscillating would be pressed against the workpiece and fed continuously. Slurry of abrasive grains suspended in a liquid is fed into the cutting zone under pressure as shown in Fig. The slurry is about 30% concentration. Abrasive particles are driven into the work surface by the oscillating tool. The force is typically about 150 000 times the weight of the individual grains. A small crater will be formed at the impact site of the grain, if the workpiece is brittle. A very large number of such small craters remove sufficiently large material from the workpiece.

As the material is removed, the tool is gradually advanced into the workpiece by a servomechanism such that constant gap is maintained between the tool and the workpiece. Finally the shape of the tool is impressed into the workpiece as shown in Fig.



The material removal rates in USM are relatively small, but in materials, which are brittle; this is the only way to produce economically complex cavities without breaking the workpiece. Since there is no direct contact between the workpiece and the tool, fragile workpieces can be conveniently used in USM.

1. **Transducer**

- The transducer in USM is utilized to convert the electrical energy to vibratory motion utilising either the piezoelectric or magnetostrictive principles.
- Piezoelectric materials such as quartz or lead-zirconate-titanate, comes to normal size when an electric current is applied to them and will increase in size when the current is removed.

- The magnetostrictive transducers constructed from nickel, permalloy (Ni 45% and Fe 55%) or permedur (Co 49%, Fe 49% and V 2%) plates which when exposed to strong magnetic field will change length.

2. Tool Cone (Horn)

- Tool cone amplifies the mechanical energy produced by the transducer. Horn mechanically amplifies the vibratory energy to give the required force-amplitude ratio.
- It should have adequate strength. Titanium, monel and stainless steels are generally used as tool-cone materials. Stainless steel is used only for low-amplitude applications.

3. Tool

- Tool tip is attached to the cone by means of silver brazing or by screws. Shape of the tool and its dimensions are governed by the size of abrasive used.
- Length of the tool should be short, since massive tools absorb the vibration energy, reducing the efficiency of machining. Also long tools cause overstressing of the tool and the brazed point. Typically, they are about 25 mm long.
- Slenderness (length to diameter) ratio of the tool should not be greater than 20.
- The tool material should be tough and ductile, but should not be too soft. Generally, low-carbon steel and stainless steel are good tool materials.

4. Abrasive Slurry

- A large variety of abrasives are available for using in USM. The abrasive selected should be harder than the material being machined. Typical abrasives used are aluminium oxide, silicon carbide and boron carbide.
- Aluminium oxide wears fast and are good for glass and ceramics.
- Boron carbide is the most popularly used abrasive. It is harder than silicon carbide and expensive. It has faster material-removal rate and can withstand high-vibrational forces. It is best for tungsten-carbide, tool steel and precious stones.
- Diamond dust is sometimes used for good accuracy, surface finish and cutting rate. It is used for diamonds and rubies.
- Abrasive grain sizes used are from 200 to 2000. The choice of grain size depends upon the finish desired. Generally, 20 to 400 size is used for roughing while 800 to 1000 grit is used for finishing.

- The abrasive is suspended in a liquid with about 30 to 60% by volume of abrasive.

The liquid serves several functions.

- It acts as an acoustic bond between the vibrating tool and the workpiece, to give efficient transfer of energy between the two.
- It acts as a coolant on the tool face.
- It also provides a medium to carry the abrasive to the cutting zone and carry the spent abrasive and dwarf away.

The liquid requires the following properties.

- A density approximately equal to that of the abrasive.
- A low viscosity to carry the abrasive down the sides of the hole between the tool and workpiece.
- High thermal conductivity to carry away the heat.

ADVANTAGES OF USM

a) USM is used for machining hard and brittle materials to complex shapes with good accuracy and reasonable surface finish.
b) It is not affected by the electrical or chemical characteristics of the work material. e Holes of any shape can be produced. It has no high-speed moving parts. Working is not hazardous.
c) Power consumption is about 0.1 watt hour/mm^3 for glass and about 5.0 watt hour/mm^3.

LIMITATIONS OF USM

a) Metal-removal rates are low.
b) Depth of hole produced is limited.
c) Tool wear is high and sharp corners cannot be produced.
d) Flat surfaces cannot be produced at the bottom of the cavity because of the ineffective slurry distribution.

APPLICATIONS:

1. Tool and die making
2. Several machining operations like turning, threading, griding, milling etc
3. Machining of hard to machine and brittle materials
4. Producing holes of round shapes
5. Dentistry work

MRR

Abrasive particles are assumed to be spherical in shape having diameter as'd' units. Abrasive particles (suspended in carrier) move under the high frequency vibrating tool. There are two possibilities when the tool hits an abrasive particle. If the size of the particle is small and the gap between the bottom of the tool and work surface is large enough, then the particle will be thrown by the tool, to hit the work surface (throwing model). Under the reverse conditions, the particle will be hammered over the work surface. In the both cases, a particle after hitting the work surface generates a crater of depth 'h' and radius 'r'.

It is also assumed that the volume of the particle removed is approximately proportional to the diameter of indentation (2r). The volume of material (Vg) removed (shown by dashed lines in Fig. 3.3a and 3.3b, assuming hemi-spherical crater) due to fracture per grit per cycle is given by

$$V_g = \frac{1}{2}\left(\frac{4}{3}\pi r^3\right). \quad \ldots(3.1)$$

From the geometry of Fig. 3.3b, it can be shown that

$$r^2 = \left(\frac{d}{2}\right)^2 - \left(\frac{d}{2} - h\right)^2$$

$$\approx dh \text{ (neglecting } h^2 \text{ terms as } h \ll d). \quad \ldots(3.2)$$

From Eqs. (3.1) and (3.2), we can write

$$V_g = K_1 (hd)^{3/2} \quad \ldots(3.3)$$

where, K_1 is a constant.

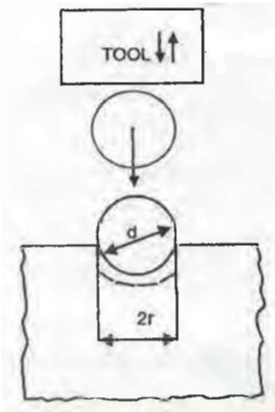


Fig. 3.3 (a) Throwing

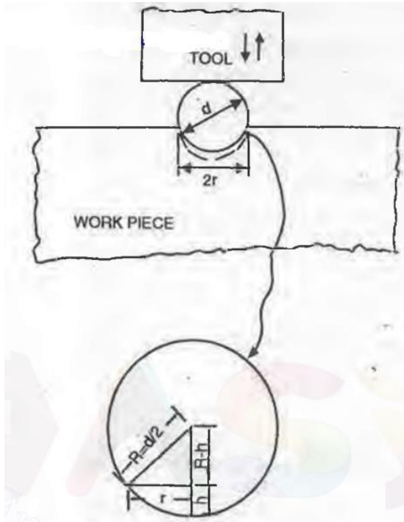


Fig. 3.3 (b) Hammering

Number of impacts (N) on the workpiece by the grits in each cycle will depend upon the number of grits beneath the tool at any time. This is inversely proportional to the diameter of the grit (assumed spherical) as given below.

$$N = K_2 \frac{1}{d^2}$$

Where, K_2 is a constant of proportionality.

All abrasive particles under the tool need not be necessarily effective. Let K_3 be the probability of an abrasive particle under the tool being effective.

Then volume (V) of material removed per second will be equal to the frequency (f) times the amount of material removed per cycle (Vc)

$$V = V_c \times f = K_1 K_2 K_3 \sqrt{\frac{h^3}{d}} \cdot f$$

Also:

The metal removal rate for this process according to Prof. Shaw is given by the relation

$$\text{M.R.R.} = 5.9 f (Ry_0)^{1/2} \frac{\sigma}{H} \text{ mm/sec.}$$

where f = frequency of the active grits striking work surface in c.p.s.

R = Radius of grit in mm

y_0 = Amplitude of vibration in mm

σ = Stress developed in tool in kg/mm^2

H = Surface hardness of the workpiece in kg/mm^2

= $\pi \times$ Compression fracture strength of abrasive particles.

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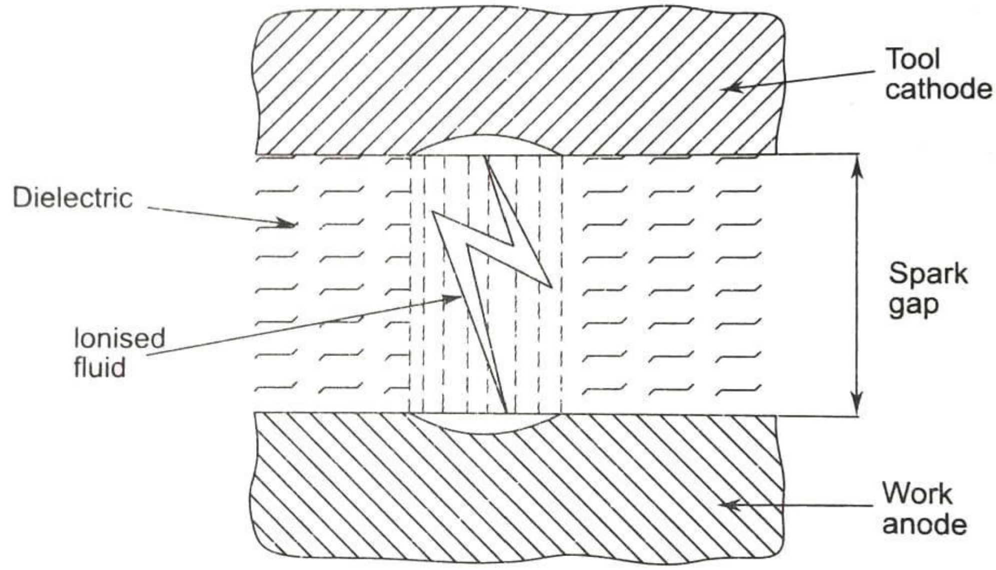
ELECTRIC DISCHARGE MACHINING

Russian scientists Boris and Lazarenko in 1943 at Moscow University found during an experiment that the sparks were more uniform and predictable in oil than in air. They came up with the idea of using this controlled sparking as a method of removing metal. They developed the Lazarenko circuit which is a relaxation circuit based on the resistance-capacitance circuit that remained the standard EDM generator for years. The tool and workpiece are immersed in a dielectric fluid and connected to a dc power supply. The capacitor gets charged from the dc power supply until it is greater than the breakdown potential of the gap between the tool and the workpiece, at which time it will be discharged as an arc-removing material from the workpiece and the tool. They have found this process to be extremely useful for machining hard metals such as tungsten or tungsten carbide.

PRINCIPLE:

- It has been recognized for many years that a powerful spark will cause pitting or erosion of the metal at both the anode (+) and cathode (-), e.g. automobile battery terminals, loose plug points, etc. This process is utilized in electric-discharge machining. This process is also called spark machining or spark-erosion machining.
- The EDM process involves a controlled erosion of electrically conductive materials by the initiation of rapid and repetitive spark discharges between the tool and workpiece separated by a small gap of about 0.01 to 0.50 mm.
- This spark gap is either flooded or immersed in a dielectric fluid. The controlled pulsing of the direct current between the tool and the work produces the spark discharge.
- Initially, the gap between the tool and the workpiece, which consists of the dielectric fluid, is not conductive; however, the dielectric fluid in the gap is ionized under pulsed application of dc as shown in Fig., thus enabling the spark discharge to pass between the tool and the work.
- Heat transfer from the spark to both tool and the workpiece melts, partially vaporizes and partially ionizes the metal in a thin surface layer.

Due to the inertia of the surrounding fluid, the pressure within the spark becomes quite large and may possibly assist in blasting the molten material from the surface leaving a fairly flat and shallow crater. The amount of metal removed per spark depends upon the electrical energy expended per spark and the period over which it is expended.



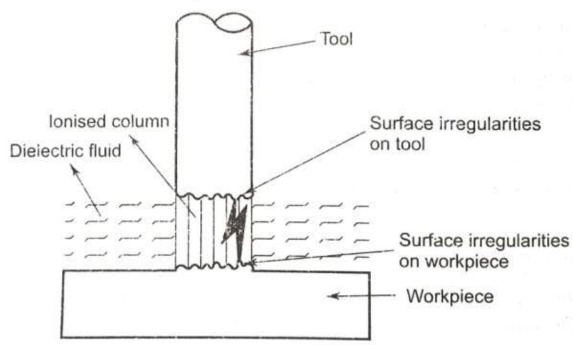
Schematic of the arc formation in EDM process

Thus, the sequence of events in EDM can be summarized as given here:

1. With the application of voltage, an electric field builds up between the two electrodes at the position of least resistance. The ionization leads to the breakdown of the dielectric, which results in the drop of the voltage and the beginning of flow of current.
2. Electrons and ions migrate to the anode and cathode respectively at very high current density. A column of vapour begins to form and the localized melting of work commences. The discharge channel continues to expand along with a substantial increase of temperature and pressure.
3. When the power is switched off, the current drops; no further heat is generated, and the discharge column collapses. A portion of molten metal evaporates explosively and/or is ejected away from the electrode surface. With the sudden drop in temperature, the remaining molten and vaporised metal solidifies. A tiny crater is thus generated at the surface.
4. The residual debris is flushed away along with products of decomposition of dielectric fluid. The application of voltage initiates the next pulse and the cycle of events.
5. Also due to the inertia of the surrounding fluid, the pressure within the spark becomes quite large and may possibly assist in 'blasting' the molten material from the surface,

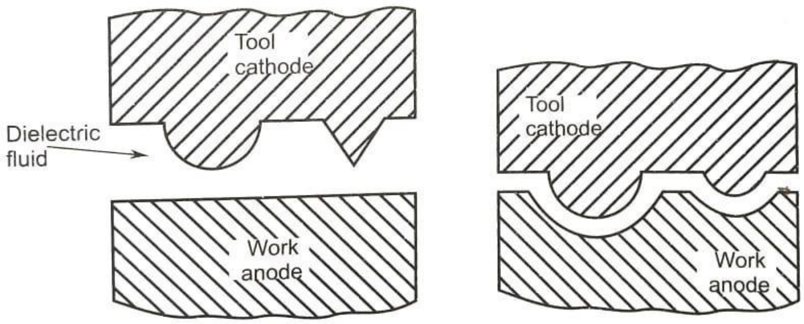
leaving a fairly flat and shallow crater. The amount of metal removed per spark depends upon the electrical energy expended per spark and the period over which it is expended.

6. At any given time only one spark will be made between the tool and workpiece at the shortest path as shown in Fig. As a result of this spark, some volume of metal is removed from both the tool and the workpiece. Then the spark will move to the next closest distance. This process continues till the required material is removed from the workpicce.



Schematic of the arc forming at the smallest distance between the tool and the workpiece in the EDM process

The temperature of the arc may reach about 10000°C. The vapour of the metal would be quenched by the dielectric medium when the arc is terminated by the electric pulse and thus, the wear debris is always spherical in nature. The wear debris would be carried away by the dielectric fluid, which is in continuous circulation. The same process as described above would be continued a number of times per second with each pulse removing a small wear particle from the workpiece, thereby causing the material to take the shape of the electrode. The arc will always be struck at a point between the workpiece which is closest from the tool (electrode); thereby the complimentary tool surface will be reproduced in the workpiece as shown in Fig.



Typical surface generation in EDM process: (a) Initial shape of electrode and workpiece (b) Final complimentary shapes of electrode and workpieces after machining

A typical schematic of the various elements present in a commercial EDM machine is shown in Fig. The main power unit consists of the required controlled pulse generator with the dc power to supply the power pulses. The pulse frequency as well as the on and off time of the pulses can be very accurately controlled using electronic controllers.

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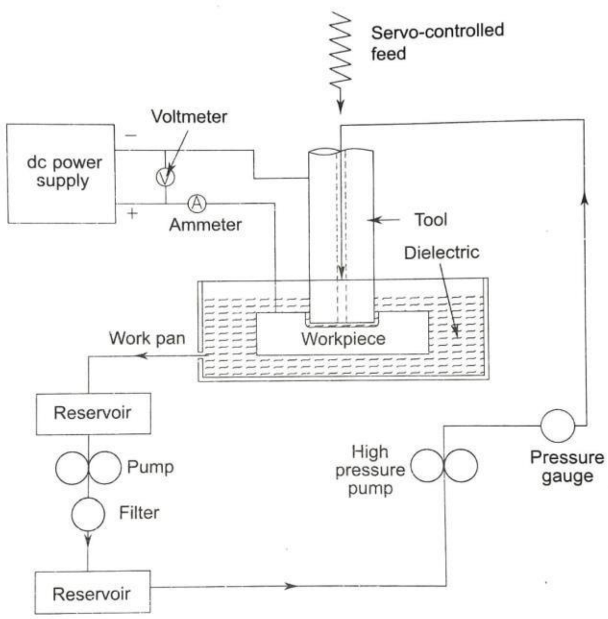


The gap between the electrode and the workpiece increases with the removal of metal. The EDM power supply voltage is dependent upon the spark gap, which needs to be maintained constant. A servo-controlled electrode feeding arrangement would be available which continuously senses the spark gap and moves the tool (electrode) to maintain this gap.

Dielectric Fluid:

1. The dielectric fluid is a spark conductor, coolant, and also a flushing medium. The requirements are explained here:
2. The dielectric fluid should have sufficient and stable dielectric strength to serve as insulation between the tool and work till the breakdown voltage is reached.
3. It should de-ionize rapidly after the spark discharge has taken place.
4. It should have low viscosity and a good wetting capacity to provide effective cooling mechanism and remove the dwarf particles from the machining gap.
5. It should flush out the particles produced during the spark out of the gap. This is the most important function of the dielectric fluid. Inadequate flushing can result in arcing, decreasing the life of the electrode and increasing the machining time.
6. It should be chemically neutral so as not to attack the electrode, the workpiece, the table or the tank.
7. Its flash point should be high to avoid any fire hazards.
8. It should not emit any toxic vapours or have unpleasant odours.
9. It should maintain these properties with temperature variation, contamination by working residuals, and products of decomposition.
10. It should be economical and easily available.

A large number of fluids satisfy the requirement and are used as dielectric fluids. Most popular are the hydrocarbon fluids, silicone-based oils and de-ionized water. Kerosene and water with glycol are generally used.

Electrodes

As explained earlier, in the EDM process, the shape of the electrode is impressed on the workpiece in its complementary form and as such the shape and accuracy of the electrode plays a very important role in the final accuracy of the workpiece machined.

The electrode material should have the following characteristics to serve as a good tool.

1. It should be a good conductor of electricity and heat.

2. It should be easily machinable to any shape at a reasonable cost.

3. It should produce efficient material-removal rates from the workpieces.

4. It should resist the deformation during the erosion process.

5. It should exhibit low electrode (tool) wear rates.

6. It should be available in a variety of shapes.

Various electrode materials used are graphite, copper, graphite, copper-graphite, brass, zinc alloys, steel, copper- tungsten, silver- tungsten, tungsten, etc.

Assignment 1:

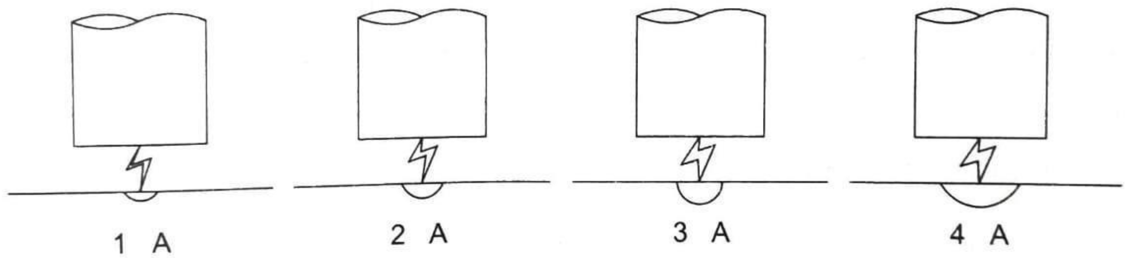
Briefly describe about all the tool materials, their properties and application.

PROCESS PARAMETERS

The metal-removal rates in EDM depend upon the following parameters, which are discussed in greater depth below:

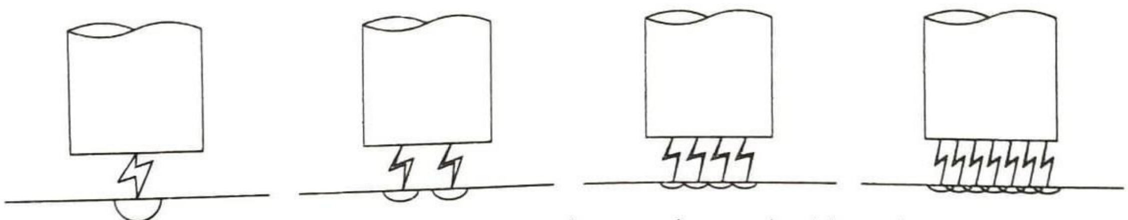
1. Current in each spark
2. Frequency of the discharge
3. Electrode material
4. Workpiece material

The amount of material removed and the surface finish produced is dependent upon the current in the spark. The material removed by the spark can be assumed to be a crater as shown in Fig. The amount removed, therefore, will depend upon the crater depth, which is directly proportional to the current. Thus, as shown schematically in Fig, the material removed increases and at the same time the surface finish also decreases.



Schematic representation of the effect of the current in each spark, which determines the material removed

However, decreasing the current in the spark, but increasing its frequency will improve the surface finish in view of the small crater size, but at the same time the material-removal rate can be maintained by increasing the frequency. The same is shown schematically in Fig.



Schematic representation of the effect of spark frequency on the material removed and the surface finish

Typical parameters used in EDM process are

• Spark gap	0.0125 to 0.125 mm
• Current	0.5 to 400 A
• Voltage (dc)	40 to 300 V
• Pulse duration	2 to 2000 μs
• Dielectric pressure	< 0.2 MPa

The metal-removal rates are about 16.4 cm^3/hour per 20 A of current. This can go as high as 250 cm^3/hour per 20 A of current.

Surface finish	3 to 10 μm Rough
	0.8 to 3 μm Finish

Characteristics of EDM Process

Mechanism of process	Controlled erosion (melting and evaporation) through a series of electric sparks.
Spark gap	0.010—0.125 mm
Spark frequency	200—500 kHz
Peak voltage across the gap	30—250 V
Metal removal rate (max.)	5000 mm^3/min
Specific power consumption	2-10 W/mm^3/min
Dielectric fluid	Kerosene liquid paraffin, silicon oil
Tool material	Brass, copper, graphite, Ag-W alloys, Cu-W alloys.
$\frac{\text{Material removal rate}}{\text{Tool wear rate}}$	0.1—10
Materials that can be machined	All conducting metals and alloys.
Shapes	Microholes, narrow slots, blind complex cavities.
Limitations	High specific energy consumption, non-conducting materials can't be machined.

APPLICATIONS

The EDM process is extensively used because of its many advantages. A few of them are discussed below:

1. There is no physical contact between the tool and the workpiece and hence, no cutting forces are acting on the workpiece. Even fragile workpieces can be machined using this process.
2. Any complex shape required in dies and moulds can be easily produced to the required degree of accuracy and finish. Since the process copies the tool shape in a complementary form, making a male electrode is easier than the complementary female form required.
3. The process is not affected by the hardness of the work material. Hence, even the hardened material can be machined.
4. The material-removal rates are almost comparable with that of the conventional machining processes.

5. Since there are no cutting forces acting on the tool, high-aspect ratio surfaces can be machined using EDM process.
6. The process is generally highly automated with very little operator skill required.
7. The actual surface produced by EDM consists of small craters, which may help in the retention of the lubricants.

DISADVANTAGES

1. The wear rate on the electrode is considerably higher.
2. Sometimes it may be necessary to use more than one electrode to finish the job.
3. The workpiece should be electrically conductive to be machined using the EDM process.
4. Energy required for the operation is more than that of Conventional process and hence will be more expensive.

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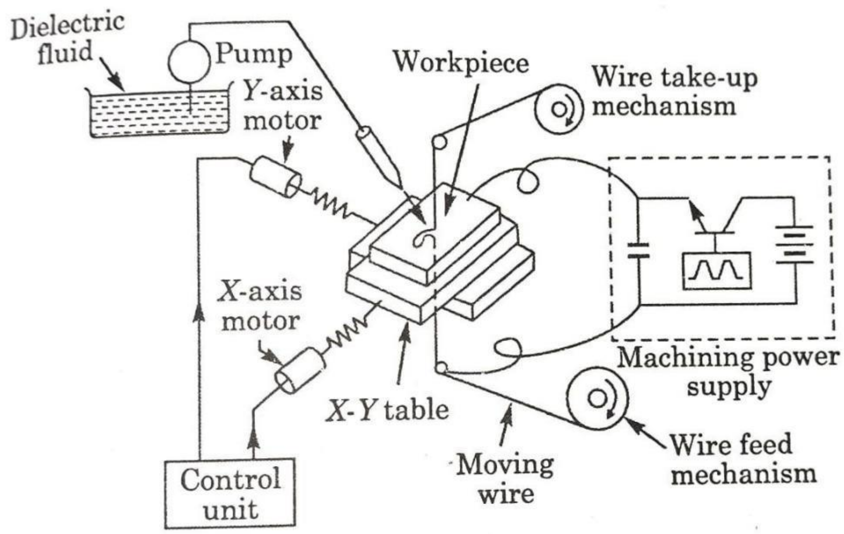
WIRE-CUT EDM

The wire-cut EDM uses a very thin wire 0.02 to 0.3 mm in diameter as an electrode and machines a workpiece with electrical discharge like a band saw by moving either the workpiece or wire.

PRINCIPLE AND DESCRIPTION OF EQUIPMENT

Erosion of the metal utilizing the phenomenon of spark discharge is the very same as in conventional EDM. The prominent feature of a moving wire is that a complicated cutout can be easily machined without using a forming electrode. Fig shows in schematic form the principle of wire-cut EDM process.



Wire-cut EDM machine basically consists of a machine proper composed of a workpiece contour movement control unit (NC unit or copying unit), workpiece mounting table and wire drive section for accurately moving the wire at constant tension; a machining power supply which apples electrical energy to the wire electrode; and a unit which supplies a dielectric fluid (distilled water) with constant specific resistance.

THE VARIOUS FEATURES OF WIRE-CUT EDM PROCESS ARE:

(i) Forming Electrode Adapted to Product Shape is not required. Since a thin wire of copper or tungsten is used as the electrode to machine the workpiece as programmed, there is no need for forming electrodes which are traditionally made by cutting and grinding an expensive alloy of silver and tungsten or copper and tungsten. This feature helps reduce man-hour requirements and insures greater economy due to use of an inexpensive electrical material. The consumption of wire on the EDM machine is about 0.03 kg/ hr. The 0.2 mm dia copper wire which is most frequently used for wire-cut EDM can generally machine for 50 to 60 hours.

(ii) Electrode Wear is Negligible. Since the wire electrode is constantly fed during machining, its wear can be practically ignored.

(iii) Machined Surfaces are Smooth. Since a new portion of wire electrode is constantly supplied at a speed of about 10 to 30 mm/sec, machining can be continued without any accumulation of chips and gases. Since a very thin electrode is used, an extremely small amount of discharge energy suffices for one spark and the workpiece is machined under conditions for finishing as specified for conventional EDM.

(iv) Geometrical and Dimensional Tolerances are Tight. Wire-cut EDM is not a sinking process with a formed electrode as in conventional EDM. The table is driven in increments of 1 µm per pulse, enabling two-dimensional contours to be machined to close tolerance and repeatability.

(v) Relative Tolerance between Punch and Die is Extremely High and Die Life is extended. A programmed full scale figure can be enlarged or reduced in 1 µm increments of compensation value. This capability allows the punch and dies to be machined with a minimum required clearance, which has been traditionally done by skill and fitting the punch and die.

(vi) Straight Holes can be produced to Close Tolerance. The wire is maintained at optimum tension by a unique wire tension control mechanism. This prevents tapers, barrel Shaped holes, machining streaks, wire breakage and wire Vibration.

(vii) EDM Machine can be Operated Unattended for Long Time at High Operating Rate. Distilled water is used as the dielectric fluid and all machine motions are controlled by NC. As a result, the wire-cut EDM machine can be operated unattended day and night without any fire hazards.

APPLICATIONS

- Wire EDM is used for machining the sheet metal dies, extrusion dies and prototype parts. It is relatively a very slow process.
- Used to cut plates as high as 300mm thick for making punches, tools and dies.

PROCESS PARAMETERS

Pulse on time: it represents the duration of current flow in microseconds in each cycle. It is set in the range of 105-125µs. The discharge energy increases with increasing pulse on time, resulting in higher cutting rate. With higher values of pulse on time, surface roughness tends to be higher. The higher value of discharge energy may also cause wire breakage.

Pulse off time: It is referred as toe and it represents the duration elapse in microseconds between the two consecutive pulses on time. It is set in the range of 43 to 63 ps. With lower value of pulse off time, there is more number of discharges in a given time, resulting in an increase in the sparking efficiency. As a result, the cutting rate also increases. Very low value of pulse off time may cause wire breakage which in turn reduces the cutting efficiency. With an increase in the discharge pulse duty factor (pulse off time increases), average gap current is reduced.

Peak current: Peak current is represented as IP and it is the maximum value of the current passing through the electrode during pulse on time. The peak current is set in the range of 150-230 A. Increase in the peak current increases the pulse discharge energy which improves the cutting rate. For higher value of the peak current, gap conditions may become unstable with improper combination of pulse on time and pulse off time settings.

Wire tension: it is represented as WT and it shows how much the wire is being stretched between upper and lower wire guides. The wire tension is set at the range of 4-12 g and maintained with the tension so, that it remains straight between the wire guides.

MRR:

Material removal rate increases with increase in discharge current. However, in case of brass and copper, it decreases after some limit, because pulse energy increases as the current increases. Material removal rate does not observe linearity with pulse energy. This may be due to the possible losses of thermal energy by conduction to the surrounding material and to the dielectric fluid. An increase in current beyond certain limit for a given electrode area and material has adverse effects on material removal rate.

Material Removal Rate is the principle of conversion of electrical energy into thermal energy. During the process of machining, the sparks are produced between the work piece and the electrode. Thus, each spark produces a tiny crater and crater formation in the material along the cutting path by melting and vaporization erodes the workpiece.

After machining, the Material Removal Rate has been measured.

Material removal rate has been calculated by the following formula:

$$MRR = \frac{W_i - W_f}{\rho \times t}$$

Where,

W_f is the final weight of workpiece material

W_i is the initial weight of the workpiece material

't' is the machining time

'ρ' is the density of the material.

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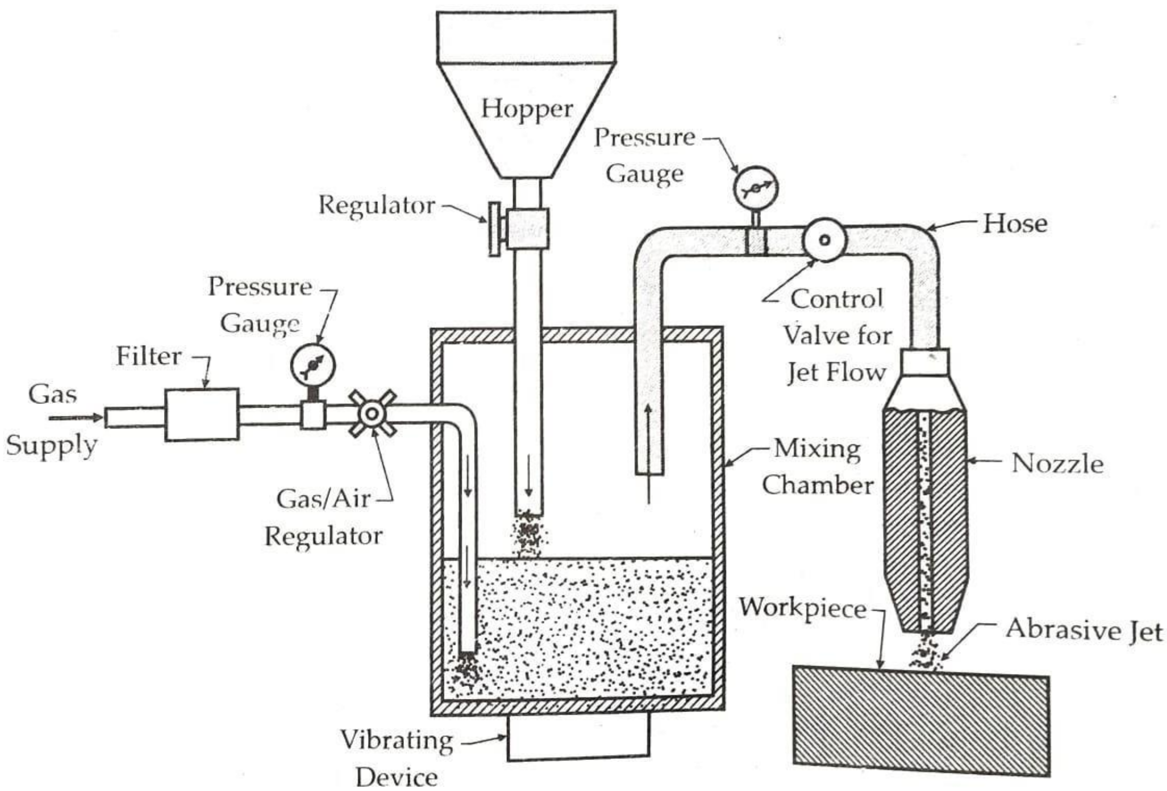
ABRASIVE JET MACHINING (AJM)

PRINCIPLE, DESCRIPTION OF EQUIPMENT

This process consists of directing a stream of fine abrasive grains, mixed with compressed air or some other gas at high pressure, through a nozzle on to the surface of the workpiece to be machined. These particles impinge on the work surface at high speed and the erosion caused by their impact enables the removal of metal. This process is mainly employed for such machining works which are otherwise difficult, such as thin sections of hard metals and alloys, cutting of materials which are sensitive to heat damage, producing intricate holes, deburring, etching, polishing etc. However this process should not be misunderstood as sand blasting because this process is basically meant for metal removal with the use of small abrasive particles, where as the sand blasting process is a surface cleaning process which does not involve any metal cutting.

Fine grained abrasive powder is filled in a vibrating chamber, called 'mixing chamber'. The gas or air at high pressure is forced into this chamber, the pressure of the gas varying from 2kg/cm2 to 8.5kg/cm2. For normal machining work the nozzle can be manipulated by hand, but for cutting critical shapes or precision cutting along an intricate contour either the workpiece or the nozzle is mounted on suitable fixtures and moved by means of well designed mechanisms along a predetermined path, such as cams, pantographs, etc.

A typical set-up for Abrasive Jet Machining (AJM) is shown in Fig. The abrasive particles are contained in a suitable holding device, like a hopper, and fed into the mixing chamber. A regulator is incorporated in the line to control the flow of abrasive particles. Compressed air or high pressure gas is supplied to the mixing chamber through a pipe line. This pipe line carries a pressure gauge and a regulator to control the gas flow and its pressure. The mixing chamber, carrying the abrasive particles, is vibrated and the amplitude of these vibrations controls the flow of abrasive particles. These particles mix in the gas stream, travel further through a hose and finally pass through the nozzle at a considerably high speed. This outgoing high speed stream of the mixture of gas and abrasive particles is known as Abrasive Jet.



GASES, ABRASIVES AND NOZZLE MATERIALS:

- The carrier gas used in this process should be nontoxic, easily available, cheap and the one that dries quickly. The gases commonly used are air, nitrogen or carbon dioxide.

- The abrasives commonly used include aluminium oxide, silicon carbide, sodium-bi-carbonate, dolomite and small size glass beads. Aluminium oxide is used for general purpose machining, grooving and cutting, silicon carbide for faster machining of hard materials, sodium-bi-carbonate for fine finishing work, dolomite for etching and light cleaning and glass beads for fine deburring and light polishing.
- The nozzles used are made of tungsten carbide or synthetic sapphire because the nozzles are required to be highly abrasion resistant.

MRR:

The material removal rate in abrasive jet machining

$$= KNd^3 v^{3/2} \left(\frac{\rho}{12H}\right)^{3/4}$$

where K = constant, N = number of abrasive particles impacting per unit time

d = mean diameter of abrasive particles, v = velocity of abrasive particles

ρ = density of abrasive particle, H = hardness of work material.

For best cutting results Al_2O_3 abrasive particles of size 15 μm to 20 μm are used. Since the cutting capacity of particles decreases after one cutting action, these are normally not reused.

APPLICATIONS OF AJM

This process is widely used for machining of brittle materials like glass, ceramics, refractories, etc., cleaning and cutting operations on materials like germanium, silicon, quartz, mica and many other operations like etching, marking, deburring, etc. Some typical applications of this process include:

(i) Fine drilling and micro welding, (ii) Aperture drilling for electronic microscopes, (iii) Machining of semiconductors, (iv) Machining of intricate profiles on hard and fragile materials, and (v) Frosting and abrading of glass articles.

ADVANTAGES OF AJM

I. Intricate cavities and holes of any shape can be machined in materials of any hardness.
II. Brittle materials of thin sections can be easily machined.
III. Normally inaccessible portions can be machined with fairly good accuracy. >» Low capital investment required.
IV. There is no direct contact between the tool and workpiece.
V. Amount of heat generated is not appreciable.

DISADVANTAGES OF AJM

a) It is not suitable for machining of ductile materials.
b) Metal removal is slow.
c) Machining accuracy is relatively poorer.
d) There is always a danger of abrasive particles getting embedded in the work material. Hence, cleaning needs to be necessarily done after the operation.
e) The abrasive powder used in the process cannot be reclaimed or reused.

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LASER BEAM MACHINING (LBM)

Laser is an electro-magnetic radiation. It produces monochromatic light which is in the form of collimated beam.

It finds uses for microdrilling it microwelding, etc. However it has low efficiency and high energy input requirements.

Light amplification by stimulated emission of radiation is called laser beam. In this process, use is made of laser beam (a narrow beam of coherent, monochromatic light) which is focused on the work-piece by lens to give extremely high energy density to melt and vaporise any material.

PRINCIPLE OF LASER BEAM PRODUCTION

Electrons are arranged in different cells in an atom and each cell has a set number of electrons. If any atom is excited, i.e. we pump some amount of external energy (either by heat, or bombardment with protons), then the atomic cell will be in excited condition and some electrons will jump up to next energy level, i.e. electrons jump from one orbit to next one.

When an atom gets some sort of energy from external source, three types of behaviours can be possible.

(1) Normally atom is not excited. (It remains at same energy level). Then it will absorb external energy, and shoot up to higher energy level.
(2) If nothing happens to that atom in the excited condition, it will radiate the energy received by it. This emission of energy will take some time but will be spontaneous,
(3) If any photon bombards an atom at the excited condition, or at higher energy level, then it will emit the excess energy instantaneously.

For production of laser beam, we generally use Ruby rod in which aluminium is the main ingredient, chromium being present as impurity in the ratio of 1 to 5000 atoms. The chromium plays very important role for laser beam production and is most desirable. If it was not there then no laser beam could be produced.

When chromium receives any radiation, it absorbs it except red and blue light photons, and thereafter emission of various colours by it takes place. This emission in normal phenomena will not be instantaneous as the atoms are not at excited level. In the case of Ruby rods, chromium will impede external radiation and after some time emit spontaneously all the radiation and light can be seen coming out of it.

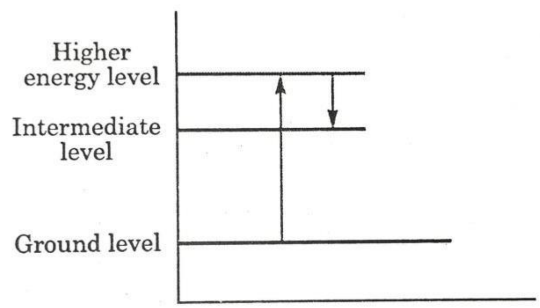
For production of laser beam it is desirable that the energy be pumped in, and pumped energy should come out instantaneously, of course, it will be of great intensity.

Thus we find that, laser beam technique involves

(1) Pumping of energy

(2) Production of stimulation effect.

When atoms are excited to higher energy level and emit energy, at one stage these come to metastable state and they remain at this metastable state for 3/1000th sec. or even smaller time. It is at this condition we try to bring stimulation of energy in case of chromium.



When chromium atom is bombarded, it jumps from ground level to higher energy level and instantaneously drops down to intermediate energy level. (Because upper position is most unstable). It has further tendency to return to ground level unless bombarded by other photons.

In case of chromium before jumping to ground level, it rests at intermediate level. Intermediate level is metastable position and it remains at this stage for 3/1000 sec. and after that to ground level radiating out the energy absorbed by it.

Stimulation effect: At intermediate stage, atom is at high energy level. If a photon hits at this stage, then it will instantaneously emit the photon received by it (because it is at higher energy level) and this is stimulation effect. This energy is utilised for various purposes like cutting, drilling, welding, etc.

The major difficulty faced was of attaining metastable condition, i.e. artificially bringing at higher energy level and keeping at that level for sufficient time so as to be bombarded by other photons.

After several reflections, all photons will come out from window (partially reflecting mirror) with great intensity. If the two faces of the rod are perfectly parallel, then the condition of all the photons moving in same direction can be achieved. Otherwise the photons will move in random way.

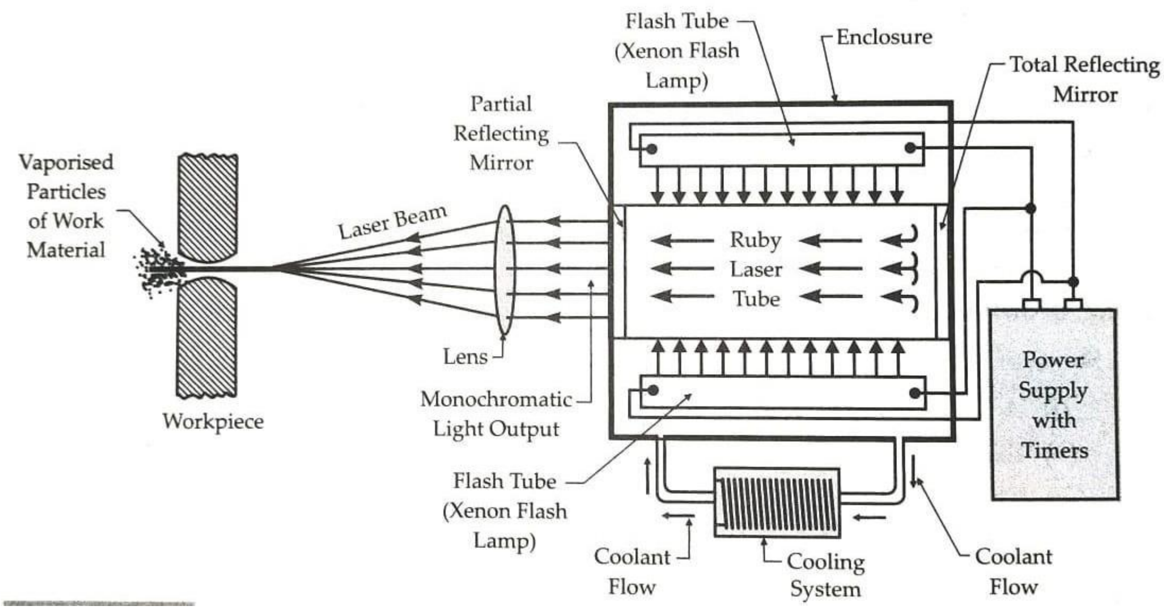


Fig. shows the setup for Laser Beam Machining, together with its circuit. It mainly consists of a Laser tube or rod, a pair of mirrors one at each end of the tube, a flash tube or lamp (energy source), a power supply source, a cooling system and a lens. The main setup is fitted inside an Enclosure, which carries a highly reflective surface inside.

The method of laser beam production: Xenon Flash lamps (photon energy) continuously bombard the chromium atoms of Ruby rod. This excites the atoms of the inside media, which absorb the radiation of incoming light energy. This results in the to and fro travel of light between the two reflecting mirrors. But, the partial reflecting mirror does not reflect the total light back and a part of it goes out in the form of a coherent stream of monochromatic light. This highly amplified stream of light is focussed through a lens, which converges it to a chosen point on the workpiece. This high intensity converged laser beam, when falls on the workpiece, melts the workpiece material, vaporises it almost instantaneously and penetrates into it. Thus, it can be called a type of thermal cutting process.

The cutting rate (mm/min.) can be expressed as

$$= C \frac{P}{EAt}$$

where C = is a constant dependent upon the material and conversion efficiency of laser energy into the material

P = laser power incident on surface, W,

E = vaporisation energy of material, W/mm^3

A = area of laser beam at focal point, mm^2,

t = thickness of material, mm.

It has been observed that material cutting rate is dependent upon the thickness of the workpiece, being maximum for thin materials and reduces exponentially for higher thickness. Thus while holes of 0.1 mm diameter may be drilled to a depth of 50 times the diameter, but hole of 1 mm diameter can be drilled through 2.5 mm thick material.

Characteristics of LBM Process

Material removal technique	Heating, melting and vaporisation.
Tool	Laser beams in wavelength range of 0.4—0.6 μm.
Power density	As high as 10^7 W/mm^2.
Output energy of laser and its pulse duration	20 J, 1 milli second.
Peak power	20 kW.
Medium	Normal atmosphere.
Material removal rate	5 mm^3/min.
Specific power consumption	1000 W/mm^3/min.
Material of workpiece	All materials except those with high thermal conductivity and high reflectivity.
Applications	Drilling micro holes (upto 250 μm) and cutting very narrow slots.
Dimensional accuracy	± 0.025 mm.
Efficiency	0.3—0.5%.
Limitations	Taper of 0.05 mm when work thickness is more than 0.25 mm. Very large power consumption.

Two types of lasers are now in common use: (a) Solid lasers, (b) Gas lasers.

Solid lasers are only capable of providing short bursts of power, whereas gas lasers produce a continuous laser beam. Solid lasers best suited to production work use a neodymium-doped glass rod as the lasing medium. The rod ends are finished as optical surfaces with reflective coatings. One end has a partially reflective coating to permit escape of the laser beam when it has reached the required intensity. The laser rod is initially excited by a high intensity flash lamp.

At present, carbon dioxide gas (CO_2) lasers are most efficient for converting electricity into laser power. Gas lasers operate in basically the same manner as solid lasers, except that a gas serves as the lasing medium and is capable of providing a continuous laser beam. This feature makes the gas laser best suited to continuous cutting or welding.

Advantages of laser beam machining

(i) Ability to machine through air, inert gas, vacuum or optically transparent liquids or solids.
(ii) Applicability to any known material.
(iii) Absence of direct contact and large forces between the tool and workpiece.
(iv) Suitability for cutting ceramic and other materials that are readily damaged by heat shock.
(v) Accuracy and ability to make very small holes and cuts.

Disadvantages of Laser beam machining

(i) Need for skilled operators.
(ii) High capital and operating cost.
(iii) Slow production rate, because precise alignment is required.
(iv) Heat damage effects on workpieces.
(v) Limited applicability (thin workpieces and removal of small amounts of material.)

Applications of laser beam machining

(i) Drilling holes in tungsten, brass and ceramic.
(ii) To generate the complex pattern on film that is used to make integrated circuits (IC).

(iii) To repair or cut patterns in thin gold film on electronic equipment.

(iv) To trim carbon resistors to accurate readings.

(v) In garment industry for cutting of patterns from single ply or multi-layer stacks of fabrics.

(vi) Dynamic balancing of gyro-rotors, watch or clock balance wheels or precision rotating parts; high Speed balancing is accomplished by vaporizing away excess metal as the part rotates on the balancing machine.

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ELECTROCHEMICAL MACHINING

Introduction

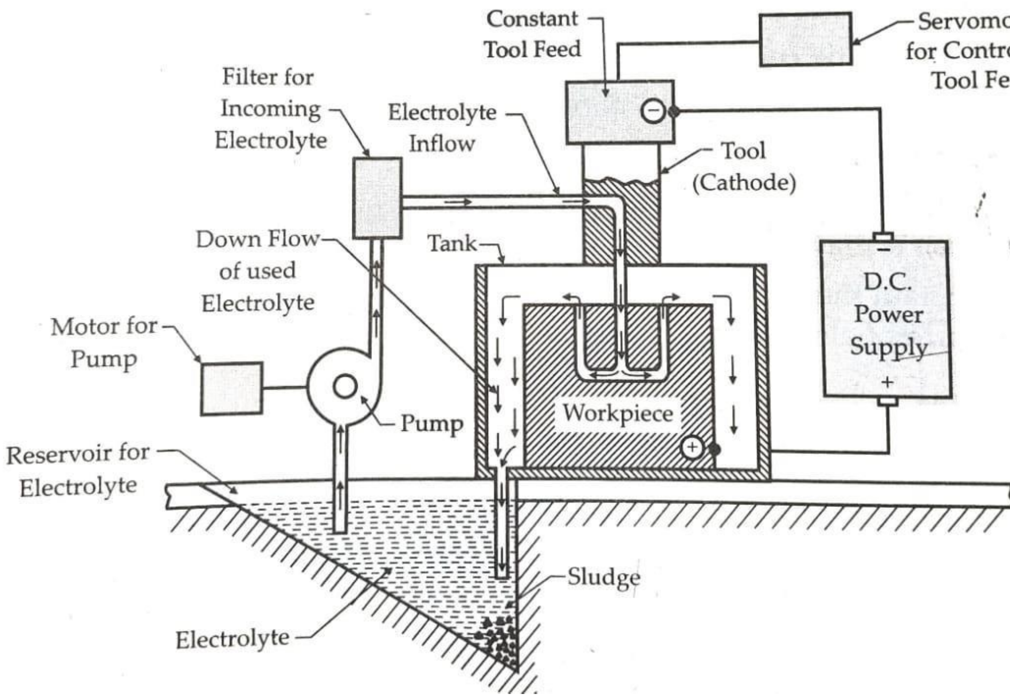
Electrochemical machining is a machining process that may be described as the reverse of electroplating. In electroplating, the metal is deposited on the workpiece, whereas instead of depositing metal on the workpiece, electrochemical machining reverses the process so that the metal is depleted or removed from the workpiece.

PRINCIPLE OF OPERATION

Electrochemical machining process is based on the fundamental laws of electrolysis which states that the amount of material deposited or dissolved is directly proportional to the current density multiplied by time.

High density direct current is passed through an electrolyte solution that fills the gap between the workpiece (anode) and the shaped tool (cathode). The electrochemical reaction depletes the metal of the workpiece.

Referring to Fig. the workpiece (which must be a conductor of electricity) is placed in a tank on the machine table and connected to the positive terminal of a D.C. supply. Thus, workpiece is made anode in the ECM process. (In electroplating the workpiece is made cathode by connecting the same to the negative terminal).



The tool electrode, shaped to form the required cavity in the workpiece, is mounted in the tool holder and connected to the negative terminal of the supply.

An electrolyte flows through the gap (which is 0.0254 to 0.76 mm) between the tool and the workpiece and is then pumped back to the working zone, either through the tool or externally, depending upon the application.

The action of the current flowing through the electrolyte is to dissolve the metal at the anode, that is, the workpiece. The electrical resistance is lowest (and hence the current is highest) in the region where the tool and the workpiece are closest. Since the metal is dissolved from the workpiece most rapidly in this region, the form of the tool will be reproduced on the workpiece. .

There is no mechanical contact between the workpiece and the tool, and any tendency of the workpiece metal to be plated on the tool (the cathode) is counteracted by the flow of the electrolyte, which removes the dissolved metal from the working zone.

MATERIAL REMOVAL RATE

Hence, the material-removal rate (MRR) in ECM (assuming 100% current efficiency) is given by

$$MRR = \frac{A\,I}{Z\,F}\ \text{kg/s}$$

The volumetric material-removal rate is given by dividing the above with the density of the workpiece material,

$$MRR = \frac{A\,I}{Z\,F\,\rho_a}\ \text{mm}^3/\text{s}$$

where A = Atomic weight of the work material,
I = Current, amperes
Z = Valency of the work material,
F = Faraday's constant = 96 540 coulombs, and
ρ_a = Density of work material

The gap resistance R is given by

$$R = \frac{\rho\,h}{A_{\text{Gap}}}$$

where ρ = Specific resistance of the electrolyte,
h = equilibrium gap, and
A_{Gap} = Cross-sectional area of the gap.

ELECTROLYTE

Electrolytes used in ECM should be carefully selected such that they provide the necessary reactions without plating the cathode. The typical functions expected to be served by an electrolyte in ECM are

- Completes the electrical circuit between the tool and the workpiece
- Allow desirable machining reactions to takes place
- Carry away heat generated during the operation
- Carry away products of reaction from the zone of machining

The properties that should be carefully looked into during the selection of the electrolyte to serve the function are

- ✓ High electrical conductivity
- ✓ Low viscosity and high specific heat
- ✓ Chemical stability
- ✓ Resistance to formation of passivating film on workpiece surface
- ✓ Noncorrosive and nontoxic
- ✓ Inexpensive and readily available

The salt solutions, with water forming a large proportion, satisfy many of the above conditions and, therefore, are generally used. Some general electrolytes used are the following:

1. Sodium chloride or potassium chloride. Most widely used because of low cost and stable conductivity over a broad range of pH values. However, it is corrosive and produces large amount of sludge. It cannot be used on tungsten-carbide or molybdenum.
2. Sodium nitrate. Less corrosive but forms a passive film on the workpiece surface. Hence, not used as a general-purpose electrolyte. It is used for machining aluminium and copper.

ECM TOOLS:

The properties expected of the tool materials are

1. High electrical and thermal conductivity
2. Good stiffness
3. Easy machinability
4. High corrosion resistance

Generally, aluminium, copper, brass, titanium, cupro-nickel and stainless steel are used as tool materials.

Typical ECM parameters used are

- Current 50 to 40 000 Amperes
- Current density 8 to 233 Amperes/cm^2
- Voltage 4 to 30 V dc
- Gap 0.025 to 0.75 mm
- Electrolyte velocity 15 to 60 m/s
- Electrolyte pressure 0.069 to 2.700 MPa
- Electrolyte temperature 24 to 65°C
- Feed rate 0.5 to 19.0 mm/min

ADVANTAGES OF ECM

1. Any good electrically conducting material can be machined and its mechanical properties have no bearing on its machinability through this process.
2. Intricate and complex shapes can be machined easily through this process.
3. Metal removal rate is quite high in comparison to traditional machining, specially in respect of high tensile and high temperature resistant materials.
4. Wear on tool is insignificant or (say) almost non-existent.
5. The machined work surface is free of stresses.
6. No cutting forces are involved in the process.
7. High surface finish, of the order of 0.1 to 2.0 microns, can be obtained.
8. Very thin sections, such as sheet metal, can be easily machined without any danger ot damage or distortion.
9. It is an accurate process and close tolerances of the order of 0.05 mm can be easily obtained. :
10. With the application of this process, many machining operations, like grinding, milling, polishing, etc., can be dispensed with.

DISADVANTAGES OF ECM

a) Materials which are non-conductors of electricity cannot be machined.
b) Power consumption is very high.

c) Corrosion and rusting of workpiece, machine tool, fixtures, etc., by electrolyte
d) Required initial investment is quite high.
e) Extremely fine corner radii, say less than 0.2 mm, cannot be produced.
f) Designing and fabrication of tools is relatively more difficult.
g) Larger floor space is required.
h) Specially designed fixtures are required to hold the workpiece in position, because it may be displaced due to the pressure of the inflowing electrolyte.
i) A constant monitoring is required to suitably vary the tool feed rate and supply pressure of electrolyte so as to avoid formation of cavitations.

APPLICATIONS OF ECM

(i) Machining of hard to machine and heat resistance materials.
(ii) Machining of blind holes and pockets, such as in forging dies.
(iii) Machining of complicated profiles, such as of jet engine blades, turbine blades, turbine wheels, etc.
(iv) Drilling small deep holes, such as in nozzles.
(v) Machining of cavities and holes of irregular shapes.
(vi) Deburring of parts.

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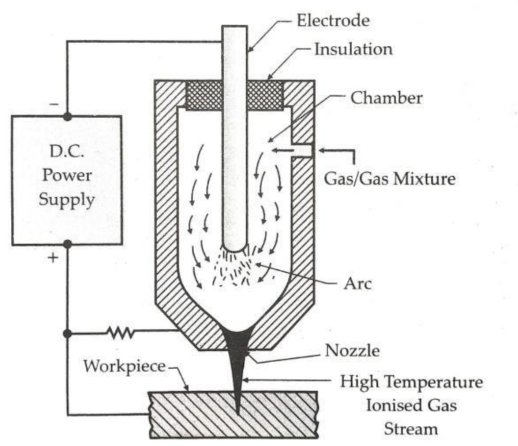
PLASMA ARC MACHINING (PAM)

When gases are heated to temperatures above 5500°C, they are partially ionised and exist in the form of a mixture of free electrons, positively charged ions and neutral atoms. This mixture is termed as plasma. The temperature of central part of plasma goes as high as between 11000°C to 28000°C, where the gas is completely ionised. In Plasma arc machining or Plasma arc cutting, a high velocity jet of this high temperature ionised gas is directed on to the workpiece surface by means of a well designed plasma-arc cutting torch, shown in Fig. This jet melts the metal of the workpiece and displaces the molten metal away from its path. The heating of workpiece material is not due to any chemical reaction but on account of the continuous attack of electrons which transfer the heat energy of high temperature ionised gas to the work material. This process can, therefore, be safely used for machining of any metal, including those which can be subjected to chemical reaction.



Material to be cut	*Gas or gas mixture used*
Aluminium	Nitrogen, Nitrogen-hydrogen, argon-hydrogen.
Magnesium	Nitrogen, Nitrogen-hydrogen, argon-hydrogen.
Stainless steel and some other non-ferrous metals	Nitrogen-hydrogen, argon-hydrogen.
Carbon and alloy steels, cast iron	Nitrogen-hydrogen, compressed air.

PRINCIPLE OF OPERATION

As shown in Fig, the Plasma-arc cutting torch carries a tungsten electrode fitted in a small chamber. This electrode is connected to the negative terminal of a d.c. power supply source and, therefore, acts as a cathode. The other (+ve) terminal of the power supply is connected to the nozzle formed near the bottom of the chamber. The nozzle acts as an anode. On one side of the torch is provided a passage for supply of gas into the chamber. There is also q provision of water circulation around the torch so that the electrode and the nozzle both remain water cooled.

A strong arc is struck between the electrode (cathode) and the nozzle (anode) and the gas forced into the chamber. As the gas molecules collide with the high velocity electrons of the arc, the former get ionised and a very large amount of heat energy is evolved. The flow of gas is so controlled that the arc remains stable. This high velocity stream of hot ionised gas, called plazma, is directed on to the workpiece to melt its material and also blow it away.

Some of the advantages offered by this process include:

(i) A faster process,
(ii) Excessively high temperatures are generated for use
(iii) Can be used to cut any metal.

However, the initial cost of the equipment is quite high and adequate safety precautions are always needed for the operator. Also, the work surface may undergo some metallurgical changes.

Main Applications

The main applications of this process include cutting of stainless steel and non-ferrous metals (such as aluminium alloys), particularly their profile cutting. With feasibility of its use under water, it is used in shipyards. Other industries using this technique include nuclear power plants, chemical industries, etc. Also, this technique has been successfully used for turning and milling of 'hard to machine' materials.

Characteristics of PAM Process

Technique of machining	Heating of workpiece by high temperature ionised gas (plasma) and causing quick melting
Tool	Plasma jet
Velocity of plasma jet	500 m/sec.
Material removal rate	150 cm^3/min
Specific energy	1000 W/cm^3-min
Power range	2 to 200 kW
Material of workpiece	All materials which conduct electricity
Voltage	30—250 V
Current	Upto 600 amp.
Cutting speed	0.1—7.5 m/min
Applications	Profile cutting of stainless steel, monel, and superalloy plates
Plate thickness	200 mm (max)
Limitation	Low accuracy.

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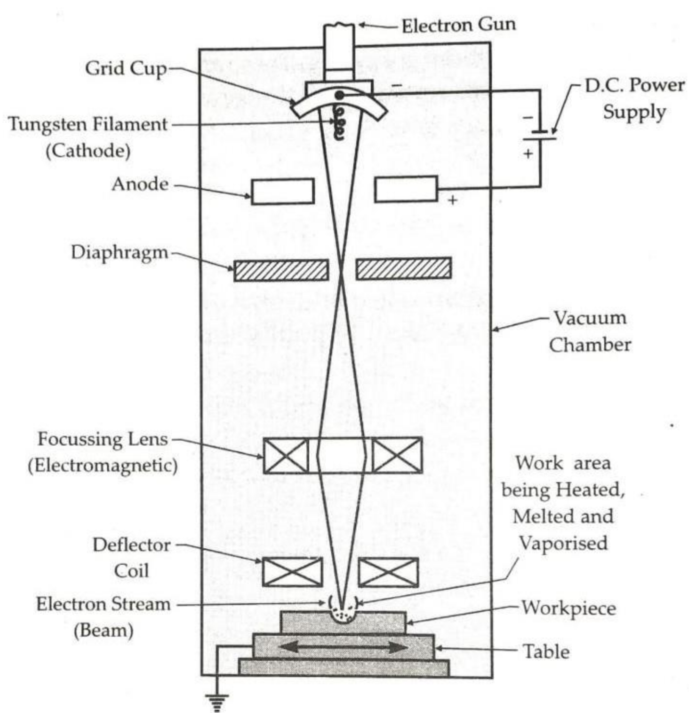
ELECTRON BEAM MACHINING (EBM)

It is a process of machining materials with the use of a high velocity beam of electrons. The workpiece is held in a vacuum chamber and the electron beam focused on to it magnetically. As the electrons strike the workpiece, their kinetic energy is converted into heat. This concentrated heat raises the temperature of workpiece materials and vaporises a small amount of it, resulting in removal of metal from the workpiece. The reason for using a vacuum chamber is that, if otherwise, the beam electrons will collide with gas molecules and will scatter.



- The main elements of Electron Beam Machining setup are shown in Fig. The complete EBM setup is enclosed in a Vacuum Chamber, which carries vacuum of the order of 10^{-5} mm of mercury. This chamber carries a door, through which the workpiece is placed over the table. The door is then closed and sealed.
- The Electron gun, which is mainly responsible for emission of electrons, consists of three main parts: a tungsten filament, the grid cup and the anode. The filament is connected to

the - ve terminal of the D.C. Power supply, to act as cathode, and the anode to the + ve terminal, as shown.

- The filament wire is heated to a temperature of about 2500°C in the vacuum. With the result, a cloud of electrons is emitted by the filament, which is directed by the grid cup to travel downwards. As the electrons are attracted by the anode, they pass through its aperture in the form of a controlled beam without colliding with it.
- A potential difference of 50 to 150 kV is maintained between the filament and the anode. As such, the electrons passing through the anode are accelerated to achieve as high a velocity as around two-third of light.
- The maximum velocity attained by the electrons, while passing out of anode, is maintained by them till such time as they strike the workpiece. It becomes possible because the electrons travel through the vacuum.
- This high velocity electron stream, after leaving the anode, passes through the tungsten diaphragm and then through the electromagnetic focussing coils (or focussing lens). By then, the stream is quite aligned and the focussing lens manages to focus it precisely on to the desired spot on the workpiece.
- The electromagnetic Deflector Coil then deflects this aligned stream (beam) on to the work, through which the path of cut can be controlled. Further, the table on which the workpiece is loaded can also be traversed to feed the workpiece as needed.
- This high velocity beam of electrons impinges on the workpiece, where its kinetic energy is released and gets converted into heat energy. The high intensity heat, so produced, melts and vaporises the work material at the spot of beam impingement. By alternately focussing and turning off the beam, the cutting process can be continued as long as it is needed.
- Melting and vaporising of the metal takes only a small fraction of a second and turning off of the beam is necessary to conduct away the heat from the workpiece. A suitable viewing device is always incorporated so as to enable the operator to observe the progress of machining operation.
- Adequate vacuum is required to be maintained inside the chamber so that the electrons can travel from cathode to anode without any hindrance, there is no arc discharge between the electrodes, there is no loss of heat from cathode, there is no contamination of

cathode and the high velocity attained by the electron beam while leaving anode is maintained upto the event of its impingement on the work.

Characteristics of EBM Process

Material Removal Technique	High speed electrons impinge on surface and kinetic energy of electrons produces intense heating to melt or vaporise the metal
Voltage	150 kV
Electron velocity	228 × 1000 km/sec.
Power density	6500 billion W/mm^2
Operations performed	Annealing, welding, or metal removal by cutting narrow slots, drilling holes of 25—125 μm in 1.25 mm thick shells. Complex contours possible by deflection by coils
Medium	Vacuum (10^{-5} mm Hg)
Materials of workpiece	All materials
Material removal rate	10 mm^3/min (max)
Specific powe consumption	500 W/mm^3 min
Limitations	Not suitable for large workpieces. Small crates produced on beam incident side of work. A little taper produced on holes. Very high specific energy consumption, necessity of vacuum, high cost of machine
Advantage	There is no effect of local heat on workpiece as the temperature of surrounding material (25—50 μm away from the machining spot) is not raised.

ADVANTAGES OF EBM

- Any material can be machined.
- Workpiece is not subjected to any physical or metallurgical damage.
- Problem of tool wear is non-existent. So, close dimensional tolerances can be achieved.
- Heat can be concentrated on a particular spot.
- An excellent technique for micro machining.
- There is no contact between the work and tool.

DISADVANTAGES OF EBM

1. High initial investment needed.
2. Highly skilled operator required to perform the operation.
3. Not suitable for producing perfectly cylindrical deep holes.
4. Suits for small and fine cuts only.
5. Workpiece size is limited due to requirement of vacuum in the chamber.
6. Low rate of metal removal.
7. High power consumption.
8. Difficult to produce slots and holes of uniform shapes and dimensions.

APPLICATIONS OF EBM

(i) Very effective for machining of materials of low heat conductivity and high melting point.

(ii) Micro-machining operations on workpieces of thin sections.

(iii) Micro-drilling operations (upto 0.002 mm) for thin orifices, dies for wire drawing, parts of electron microscopes, fibre spinners, injector nozzles for diesel engines, etc.

PROCESS PARAMETERS

The important parameters in EBM process are beam current, duration of pulse, lens current and signals for the deflection of beam. The values of these parameters during EBM are controlled with the help of a computer. Beam current varies from 100μA to 1A and it governs the energy/pulse being supplied to the workpiece.

Higher the energy/pulse more rapidly the hole can be drilled. Pulse duration during EBM varies in the range of 50 μs to 10 ms depending upon the depth and diameter of the hole to be drilled. Drilling using longer pulse duration results in a wider and deeper drilled hole. It also affects HAZ as well as the thickness of the recast layer which is normally 0.025 mm or less. The extent of both these effects should be minimum possible.

The working distance (i.e. the distance between the electron beam gun and the focal point) and the focused beam size (diameter) are determined by the magnitude of lens current. The shape o f the hole along its axis (straight, tapered, etc.) is determined by the position of the focal point below the top surface of the workpiece. To obtain the hole shape other than circular, the movement of the beam can be programmed.

The material removal rate (MRR) at which the workpiece material is vaporized can be calculated from Eq.

$$MRR = \eta \frac{P}{W}$$

Where, η is the cutting efficiency, P is the power (J/s) and W is the specific energy (J/cm^3) required to vaporize the work-material. Specific energy (W) can be calculated as follows:

$W = CPs\ (T_m - T_i) + CP_l\ (t_b - t_m\ ) + H_f + H_v$

where, Cp is specific heat, Tm is melting temperature, Ts is initial temperature of workpiece, Tb is boiling temperature, Hf is latent heat of fusion, and Hv is the latent heat of vaporization. The cutting efficiency is usually below 20%. Here, CP is assumed constant although it varies with temperature. Suffix s and I indicate solid and liquid states, respectively.

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CHAPTER 2

PLASTIC PROCESSING

In general terms, the word Plastic has been used in the past for all those materials which could be readily molded by heating or pressure or both. But, the modern applications have changed this concept and have limited the area of this word to cover only those Synthetic Organic Materials which become Plastic when heated and can be formed into different shapes under pressure. After having been processed and finished, they are observed to be fairly hard and rigid. Various useful articles can be produced from them rapidly, accurately and with excellent surface finish. They are marked by their extreme lightness in weight, high corrosion resistance and good dielectric strength. Also they can be produced in different colours or as transparent. Plastics are also known as 'Synthetic Resins'.

In scientific terms these organic compounds are called polymers. The term polymer has its base in Greek terminology, where poly' means 'many' and 'mers' means 'parts'. Thus, the term Polymer stands to represent a substance built up of several repeating units, each unit being known as a Monomer. Thousands of such units or Monomers join together in a polymerization reaction to form a Polymer. There are some natural polymers like starch, resins, shellac, cellulose, proteins, etc., but our studies in this chapter will mostly confine to the synthetic polymers only, because they find a wide application in engineering work.

CLASSIFICATION

All the plastics are broadly classified into two main groups as under:

1. **Thermosetting Plastics.** Those plastics which are hardened by heat, effecting a non reversible chemical change, are called Thermosetting Plastics. In other words, we can say that they acquire a permanent shape when heated and pressed and cannot be softened by reheating. They are also known as Heat-setting or Thermosets.

During heating, the materials undergo chemical change so that they can be moulded only once to form into rigid shape; that is, the materials will not soften if reheated. The major thermosetting materials are phenol-formaldehyde, polyesters, epoxy resins, alkyd resin, polyurethanes etc.

2. **Thermoplastics.** Those plastics which can be softened again and agian by heating are calledThermoplastics. Thus, they can be heated and reshaped by pressing many times. On cooling, theybecome hard. They are also known as Cold-setting Materials. They can be shaped into bars, tubes, sheets, films, and many other shapes. During heating and cooling no chemical change occurs, and the parts produced can be reheated to change their shape.

The major thermoplastics materials are PVC (polyvinyl chloride), polythene, polypropylene, polystyrene, ABC plastics (acrylobutadiene styrene), cellulose acetate and nitrate, polytetrafluory ethylene (PTFE)

POLYMER ADDITION

One or more of the following materials are added to the Polymers, either before or during Polymerization, to make them processable plastics:

1. Catalysts or Accelerators. They are also known as Hardeners. They are the catalysts which are added to accelerate the chemical reactions during polymerization of plastics.

2. Fillers. These are the materials added to synthetic resins to dilute them in order to reduce their consumption. They also increase their bulk and, thus, reduce the material cost. Many of them, especially when they are finely distributed, help in increasing strength, stiffness and thermal resistance of the plastics. Materials added for this purpose include clay, tale, wood flour, mica, quartz, alumina, carbon black, calcium carbonate, asbestos, glass fibres, etc.

3. Modifiers. These are the chemicals added to plastics for changing the properties of base resin. Some of them help in improving mechanical properties as well.

4. Plasticizers. They are the chemicals added for either softening the resins at forming temperature or to improve their toughness at the finished stage and to impart flexibility to their finished products. A Plasticizer is normally a fluid of high molecular weight.

5. Stabilizers. Their additions to plastics help in preventing deterioration due to the action of heat and light.

6. Initiators. They help in initiating or starting the reaction, i.e. Polymerization. H_2O_2 is commonly used for this purpose.

7. Dyes and Pigments. They are the colouring agents, added to impart different colours and shades to plastics.

USEFUL COMMON PROPERTIES OF PLASTICS

The following useful properties are common with most of the plastics

1. Lightness in weight

2. Good resistance to most of the chemicals

3. Good corrosion resistance.

4. High electrical insulation.

5. Easy to shape and mould.

6. Can be made transparent or coloured.

7. Non-resonant.

8. Good resistance to peeling.

9. Non-conductance of heat.

10. Resistance to moisture and greases.

PLASTIC PROCESSING METHODS

The following methods are commonly employed for processing plastics into various usable articles:

1. Compression moulding
2. Transfer moulding
3. Injection moulding
4. Blow moulding
5. Extrusion
6. Casting
7. Calendering

Moulding

Moulding is a manufacturing process used to shape materials, particularly plastics, into specific forms by using a rigid frame or mould. The process involves the application of heat and pressure to a material to achieve the desired shape. Moulding is a fundamental technique in the plastic industry and is essential for producing a wide range of plastic products, from simple containers to complex automotive components.

Moulding is usually defined as the process of shaping of plastic material by the simultaneous application of heat and pressure or pressure alone in a closed chamber called the mould.

Steps in moulding process

1. **Material Preparation:** The raw material, typically in the form of **pellets, powder, or resin**, is prepared for the moulding process. This material is often plastic but can also include other substances such as rubber or metal.

2. **Heating:** The material is heated until it becomes soften or molten. The heating method and temperature depend on the type of material and the moulding process used.

3. Mould Filling: The heated material is introduced into a mould cavity. Depending on the process, this might involve injecting, compressing, or blowing the material into the mould.

4. Cooling: The mould is cooled to solidify the material into the desired shape. Cooling times vary based on the material and the thickness of the part being produced.

5. Ejection: Once the material has solidified, the mould is opened, and the finished part is ejected. The part may undergo additional finishing processes such as trimming, painting, or assembly

Advantages:

- **Versatility:** Capable of producing a wide range of shapes and sizes.
- **Efficiency:** High production rates, particularly with automated processes.
- **Precision:** Ability to create complex and detailed parts with high accuracy.
- **Material Utilization:** Efficient use of materials, with minimal waste.

Limitations:

- **Initial Costs:** High upfront costs for mould design and production.
- **Cycle Time:** Some processes have longer cycle times, affecting production speed.
- **Material Constraints:** Certain materials are better suited for specific moulding processes.
- **Design Restrictions:** Complex designs may require specialized moulds, increasing costs and production time.

Moulding Methods

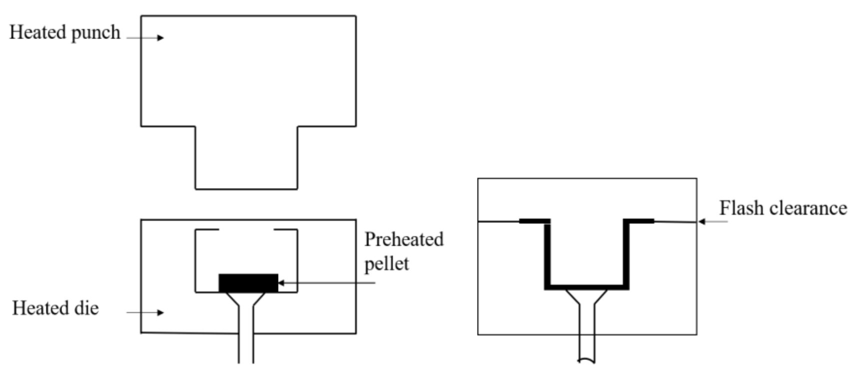
Moulding of plastics comprises forming an article to the desired shape by application of heat and pressure to the moulding compound in a suitable mould and hardening the material in the mould.

Process determination is sometimes complex because there are two types of moulding materials in general use, i.e., thermosetting and thermoplastic, and four basic moulding methods, i.e. compression, transfer, injection and extrusion moulding.

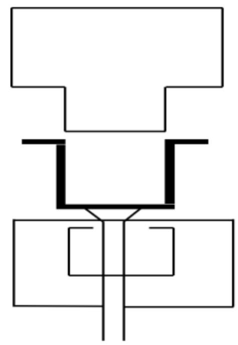
Thermosetting materials are generally processed by compression and transfer moulding and for thermoplastic materials injection and extrusion processes are used.

COMPRESSION MOULDING.

- The compression moulding is widely used for thermosetting plastics. However, it is also applicable to thermoplastic materials. This process involves forcing a measured quantity powder or the preform, into the mould. The mould is closed and then heated, which softens the plastic to such an extent that it flows under pressure and completely the die cavity.
- The pressure is maintained till the plastic cured and becomes rigid. Thereafter the mould is opened and a part ejected from the mould cavity. In case of thermoplastic, the hardening is affected by chilling the mould while still under pressure.
- After cooling the parts are removed from the mould. However, thermosetting plastics can be removed without cooling the mould. The parts may be visually inspected and any flash is trimmed off. The principle of compression moulding is illustrated in below Fig.



(a) Preheated pellet placed in heated mould (b) Punch descends and applies pressure



(c) After cooling part removed from the mould

- The time taken for moulding cycle (all the steps beginning with charging the mould cavity and ending with ejection of parts) is referred as cycle time.
- The cycle time depends on the type of plastics, mould temperature and pressure, thickness of the section and the cooling rate. The moulding cycles for thermosetting plastics may take from 15 to 30 seconds for thin-walled parts and 1 to 5 min. for average parts. Moulding temperatures usually range from 120°C to 175°C, and pressure from 30 N/mm2 to 50 N/mm2 . The moulding cycle for thermoplastics may takes one hour or more depending on the thickness.

Advantages of compression moulding:

1. Mould is simple and easy to make
2. No wastage of raw materials due to absence of gates and riser
3. Suitable shallow components having no inserts
4. Accuracy and surface finish are good
5. Parts with more uniform properties can be obtained

Disadvantages of compression moulding:

1. Not suitable for castings with intricate shapes.
2. Not suitable for thick sections.
3. Not economical when large quantities are desired
4. For same part, the cycle time is more as compared to transfer moulding

Compression moulding is most economica1 for small production runs. The process is most suitable for parts having simple shapes, but requiring high impact strength. Typical compression moulding parts include gaskets, seals, automotive panels, handles, container caps, fitting and washing machine housings.

Moulds for compressing process

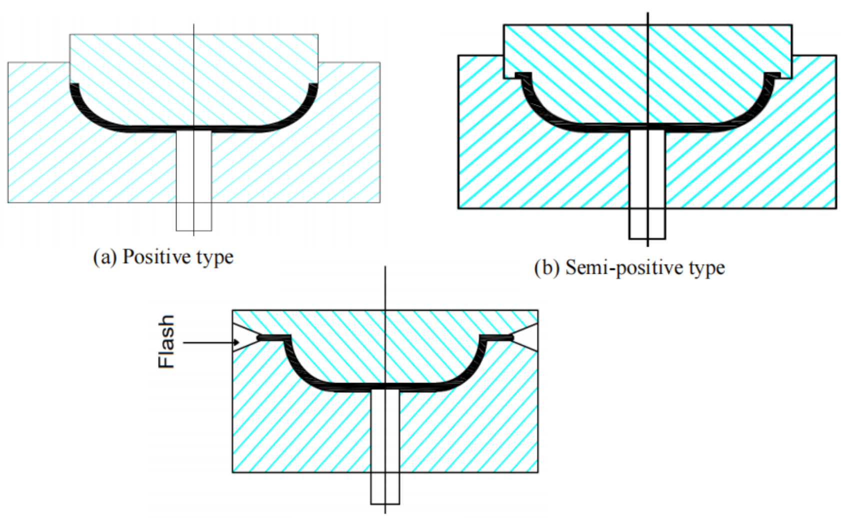
There are three basic types of processes for compression moulding.

(1) Positive type. (2) Semi positive type. (3) Flash type.

1. Positive type: In the positive type, the plunger fits tightly in the mould. In this case the amount of charge must be controlled closely to produce accurate size. Any variation in the amount of materials change into the cavity will result the variation of density in the parts produced.

2. Semi-positive type: In the semi-positive type, the plunger engages with a mould wall only during the last stage of its travel. In this case, excess materials can escape vertically until the plunger engages with the mould, and the charge does not have to be controlled very closely. Moreover, the vertical flash that results can be trimmed off easily. This this type of mould is suitable for deep mouldings and best suited for mass production of high-quality products.

3. Flash mould: This is simple type of mould. In this case the mould cavity is charged with slightly more material than is needed to produce the finished products, and the excess is squeezed out around the cavity in a thin flash. In flash moulding some materials and all components must be trimmed.



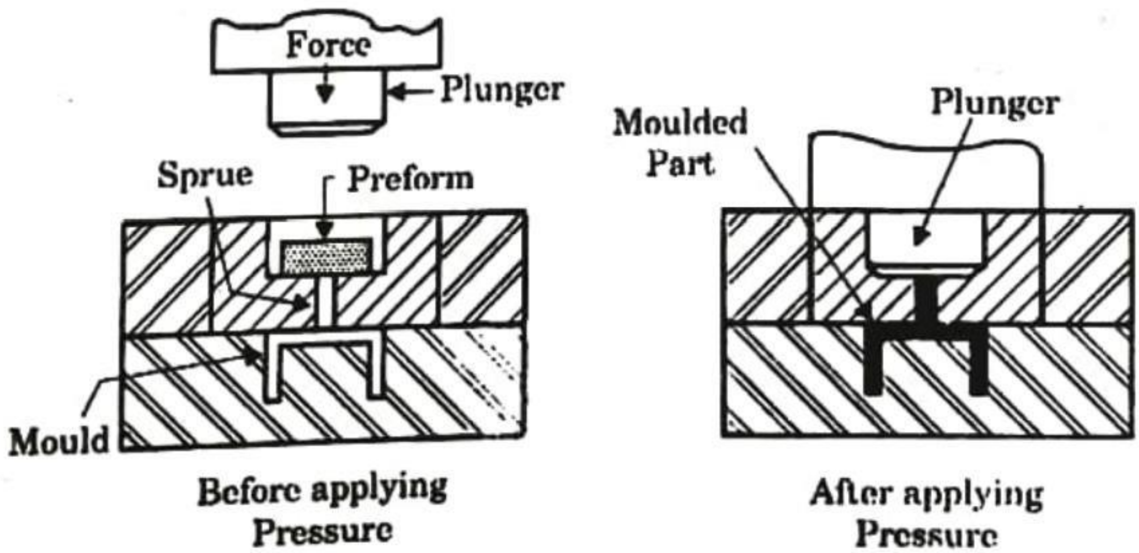
(a) Positive type

(b) Semi-positive type

(c) Flash type

TRANSFER MOULDING

- In this, the heat and pressure are applied to the compound separately outside the mould, and when the latter becomes fluid it is transferred to the mould under pressure, through a sprue and gate, where it cures finally.
- The material enters the mould at high pressure (70 N/mm2) and cured at about 125°C to 175°C. In closed mould the plastic attains its shape and cured.
- The mould is costly, but more uniform density and high mechanical strength in the products can be obtained. The other advantage of transfer moulding is that the change flow more readily permitting to produce large and intricate parts in a shorter cycle.
- The process is suitable for thermos-setting plastics. Typical parts made by transfer moulding are



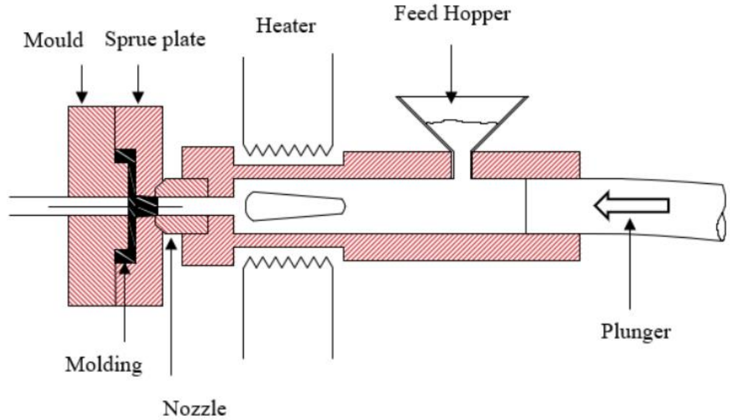
electrical components and is particularly suitable for intricate shapes having varying wall thickness. Mould tends to be more expensive than those compression moulding and materials is wasted in the channels during filling.

INJECTION MOULDING

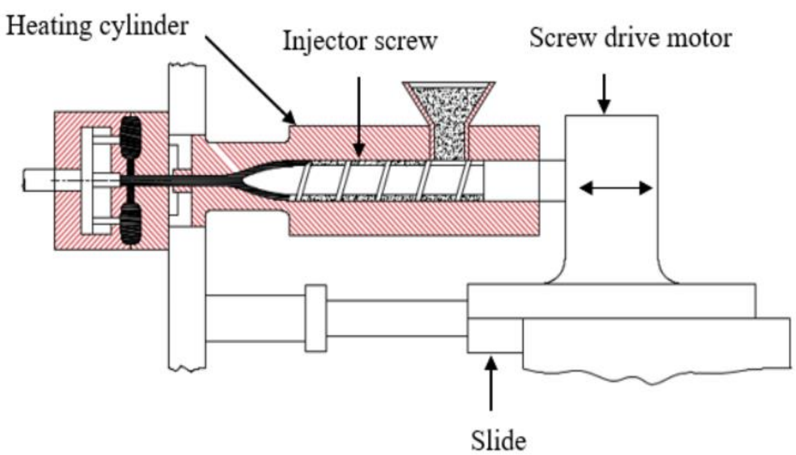
- In this technique, a measured quantity of raw material is fed from the hopper into the chamber for each cycle. This charge is forced forward by the ram or screw into the heating chamber where its temperature is raised to about 150°C to 250°C, and pressure is built up to about 100 N/mm2 to 150 N/mm2 ; and then it is injected into the mould through a nozzle.
- The torpedo (spreader) increases the chamber temperature to allow faster moulding cycle. The mould is filled with plastic under high pressure. The pressure is maintained for a few seconds so

that parts become rigid. Further the cooling is allowed (in the mould) before the mould is opened and finished articles are ejected. The gates connecting the product to sprue are removed.

- Injection molding for thermosetting plastics is known as jet molding. In this process, the mold is maintained at a high temperature to facilitate hardening. The heating chamber is kept at a moderate temperature to prevent the plastics from hardening prematurely, while the nozzle is heated to a high temperature during the injection phase.



Injection moulding (Ram type)



Injection moulding (Screw type)

<u>Advantages and limitations</u>

- Since speed is one main advantage in injection moulding, complicated moulds with inserts should be avoided, if possible.
- Moulding normally requires no further machining.
- Injection moulding is generally limited to forming thermoplastic materials as In the case of thermosetting plastics the sprue and runner material is wasted as recycling of this product is not

possible.

- Further it is difficult to mould parts with large variations in wall thickness.

Applications

- Injection moulding can produce complex shapes with inserts, threads, holes, etc. and the rate of production is high. The process is particularly suitable for small parts such as knobs for electronic equipment, tool handle, pipe fittings etc. It is a high-rate production process will good dimensional control.

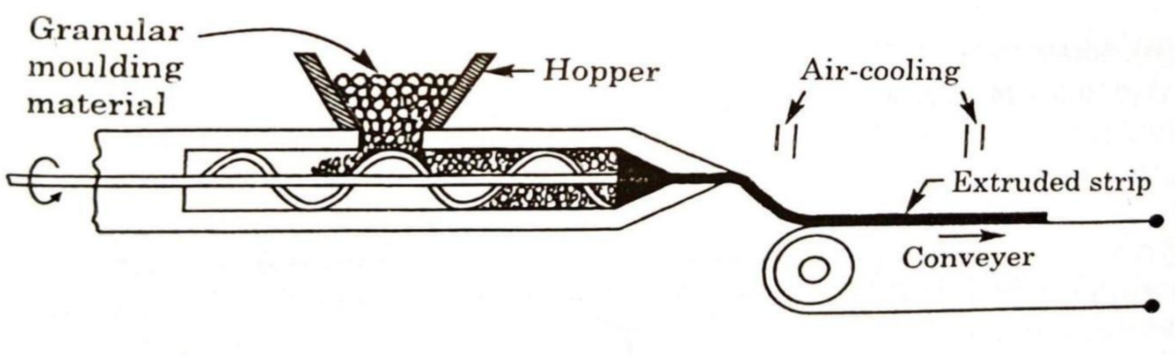
EXTRUSION OF PLASTICS

- Extrusion process is a continuous operation in which powdered polymer or monomers is fed by a screw along a cylindrical chamber, As the powder moves toward the die, it is heated and melts, The molten plastic is forced through a die opening of the desired shape.

- The material in granular form together with necessary additives is placed into a feed hopper which feeds the cylinder of the extruding machine; the hopper portion is kept cool by Circulating water in order to avoid pre- mature softening of the feed and a blockage in the supply system. The cylinder is so heated by electricity, oil or steam that closely controlled temperature zones are set up along its length.

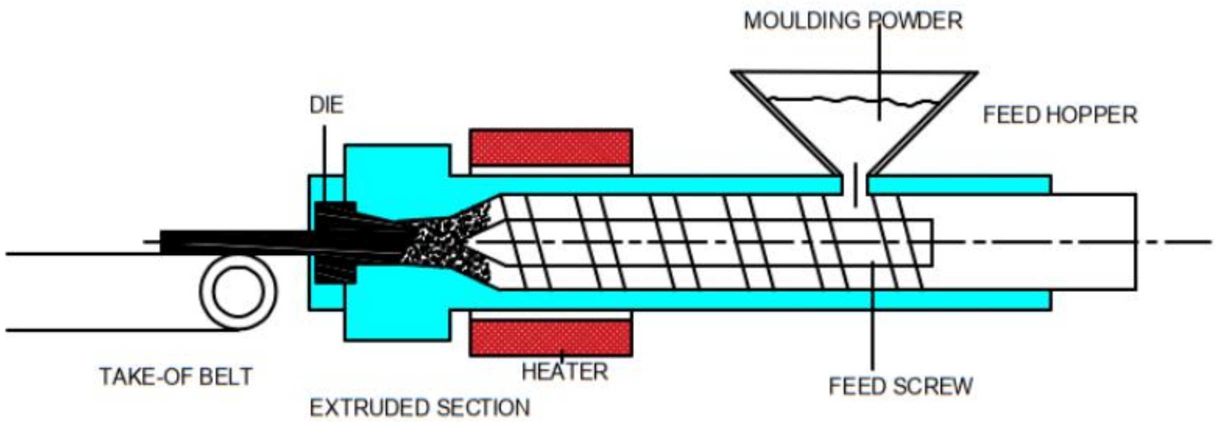
- A rotating Screw is used for carrying and mixing of material through cylinder and forcing it through a die of required shape. The Screws are designed to suit each application. These vary in size and form.

- Generally a screw has three zones, viz., (i) feed zone in which case screw core is of smaller size and fins (blades) are bigger to carry more low density stock, (ii) compression zones in which screw core diameter gradually increases or the screw pitch decreases, and (iii) metering stage.



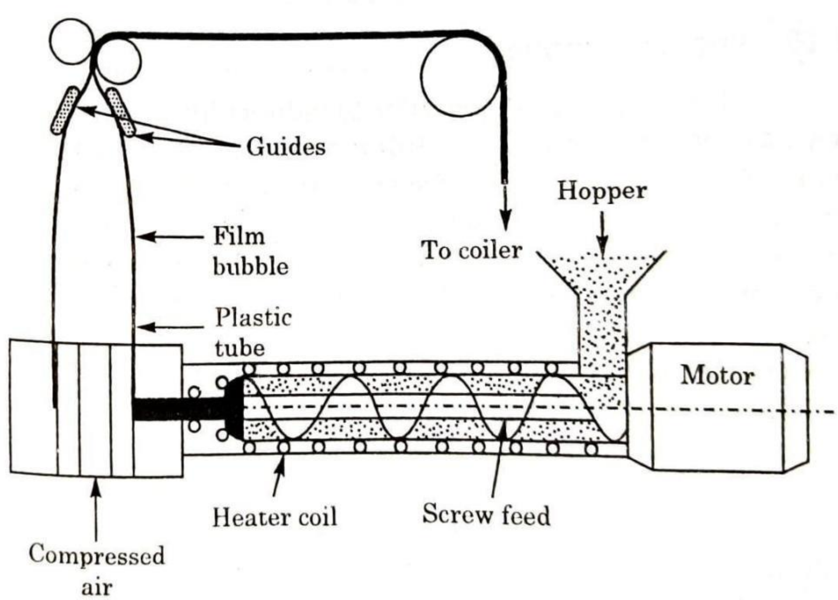
- The extruded shape (which may be in the form of rod, tube, section, or sheet) coming from the die is carried through a cooling medium by a conveyor and when it has been cooled sufficiently to retain shape, it is cut into lengths or coils. In some instances, the material must be held to a shape during its cooling.

- Cooling is done by exposure to air at room temperature, by passing through a liquid bath at a controlled temperature, or by jets of compressed air. Too rapid cooling must be prevented as it causes warpage and sets some internal strains in the finished pieces.



Depending on die design and opening, forms like meter wide sheets, solid and hollow sections of many forms, blown film to about 2 m diameter, wire covering and blow mouldings can be produced.

Advantages of extrusion are low initial cost, continuous production, introduction of anisotropy to provide high uniaxial strength. However some further work may be required in assembling the components.



Extrusion die can also be used to produce a tube into which compressed air or nitrogen is blown to give a film bubble from which sheet of upto 0.7 mm thickness can be produced.

LAMINATING PLASTICS

Laminating plastics comprise sheets of paper, fabric, asbestos, wood or similar materials, which are first impregnated or coated with resin and bonded together by heat and pressure to form commercial materials. These materials are hard, strong, impact resisting, unaffected by heat or water and have good machining characteristics which permit is fabrication into gears, handles, bushings, furniture and many other articles.

Laminations are classified into three categories depending upon the pressure required to cure the resin in manufacture.

a. Laminations cured at 0 to 2 kgf/cm^2 are called contact pressure laminations.

b. Those cured at pressures below 27 kgf/cm^2 are called low pressure laminations and

c. Those cured between 80 to 140 kgf/cm^2 are referred to as high pressure laminations.

Commercially laminates are available in sheets, rods, tubes and special shapes. Among these, sheet form is more common.

HIGH PRESSURE LAMINATES

- Phenolics, melamines, ureas and silicons are the most commonly used resins in high pressure laminates. Commercially they are available in sheet, rod, tube and some simple moulded parts, such as refrigerator's inner doors etc.

- Manufacturing sequence of laminated products is as follows. Firstly, the resinoid material is dissolved by a solvent to convert it into liquid varnish. Rods of fabric paper are then passed through a bath for impregnation.

- They are then passed through a drier which evaporates the solvent, leaving a fairly stiff sheet impregnated with the plastic material. The whole of operation is a continuous process and is shown in Fig.

- The sheets are cut into convenient sizes and staked together by hydraulic press, sufficient to make up the desired thickness of the final sheet. Under action of heat and pressure, a hard rigid plate having desirable properties for many industrial applications is formed.

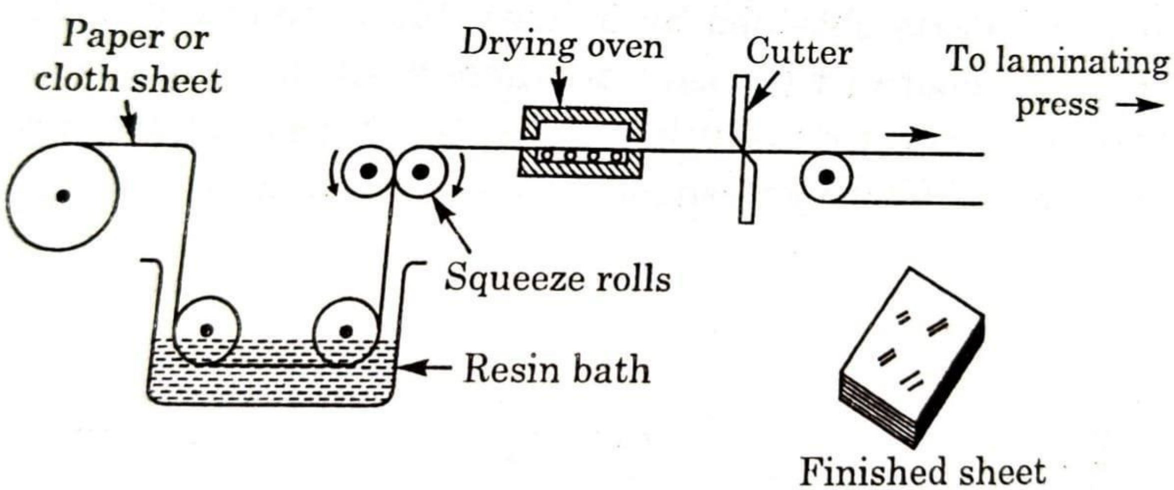
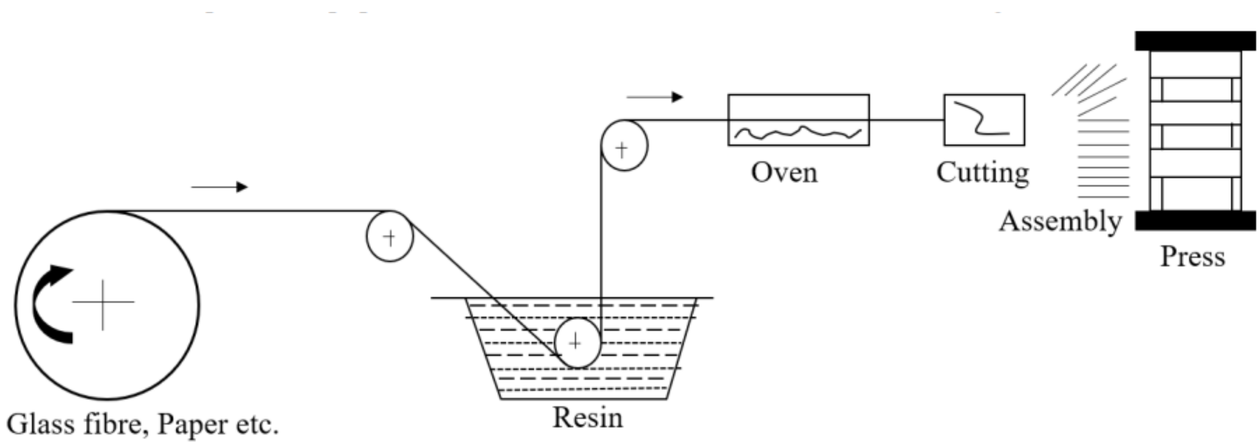


Fig. Manufacture of Laminating Sheet.

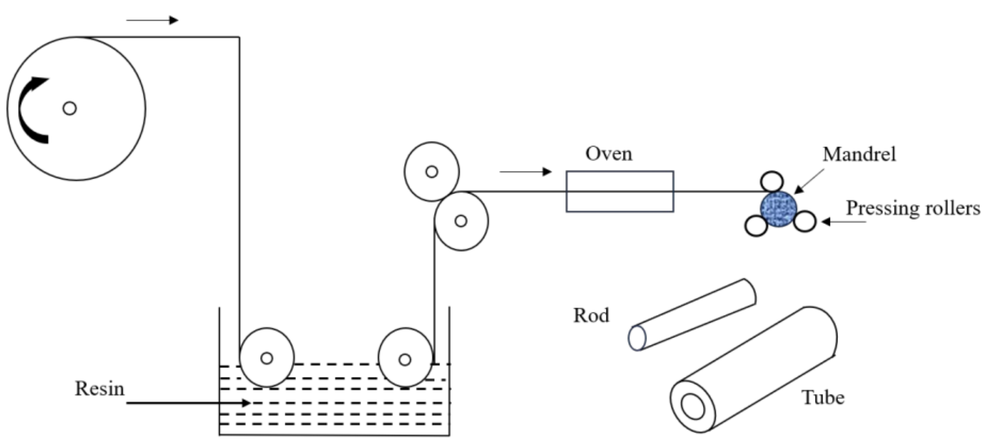
For the production of tubes, the paper or the fabric is rolled on a steel mandrel of desired diameter and then placed within the steel mould for the final processing. In the production of rods, the paper or fabric is rolled over the mandrel of very small diameter, which is withdrawn before the material is placed in the mould.

High pressure laminations are chiefly composed of cotton-cloth, paper, asbestos and glass fabrics. Heavy cloth laminates are used for gear blanks, cams and other industrial purposes. Electrical insulation and punch stock materials are made from paper laminates.



Laminated tubes and rods

Laminated tubes are manufactured by tightly winding the resin-impregnated sheet onto a steel mandrel of the required diameter under pressure. This is achieved by rotating the mandrel between three large steel rollers, which apply pressure. The curing is done by heating a suitable oven, and after curing the material is removed.



Laminated rods are produced by wrapping resin-impregnated paper around a mandrel with the smallest feasible diameter. Before the curing process, the mandrel is removed, and the rolled material is transferred to a mold where the central hole is sealed. Heat and pressure are then applied to complete the curing process.

High-pressure laminated sheets, tube and rods are usually machined to get desired shape, size and surface finish.

LOW PRESSURE LAMINATES/ REINFORCED PLASTIC MOULDING

- ✧ Low pressure laminating is also called as **reinforced plastic moulding** includes several methods to produce products such as storage bins, loudspeaker horns, machinery housings and aircraft panels.
- ✧ In low pressure laminating, layers of the reinforcing material are placed in mould, and resin is sprayed on each layer. **Fibre glass** is most generally used reinforce material. Reinforced plastic mouldings may be cured under low pressure in vacuum bag or pressure bag moulding. By proper distribution of the fibres, parts with uniform strength can be produced.

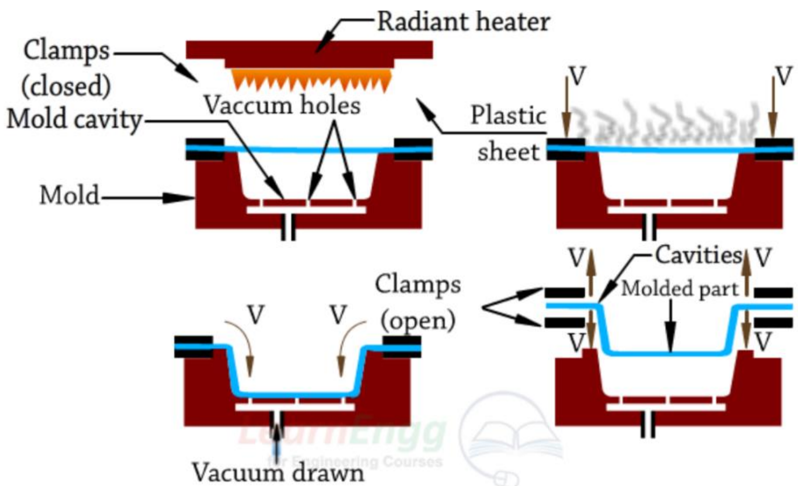
vacuum bag and pressure bag moulding

Vacuum bag and pressure bag moulding are advanced manufacturing techniques used to consolidate composite materials like carbon fiber or fiberglass with resin systems. While vacuum bag moulding relies on negative pressure to compress the laminate, pressure bag moulding uses positive air pressure (up to 50–150 psi) to achieve higher compaction and sharper detail.

Vacuum Bag Moulding

Vacuum bag moulding is an open-mould technique where a flexible film is sealed over a wet lay-up or prepreg material on a rigid mould.

Process: A vacuum pump removes air from the sealed bag, allowing atmospheric pressure to compress the layers, remove air pockets, and squeeze out excess resin.



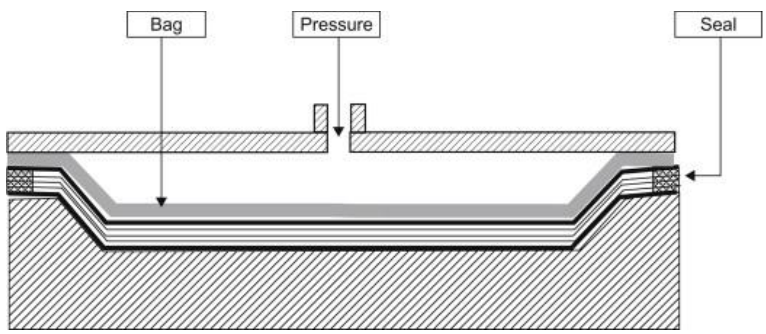
Materials: Common bagging films include **nylon**, **polyethylene**, or **PVA**. Essential consumables include **peel ply** (for easy separation), **breather fabric** (to provide an air path), and **sealant tape**.

Applications: It is widely used in the **aerospace**, **marine** (boat hulls), and **automotive** industries for high strength-to-weight ratio parts.

Pressure Bag Moulding

Pressure bag moulding is similar to vacuum bagging but introduces an additional external force to the process.

Process: A flexible "male" bag is placed inside a "female" mould and inflated with heated compressed air or steam. This positive pressure forces the composite tightly into the mould contours.



Key Differences: Unlike vacuum bagging, which is limited to 1 atmosphere of pressure, pressure bag moulding can apply 50 to 150 psi. This results in even **fewer voids**, **better surface finishes**, and the ability to form more **complex shapes**.

Applications: Typical uses include **crash helmets**, **bicycle frames**, and complex medical or electronic enclosures.

BLOW MOULDING

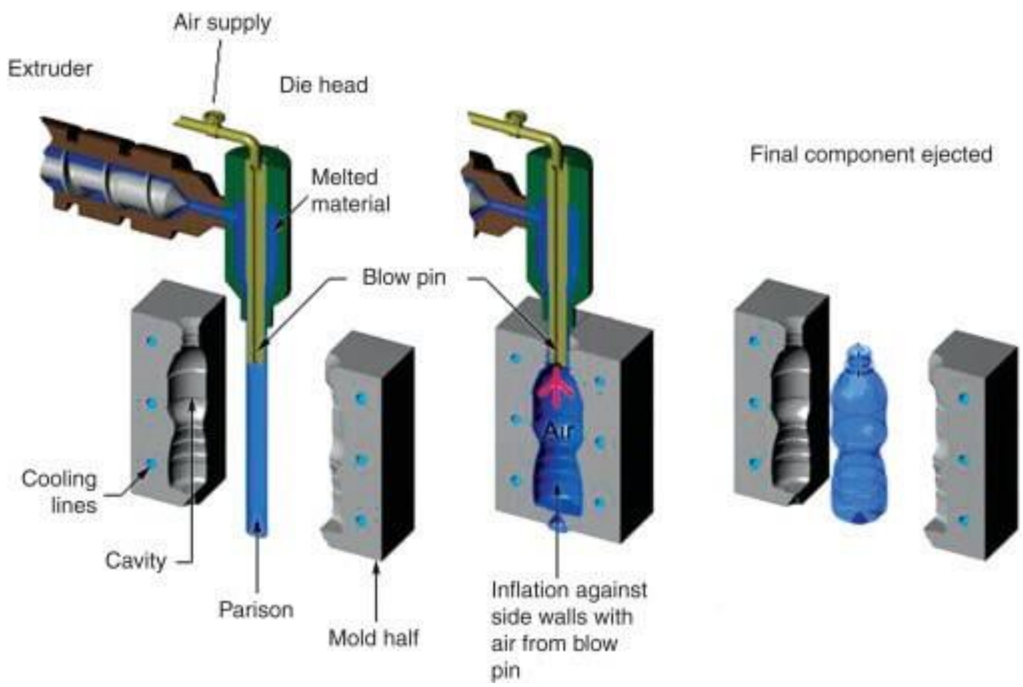
The process is applied to only thermoplastics which are used for producing hollow objects such as bottle by applying air pressure to the extruded material when it is in heated and in soft condition. In this process the air pressure required is between 274 kN/m2 and 689 kN/m2 .

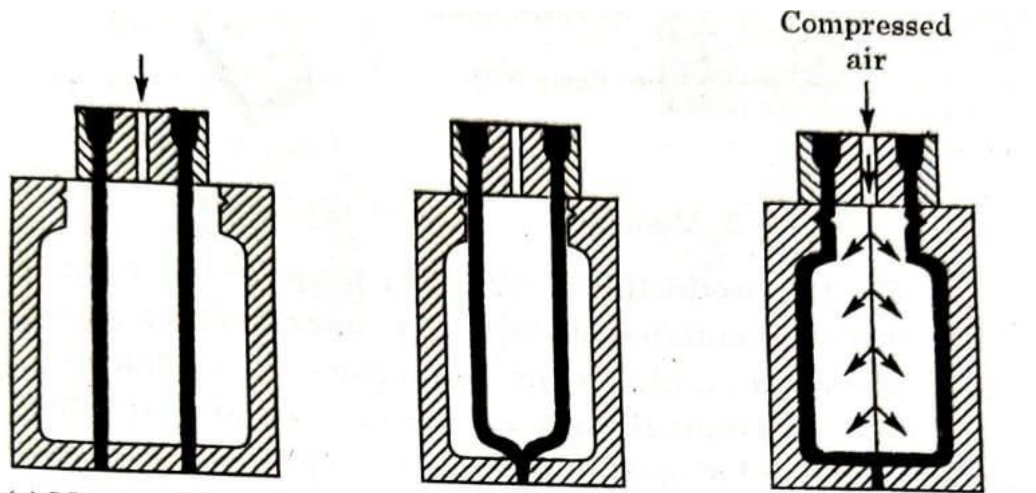
Usually, the higher the pressure, better the surface finish of the blown items. The products obtained from blow moulding include water bottles, toys, ornaments, containers etc.

Blow moulding can be accomplished in two manners; one is direct blow moulding and the other indirect blow-moulding.

In direct blow moulding, a measured amount of material in the form of tube is extruded in a split cavity die. The split mould is closed around the tube, sealing off the lower end. The air under pressure is blown into the tube, which causes the tube to expand to the walls of cavity.

In indirect blow moulding, a uniformly softened sheet material by heat is clamped at the edges between the die and cover. The air under pressure is applied between the sheet and cover, which causes the sheet to attain a hemispherical shape or the configuration of mould whatever it may be. Parts obtained by indirect blow moulding have excellent appearance but they are more costly as only 50 per cent of the sheet stock is utilized and also there is a tendency for excessive thinning of sheet at the deepest point.

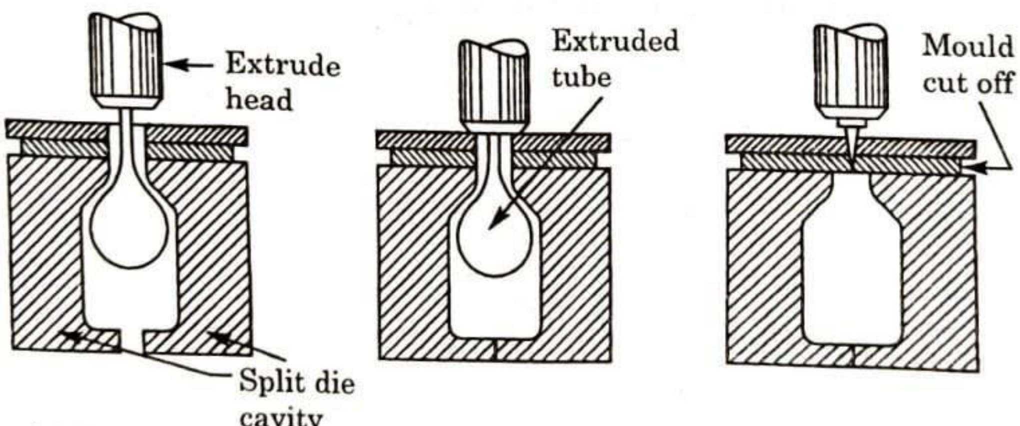




(a) Measured length of plastic tube extruded.

(b) Mould closed, cutting off length, and sealing end of tube.

(c) Compressed air expands tube to fit shape of mould.

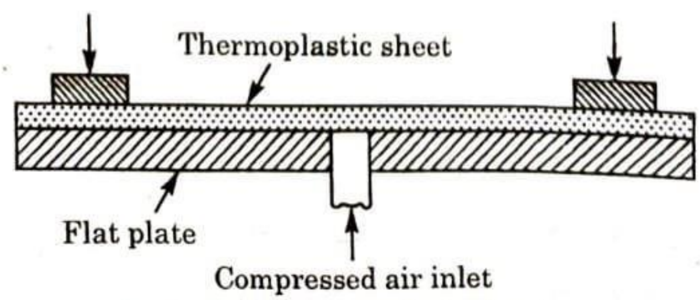


(a) Sealed tube-extruded in open mould.

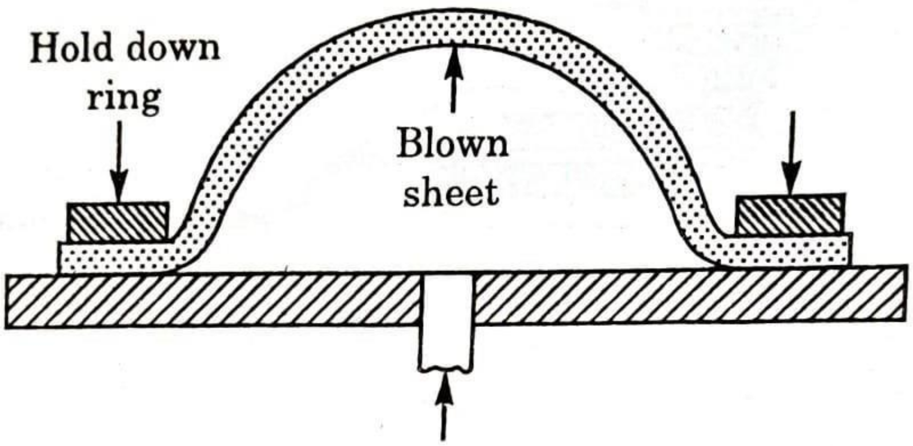
(b) Mould closed, tube expanding under pressure.

(c) Tube fully expanded and sealed into mould.

Direct blow moulding (Thermoplastic bottle).



(a) Sheet in place ready for heating.

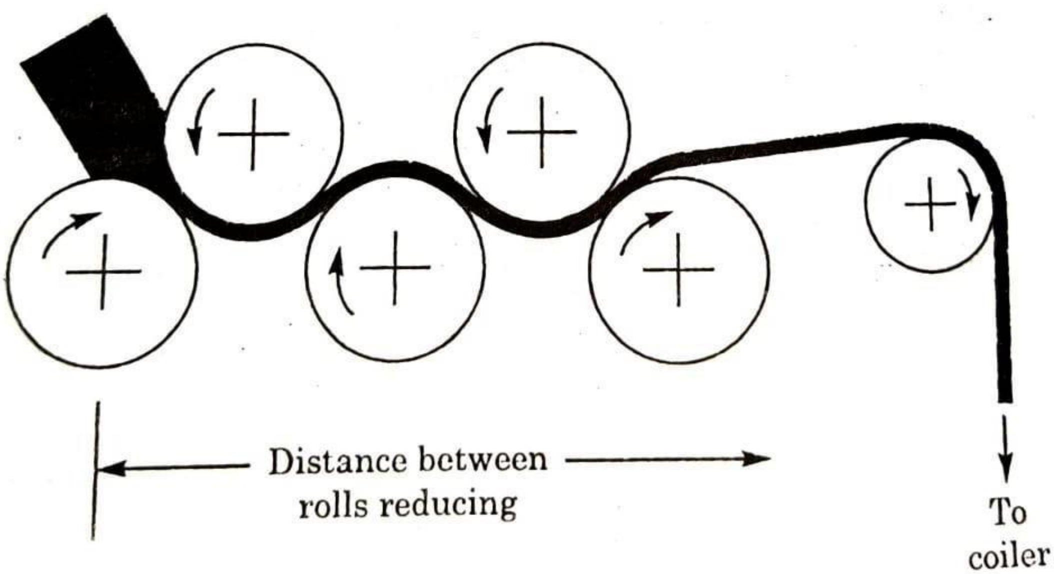


(*b*) Heated sheet blown to the desired shape.

Fig. Indirect blow moulding.

CALENDERING

Sheets (of PVC) can be produced by calendering process. The polymer is first mixed with the plasticizers and other additives such as colouring agents. The mix is then heated for a short time to produce a rough sheet which is fed through a series of rolls. The thickness is gradually reduced, and at the same time a smooth or textured surface, as required, is produced. The finished thickness is determined by the setting of the gap between the last pair of rolls.



PLASTICS AS ENGINEERING MATERIALS

At present, plastics in many fields have become indispensable and at some places they have safely replaced other materials. In many fields plastics are going to replace even steel. People at present are thinking of making plastic wheels and plastic cycles have already been made. There is no single type of plastic; rather there is a huge variety of its forms. Its versatility renders them of service in solving many problems. The important properties of plastics which have made them suitable for large number of engineering uses are: (i) electrical insulation, (ii) freedom from corrosion, (iii) resistance to chemical attack, (iv) attractive appearance, (v) low weight, (vi) transparency, (vii) easy manufacture and (viii) their capability of taking variety of colours.

These are being consumed in nearly all industries in the form of laminated sheets and tubes, in the form of reinforced plastics. Polyvinyl chloride has been very much successful in replacing rubber in distribution of electricity. They are being used in radios, telephone hand pieces, in telecommunication as high frequency insulation, in automobiles, in film industry and even in clothing.

Their latest uses include many unstressed and semi stressed parts of aircraft due to its weight saving potentialities. A great credit for all this goes to research in chemical technology which has been able to give us complete properties of a wide variety of plastics.

Name of Plastic	*Typical Applications*
Nylons	Automotive king pins, pedal shafts seat, swivels, steerings and controls, bearings, wear strips, guides, stop pins, valve seats, gaskets, and hold down pedals.
Acetals	Bearings, sleeves, plugs, flexible shafts, conveyor parts, impeller and pump parts, valve liners and for slides to eliminate jerky starts and slip-stick.
Polyimides	Valve parts, bushings and slide blocks.
Phenolics	Housings, automotive transmission rings, transmission thrust washers, oil well plugs, diaphragm plates, automotive power brake systems, small tool housings and laminated gears.

Plastic	*Application*
Nylons	Heavy gears, for vibration damping, cams, low friction gears.
Acetals	For gears working under humid conditions, for maximum fatigue life of gears, precision gears, conveyor rollers, creep resistant parts, racks, submerged couplings and pump parts, cams, sprockets, leaf springs, bushings, mechanical and pencil parts.
Phenolics	Large size gears for dimensional stability, marine couplings, steel mill and other heavy duty machinery, aircraft landing gear unit.
Polycarbonates	For intermittent very high impact rollers and dimensional stability, centrifuge tubing, material handling equipment.

Plastic	*Application*
Alkyd	Insulating brackets, small switch gears.
Ceramoplastic	High temperature insulation. Hermetic seals.
Diallyl phithalate	Air ducts
Epoxy	Corrosion resistant liners.
FPR	Flexible hoses, seals and bellows.
Polycarbonate	Pump impellers.
Polyimides	Valves, soldering fixtures, welding gun components.
Polyphenylene Oxide	Pump and blower housings, fan shrouds, blower wheels.
PTFE	Gaskets, flexible joints, brake linings, piston rings, bellows and seals.

ADDITIVE MANUFACTURING

WHAT IS ADDITIVE MANUFACTURING?

The term Rapid Prototyping (or RP) is used in a variety of industries to describe a process for rapidly creating a system or part representation before final release or commercialization of the product.

In other words, the emphasis is on creating something quickly and that the output is a prototype or basis model from which further models and eventually the final product will be derived.

In a product development process, the term rapid prototyping was used widely to describe technologies which created physical prototypes directly from digital data. This text is about these technologies, first developed for prototyping, but now used for many more purposes.

Users of RP technology have now come to realize that the quality of the output from these machines has a much closer link to the final product. Many parts are in fact now directly manufactured in these machines; so it is not possible for us to label them as "prototypes."

The term Rapid Prototyping also overlooks the basic principle of these technologies in that they all fabricate parts using an additive approach. A recently formed Technical Committee within ASTM International agreed that new terminology should be adopted. While this is still under debate, recently adopted ASTM consensus standards now use the term **Additive Manufacturing.**

Referred to in short as AM, the basic principle of this technology is that a model, initially generated using a three-dimensional Computer Aided Design (3D CAD) system, can be fabricated directly without the need for process planning.

The key to how AM works is that parts are made by adding material in layers; each layer is a thin cross-section of the part derived from the original CAD data. Obviously in the physical world, each layer must have a finite thickness to it and so the resulting part will be an approximation of the original data.

The thinner each layer is, the closer the final part will be to the original. All commercialized AM machines to date use a layer-based approach; and the major ways that they differ are in the materials that can be used, how the layers are created, and how the layers are bonded to each other.

WHAT ARE AM PARTS USED FOR?

Initially, AM was used specifically to create visualization models for products as they were being developed. It is widely known that models can be much more helpful than drawings or renderings in fully understanding the intent of the designer when presenting the conceptual design. While drawings are quicker and easier to create, models are nearly always required in the end to fully validate the design.

Following this initial purpose of simple model making, AM technology developed as materials, accuracy, and the overall quality of the output improved. Models were quickly employed to supply information about what is known as the "3 Fs" of Form, Fit, and Function.

AM, when used in conjunction with other technologies to form process chains, can be used to significantly shorten product development times and costs.

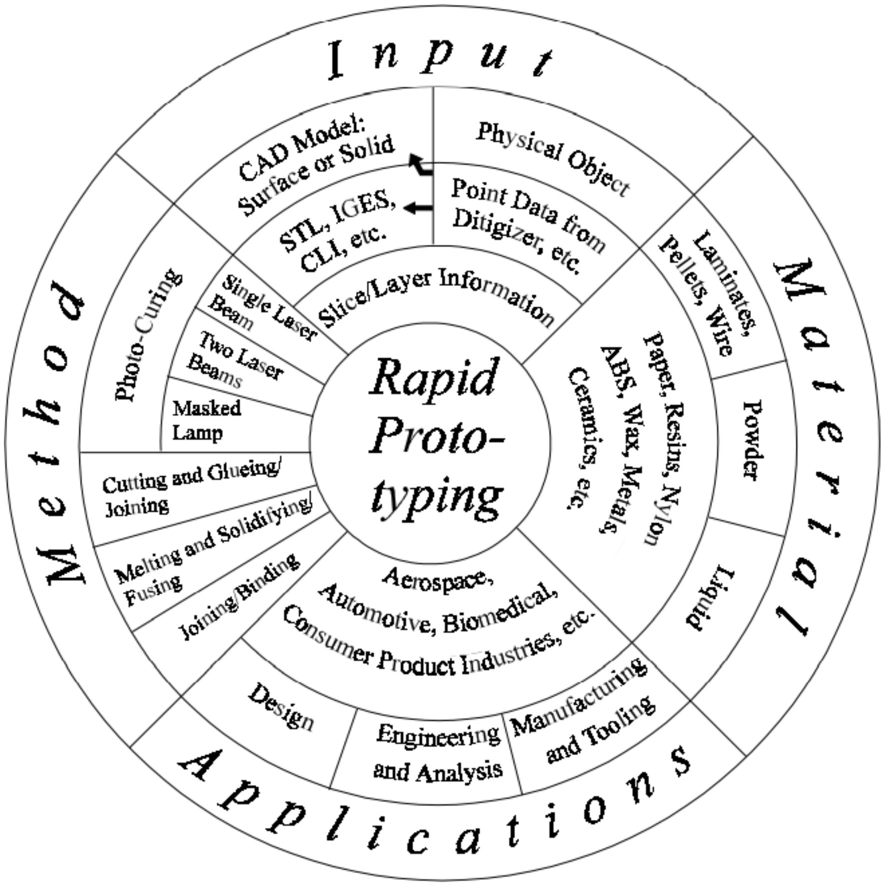
FUNDAMENTALS OF RAPID PROTOTYPING

1. Design of a model or component on a Computer-Aided Design/ Computer-Aided Manufacturing (CAD/CAM) system.
    - The model which represents the physical part to be built must be represented as closed surfaces which define an enclosed volume. This means that the data must specify the inside, outside and boundary of the model.
    - This is not necessary if the modeling technique used is solid modeling. This is by virtue of the technique used, as a valid solid model will automatically be an enclosed volume.
    - This requirement ensures that all horizontal cross sections that are essential to RP are closed curves to create the solid object.

2. The solid or surface model to be built is next converted into a format i.e. the "STL" (STereoLithography) file format which originates from 3D Systems.
   - The STL file format approximates the surfaces of the model by polygons.
   - Highly curved surfaces must employ many polygons, which mean that STL files for curved parts can be very large.
3. A computer program analyzes a STL file that defines the model to be fabricated and "slices" the model into cross sections.
   - The cross sections are systematically recreated through the solidification of either liquids or powders and then combined to form a 3D model.
   - Another possibility is that the cross sections are already thin, solid laminations and these thin laminations are glued together with adhesives to form a 3D model. Other similar methods may also be employed to build the model.

CAD image of a teacup with further images showing the effects of building using different layer thicknesses

THE RAPID PROTOTYPING WHEEL



1. **Input:** Input refers to the electronic information required to describe the physical object with 3D data. There are two possible starting points — a computer model or a physical model. The computer model created by a CAD system can be either a surface model or a solid model. On the other hand, 3D data from the physical model is not at all straightforward. It requires data acquisition through a method known as **reverse engineering.** (In reverse engineering, a wide range of equipment can be used, such as CMM (coordinate measuring machine) or a laser digitizer, to capture data points of the physical model and "reconstruct" it in a CAD system.)

2. **Method:** While they are currently more than 20 vendors for RP systems, the method employed by each vendor can be generally classified into the following categories: photo-curing, cutting and glueing/joining, melting and solidifying/fusing and joining/binding. Photo-curing can be further divided into categories of single laser beam, double laser beams and masked lamp.
3. **Material:** The initial state of material can come in either solid, liquid or powder state. In solid state, it can come in various forms such as pellets, wire or laminates. The current range materials include paper, nylon, wax, resins, metals and ceramics.
4. **Applications:** Most of the RP parts are finished or touched up before they are used for their intended applications. Applications can be grouped into (1) Design (2) Engineering, Analysis, and Planning and (3) Tooling and Manufacturing. A wide range of industries can benefit from RP and these include, but are not limited to, aerospace, automotive, biomedical, consumer, electrical and electronics products.

ADVANTAGES OF RAPID PROTOTYPING

- RP systems can directly produce functional parts in small production quantities.
- The parts produced with appropriate post processing, will have an accuracy, surface finish, material qualities and properties close to the final product.
- Time to produce any part will be fast, and can be in a matter of hours.

- The ability to experiment with physical objects in a relatively short period of time. Functional Testing Enables form, fit, and functional testing. Helps verify assembly and performance before mass production.
- The product designers can increase part complexity with little effects on time and cost. They can optimize part design to meet customer requirements.
- The manufacturer can reduce the labor cost. Inspection and assembly are also consequently reduced as well.
- Reduced material waste, waste disposal costs, material transportation costs, inventory cost.
- The consumer can buy products which meet more closely individual needs and wants.

LIMITATIONS OF AM

1. High Initial and Operating Costs

- Industrial-grade machines (e.g., metal 3D printers) are very expensive.
- Materials such as metal powders and specialized polymers cost more than conventional raw materials.
- Maintenance and calibration costs are high.

2. Limited Material Options

- Fewer material choices compared to traditional manufacturing.
- Some materials lack long-term durability or strength.
- Material properties can vary depending on printing method.

3. Slow Production Speed

- Printing is generally slower than mass production methods like injection molding.
- Not ideal for high-volume manufacturing.
- Post-processing (curing, heat treatment, finishing) adds extra time.

4. Size Constraints

- Limited by build volume of the printer.
- Large parts may need to be printed in sections and assembled.

5. Surface Finish and Accuracy Issues

- Often requires post-processing for smooth surfaces.
- Layer-by-layer fabrication can create visible layer lines.
- Dimensional accuracy may be lower than CNC machining.

6. Mechanical Property Limitations

- Parts may have anisotropic properties (weaker between layers).
- Fatigue strength can be lower compared to forged or cast parts.

7. Post-Processing Requirements

- Support structure removal.
- Heat treatment for metal parts.
- Surface polishing or machining often needed.

COMMONLY USED TERMS

- Worldwide, the most commonly used term is Rapid Prototyping. The term is apt as the key benefit of RP is its rapid creation of a physical model. However, prototyping is slowly growing to include other areas. Soon, Rapid Prototyping, Tooling and

Manufacturing (RPTM) should be used to include the utilization of the prototype as a master pattern for tooling and manufacturing.

- Some of the less commonly used terms include Direct CAD Manufacturing, Desktop Manufacturing and Instant Manufacturing. The rationales behind these terms are also speed and ease, though not exactly direct or instant!
- CAD Oriented Manufacturing is another term and provides an insight into the issue of orientation, often a key factor influencing the output of a prototype made by RP methods like SLA.
- Another group of terms emphasizes on the unique characteristic of RP — layer by layer addition as opposed to traditional manufacturing methods such as machining which is material removal from a block. This group includes Layer Manufacturing, Material Deposit Manufacturing, Material Addition Manufacturing and Material Incress Manufacturing.
- There is yet another group which chooses to focus on the words "solid" and "freeform" — Solid Freeform Manufacturing and Solid Freeform Fabrication. Solid is used because while the initial state may be liquid, powder, individual pellets or laminates, the end result is a solid, 3D object, while freeform stresses on the ability of RP to build complex shapes with little constraint on its form.

CLASSIFICATION OF RAPID PROTOTYPING SYSTEMS

While there are many ways in which one can classify the numerous RP systems in the market, one of the better ways is to classify RP systems broadly by the initial form of its material, i.e. the material that the prototype or part is built with. In this manner, all RP systems can be easily categorized into (1) liquid-based (2) solid-based and (3) powder based.

Liquid-Based

Liquid-based RP systems have the initial form of its material in liquid state. Through a process commonly known as curing, the liquid is converted into the solid state. The following RP systems fall into this category:

(1) Stereolithography Apparatus (SLA)

(2) Solid Ground Curing (SGC)

(3) Solid Creation System (SCS)

(4) Solid Object Ultraviolet-Laser Printer (SOUP)

(5) E-Darts

(6) Aaroflex

(7) Rapid Freeze

(8) Two Laser Beams

Solid-Based

Except for powder, solid-based RP systems are meant to encompass all forms of material in the solid state. In this context, the solid form can include the shape in the form of a wire, a roll, laminates and pellets. The following RP systems fall into this definition:

(1) Laminated Object Manufacturing (LOM)

(2) Fused Deposition Modeling (FDM)

(3) Paper Lamination Technology (PLT)

(4) Multi-Jet Modeling System (MJM)

(5) ModelMaker and PatternMaster

(6) Slicing Solid Manufacturing (SSM), Melted Extrusion Modeling (MEM) and Multi-Functional RPM Systems (M-RPM)

(7) Quick cast

Powder-Based

In a strict sense, powder is by-and-large in the solid state. However, it is intentionally created as a category outside the solid-based RP systems to mean powder in grain-like form. The following RP systems fall into this definition:

(1) Selective Laser Sintering (SLS)

(2) EOSINT Systems

(3) Three-Dimensional Printing (3DP)

(4) Laser Engineered Net Shaping (LENS)

(5) Direct Shell Production Casting (DSPC)

(6) Multiphase Jet Solidification (MJS)

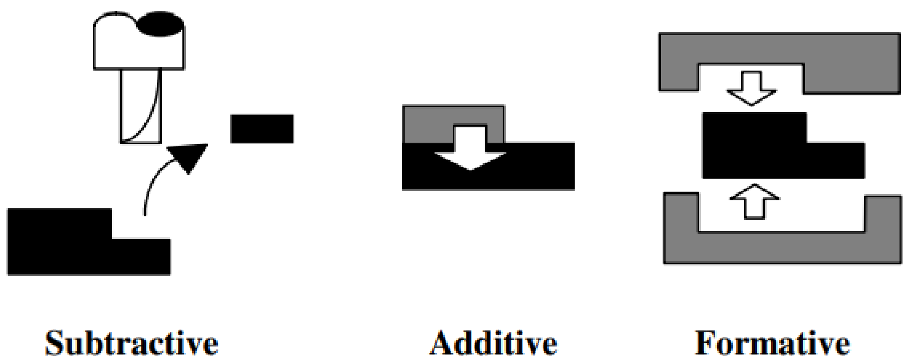
(7) Electron Beam Melting (EBM)

(8) Lasform Technology

(9) Direct Metal Deposition (DMDTM)

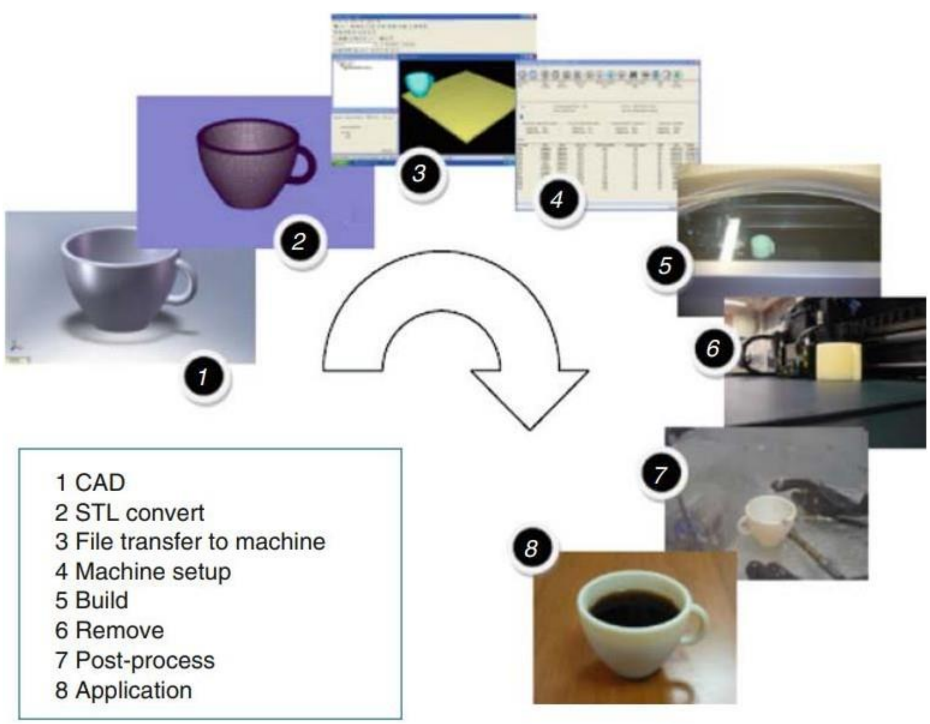
FUNDAMENTAL AUTOMATED PROCESSES

There are three fundamental fabrication processes as shown in Figure. They are Subtractive, Additive and Formative processes.



In the subtractive process, one starts with a single block of solid material larger than the final size of the desired object and material is removed until the desired shape is reached. In contrast, an additive process is the exact reverse in that the end product is much larger than the material when it started. A material is manipulated so that successive portions of it combine to form the desired object. Lastly, the formative process is one where mechanical forces or restricting forms are applied on a material so as to form it into the desired shape. There are many examples for each of these fundamental fabrication processes. Subtractive fabrication processes include most forms of machining processes — CNC or otherwise. These include milling, turning, drilling, planning, sawing, grinding, EDM, laser cutting, waterjet cutting and the likes. Most forms of rapid prototyping processes such as Stereolithography and Selective Laser Sintering fall into the additive fabrication processes category. Examples of formative fabrication processes are: Bending, forging, electromagnetic forming and plastic injection molding. These include both bending of sheet materials and molding of molten or curable liquids. The examples given are not exhaustive but indicative of the range of processes. Hybrid machines combining two or more fabrication processes are also possible. For example, in progressive pressworking, it is common to see a hybrid of subtractive (as in blanking or punching) and formative (as in bending and forming) processes.

AM PROCESS STEPS



The above-mentioned sequence of steps is generally appropriate to all AM technologies. There will be some variations dependent on which technology is being used and also on the design of the particular part.

Step 1: Conceptualization and CAD

The first step in any product development process is to come up with some idea as to how the product will look and function. Conceptualization can take many forms, from textual and narrative descriptions to sketches and representative models.

If AM is to be used, the product description must be in a physical mode. For complex products there are likely to be many stages in the development process where models can be used.

For these purposes it is therefore important that the model description be entered into a computer. AM technology would not exist if it were not for 3D CAD. Only after we gained the ability to represent solid objects in computers were we able to develop technology to physically reproduce such objects.

All AM parts must start from a software model that fully describes the external geometry. This can involve the use of almost any professional CAD solid modeling software, but the output must be a 3D solid or surface representation. Reverse engineering equipment (e.g., laser scanning) can also be used to create this representation.

It is most important that such 3D geometric models can be shared by the entire design team for many different purposes, such as interference studies, stress analyses, FEM analysis, detail design and drafting, planning for manufacturing, including NC programming, etc.

Step 2: Conversion to STL

Nearly every AM technology uses the STL file format. The term STL was derived from STereoLithograhy, which was the first commercial AM technology from 3D Systems in the 1990s.

The STL file format approximates the surfaces of the model using tiny triangles. Highly curved surfaces must employ many more triangles, which mean that STL files for curved parts can be very large.

The minimum size of these triangles can be set within most CAD software and the objective is to ensure the models created do not show any obvious triangles on the surface. Basic thumb rule is to ensure that the minimum triangle offset is smaller than the resolution of the AM machine.

A CAD model on the left converted into STL format on the right

The process of converting to STL is automatic within most CAD systems, but there is a possibility of errors occurring during this phase. There have therefore been a number of software tools developed to detect such errors and to rectify them if possible. (STL file repair software, like the MAGICS software from the Belgian company. Such software may therefore be applied as a checking stage to ensure that there are no problem with the STL file data before the build is performed.)

Nearly every AM machine accepts the STL file format, which has become a de facto standard, and nearly every CAD system can output such a file format. This file describes the external closed surfaces of the original CAD model and forms the basis for calculation of the slices.

Almost, if not all, major CAD/CAM vendors supply the CAD-STL interface. Since 1990, almost all major CAD/CAM vendors have developed and integrated this interface into their systems. This conversion step is probably the simplest and shortest of the entire process chain. However, for a highly complex model coupled with an extremely low performance workstation or PC, the conversion can take several hours. Otherwise, the conversion to STL file should take only several minutes.

Step 3: Transfer to AM Machine and STL File Manipulation

Once the STL file has been created, it can be sent directly to the target AM machine. Data transmission via agreed data formats such as STL or IGES may be carried out through a diskette, email (electronic mail) or LAN (local area network).

Once the STL files are verified to be error-free, the RP system's computer analyzes the STL files that define the model to be fabricated and slices the model into cross-sections. The cross-sections are systematically recreated through the solidification of liquids or binding of powders, or fusing of solids, to form a 3D model.

AM system software normally has a visualization tool that allows the user to view and manipulate the part. The user may wish to reposition the part or even change the orientation to allow it to be built at a specific location within the machine. It is quite common to build more than one part in an AM machine at a time. This may be multiples of the same part (thus requiring a copy function) or completely different STL files.

Some applications may require the AM part to be slightly larger or slightly smaller than the original to account for process shrinkage or coatings; and so scaling may be required prior to building.

Applications may also require adding text and simple features to STL formatted data. This would be done in the form of adding 3D embossed characters.

Step 4: Machine Setup

The AM machine must be properly set up prior to the build process. Such settings would relate to the build parameters like the material constraints, energy source, layer thickness, timings, etc.

All AM machines will have at least some setup parameters that are specific to that machine or process.

Some machines are only designed to run one or two different materials and with no variation in layer thickness or other build parameters. These types of machine will have very few setup changes.

Other machines are designed to run with a variety of materials and permit parts to be built quicker but with poorer layer resolution, for example. Such machines can have numerous setup options available.

Normally, an incorrect setup procedure will still result in a part being built. The final quality of that part may, however, be unacceptable.

Step 5: Build

This is where the previously mentioned layer-based manufacturing takes place and is fully automated. The building process may take up to several hours to build depending on the size and number of parts required.

All AM machines will have a similar sequence of layer control, using a height adjustable platform, material deposition, and layer cross-section formation.

Some machines will combine the material deposition and layer formation simultaneously while others will separate them. All machines will repeat the process until either the build is complete or there is no source material remaining. In either case, the machine will alert the user to take action.

Building the part is mainly an automated process and the machine can largely carry on without supervision. Only superficial monitoring of the machine needs to take place at this time to ensure no errors have taken place like running out of material, power or software glitches, etc.

Step 6: Removal and Cleanup

Once the AM machine has completed the build, the parts must be removed. This may require interaction with the machine, which may have safety interlocks to ensure for example that the operating temperatures are sufficiently low or that there are no actively moving parts.

Ideally, by this stage the output from the AM machine should be ready for use. The part must be either separated from the build platform on which the part was produced or removed from excess build material surrounding the part.

Some AM processes use additional material. This material will be used as support structures to help keep the part from collapsing or warping during the building.

There is also a degree of manual skill required since mishandling of parts and poor technique in support removal can result in a low quality output. The cleanup stage may also be considered as the initial part of the post-processing stage.

Step 7: Postprocessing

Once removed from the machine, parts may require an amount of additional cleaning up before they are ready for use. Parts may be weak at this stage or they may have supporting features that must be removed. This therefore often requires time and careful, experienced manual manipulation.

The cleaning task refers to the removal of excess parts which may have remained on the part. Thus, for SLA parts, this refers to excess resin residing in entrapped portion such as a blind hole of a part, as well as the removal of supports. Similarly, for SLS parts, the excess powder has to be removed. Likewise for LOM, pieces of excess woodlike blocks of paper which acted as supports have to be removed.

Step 8: Application

Parts may now be ready to be used. However, they may also require additional treatment before they are acceptable for use. For example, they may require priming and painting to give an acceptable surface texture and finish. Treatments may be laborious and lengthy if the finishing requirements are very demanding. They may also be required to be assembled together with other mechanical or electronic components to form a final model or product.

DISTINCTION BETWEEN AM AND CNC MACHINING

Basis	Additive Manufacturing (AM)	CNC Machining
Basic Principle	Builds parts **layer by layer** by adding material	Removes material from a solid block (subtractive process)
Material Usage	Minimal waste; material added only where needed	Produces significant waste (chips and scrap)
Complex Geometry	Easily produces complex and internal geometries	Difficult to produce very complex internal shapes
Production Speed	Slower for large-scale production	Faster for mass production of simple parts
Initial Cost	High machine and material cost	Moderate to high machine cost; lower material cost
Surface Finish	Often rough; requires post-processing	Excellent surface finish and high precision
Accuracy & Tolerance	Moderate accuracy	Very high accuracy and tight tolerances
Strength of Parts	May have anisotropic properties	Generally stronger and uniform properties
Tooling Requirement	No special tooling required	Requires cutting tools and fixtures
Best Suited For	Prototyping, customized parts, complex designs	Production parts, precision components

Summary

AM is best for complex, low-volume, and customized production.

CNC machining is ideal for high-precision, strong parts and medium-to-high volume production.

OTHER RELATED TECHNOLOGIES

There are, however, other ways in which the STL files can be generated and other technologies that can be used in conjunction with AM technology.

REVERSE ENGINEERING TECHNOLOGY

- RE is the process of capturing geometric data from another object. This data is usually initially available in what is termed “point cloud” form, meaning an unconnected set of points representing the object surfaces.
- These points need to be connected together using RE software like **Geomagic,** which

may also be used to combine point clouds from different scans and to perform other functions like hole-filling and smoothing.

- In many cases, the data will not be entirely complete. Samples may, for example, need to be placed in a holding fixture and thus the surfaces adjacent to this fixture may not be scanned. So the representation may not turn out exactly how the object is in reality.
- Engineered objects would normally be scanned using **laser-scanning or touch probe technology**.
- Objects that have complex internal features or anatomical models may make use of Computerized Tomography (CT), which was initially developed for medical imaging but is also available for scanning industrially produced objects. This technique essentially works in a similar way to AM, by scanning layer by layer and using software to join these layers and identify the surface boundaries. Boundaries from adjacent layers are then connected together to form surfaces. The advantage of CT technology is that internal features can also be generated. High energy X-rays are used in industrial technology to create high resolution images of around 1 µm.

COMPUTER-AIDED ENGINEERING

- 3D CAD is an extremely valuable resource for product design and development. One major benefit to using software-based design is the ability to implement change easily and cheaply. If we are able to keep the design primarily in a software format for a larger proportion of the product development cycle, we can ensure that any design changes are performed virtually on the software description rather than physically on the product itself.
- The more we know about how the product is going to perform before it is built, the more effective that product is going to be. This is also the most cost-effective way to deal with product development. If problems are only noticed after parts are physically manufactured, this can be very costly.
- However, 3D CAD is also commonly linked to other software packages, often using techniques like finite element method (FEM) to calculate the mechanical properties of a design, collectively known as Computer-Aided Engineering (CAE) software. Forces, dynamics, stresses, flow, and other properties can be calculated to determine how well a design will perform under certain conditions. While such software cannot easily predict the exact behavior of a part, for analysis of critical parts a combination of CAE, backed up with AM-based experimental analysis, may be a useful solution.

WEB BASED RAPID PROTOTYPING

Web-based Rapid Prototyping systems refer to **internet-enabled platforms and services** that allow designers, engineers, and companies to remotely access rapid prototyping technology and manufacturing resources through the web. These systems integrate **rapid prototyping (RP) machines and services with online infrastructure** so that users can submit designs and receive prototypes without physically being present at a manufacturing facility.

Key Components

a) **Internet Interfaces & Portals**
Users upload design files (like STL from 3D CAD) to a website or web service.

b) **File Processing & Checking**
The system verifies the files for manufacturability and may automatically fix common errors.

c) **Machine Selection & Scheduling**
Software chooses a suitable RP technology (e.g., SLA, SLS, FDM) and schedules production in the queue.

d) **Remote Control / Monitoring**
Advanced systems may allow users or administrators to monitor printing progress online.

Advantages of Web-Based RP Systems

- **Remote Accessibility:** Users anywhere can access prototyping services without owning machines.
- **Shared Resources:** Small and medium enterprises (SMEs) can use costly RP equipment on demand.
- **Faster Development Cycle:** Eliminates the need for local setup and shortens lead times.
- **Enhanced Collaboration:** Teams in different locations can coordinate product development online.

CONCURRENT ENGINEERING (CE)

- **Concurrent engineering** (**CE**) is a work methodology emphasizing the parallelization of tasks (i.e. performing tasks concurrently), which is sometimes called **simultaneous engineering** using an integrated product team approach.
- It refers to an approach used in product development in which functions of design engineering, manufacturing engineering, and other functions are integrated to reduce the time required to bring a new product to market.
- Concurrent engineering, also known as simultaneous engineering, is a method of designing and developing products, in which the different stages run simultaneously, rather than consecutively. It decreases product development time and also the time to market, leading to improved productivity and reduced costs.
- This **streamlined** approach towards an engineering product forces several teams such as **product design**, **manufacturing**, **production, marketing**, product **suppor**t, **finance,** etc., within the organization to work simultaneously on new product development.

For instance, while engineering product designers begin to design the product, the sales team can start working on the marketing and the product support department can start thinking about the after-sale support. While the mechanical designers work on the packaging design, the software engineers can start looking at the software code.

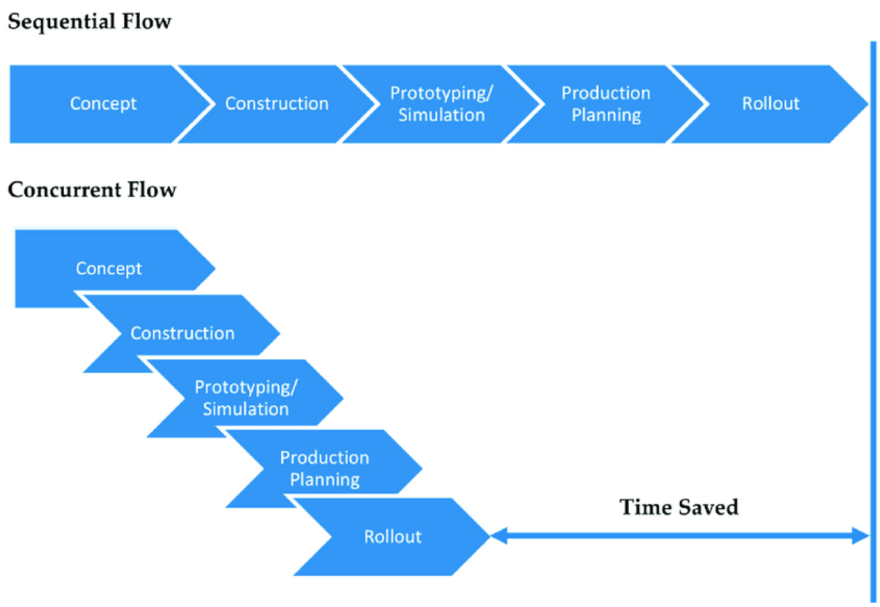
Advantages of concurrent engineering

- It encourages multi-disciplinary collaboration
- Reduces product cycle time
- Reduces cost
- Increases quality by supporting the entire project cycle – enhanced quality
- Increases productivity by stopping mistakes in their tracks
- Gives a competitive edge over the competitors

Disadvantages of concurrent engineering

- Complex to manage
- Relies on everyone working together hence communication is critical

- Room for mistakes is small as it impacts all the departments or disciplines involved



APPLICATIONS OF AM

Applications		
Design	***Engineering, Analysis and Planning***	***Manufacturing and Tooling***
• CAD-model verification (design specification) • Visualizing objects • Proof of concept • Marketing and presentation model	• Form and fit-models • Flow analysis • Analysis of stress distribution • Pre-series parts • Diagnostic and pre-surgical operation planning • Design and fabrication of custom protheses and implants	• Tooling mold parts — direct soft tools — indirect soft tools — direct hard tools — indirect hard tools • Casting — sand-casting — investment casting — evaporative pattern casting — die casting • EDM electrodes • Master models

Industries		
• Aerospace • Jewelry • Consumer electronics	• Automotive • Coin • Home appliances	• Biomedical • Tableware • etc.

Typical application areas of RP

FLEXIBLE MANUFACTURING SYSTEM (FMS)

- Flexibility can have different interpretations; but it generally refers to the system's responsiveness to changing demand patterns, so that both part style and the production volume that can be adjusted rapidly to meet changing requirements.
- FMS is the production with machine systems capable of making a different product without retooling or similar changeover.
- In today's competitive global market, manufactures have to modify their operations to ensure a better and faster response to needs of customers, higher quality of products and faster response in introduction of new products. In conventional manufacturing change cannot be tolerated as it relied on economics of scale.
- FMS not only improves productivity but also provides the required flexibility enabling the factories to become more reactive to market demand.
- A **Flexible Manufacturing System (FMS)** is an automated production system consisting of **computer-controlled machines, automated material handling systems, and a central computer control unit**. It is designed to manufacture **different types of products efficiently with minimal changeover time**. FMS provides flexibility to handle variations in product design, production volume, and manufacturing processes.

COMPONENTS OF FMS

1. **WORKSTATIONS/PROCESSING STATIONS:** The workstations are typically CNC machine tools that perform machining operations on parts. These are the processing stations where manufacturing operations take place.

Examples: CNC machines, turning centers, milling machines, assembly stations, Loading/unloading stations and inspection stations.

i) **Machining centre:** are usually CNC machine tools with appropriate automatic tool changing and tool Storage features to facilitate quick physical changeover as necessary.

ii) **Load and unload stations:** Where raw parts enter the system and completely processed parts exit the system.

iii) **Assembly workstations:** consists of a number of workstations with industrial robots that sequentially assemble components of the base parts.

iv) **Inspection stations:** the parts manufactured are inspected here for quality purpose.

v) **Others:** sheet metal fabrication which has station for press working operations, such as punching, shearing, forging stations.

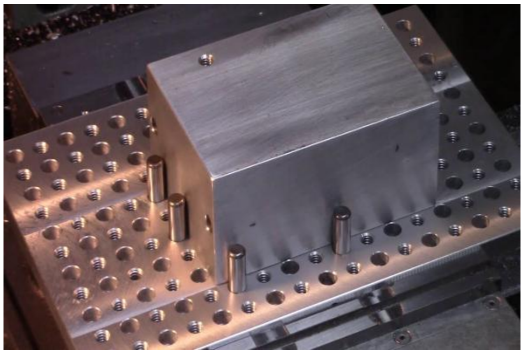
2. MATERIAL HANDLING AND STORAGE SYSTEMS:

- The primary material handling system establishes the FMS layout and is responsible for moving parts between stations in the system.
- The secondary handling system consists of transfer devices, automatic pallet changers and other mechanisms to transfer parts from the primary material handling system to the processing station or to a supporting station. It is also responsible for the accurate positioning of the part of the workstation, so that the machining process may be performed upon the part in the correct manner.

The functions of the material handling and storage system in FMS are:

- Allows systematic and independent movement of the work parts between stations.
- Enables handling of a variety of work part configurations by means of pallet fixtures

for prismatic parts and industrial robots for rotational parts.



- Provide temporary storage.

3. COMPUTER CONTROL SYSTEM:

It consists of a central computer and series of microcomputers that control individual machines in FMS. A central computer controls and coordinates all operations in the system. It performs functions such as scheduling, routing of parts, machine monitoring, and tool management.

The various functions are:

Control of each workstation: often in the form of a CNC control.

Distribution of control instructions: to workstations by means of a central computer to handle the processing occurring at different workstations.

Production control: management of the mix and rate at which various parts are launched into the system is important,

Traffic control: so that parts arrive at right location at the right time and right condition.

Workpiece monitoring: to ensure that we know the location of every element in the system.

Tool control: is connected with managing tool location and tool life.

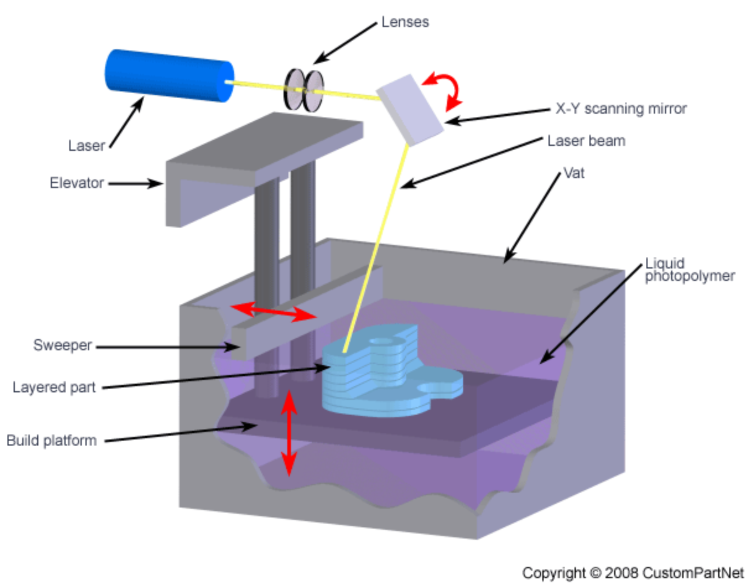
Performance monitoring: the computer must collect the data on the various operations ongoing in the FMS and present performance findings based on this.

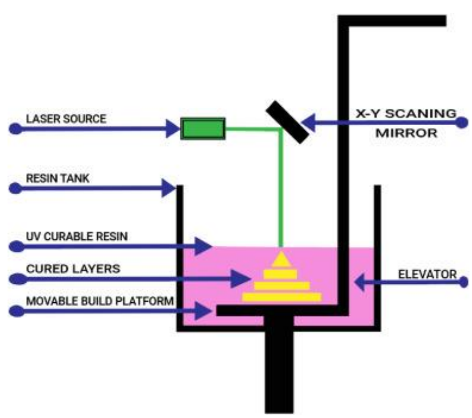
Advantages of FMS

- ✧ High flexibility in production
- ✧ Reduced production time
- ✧ Improved product quality
- ✧ Reduced labor cost
- ✧ Lower inventory levels
- ✧ Faster response to market demand

STEREOLITHOGRAPHY APPARATUS (SLA)

Stereolithography Apparatus (SLA) is one of the earliest and most widely used **3D printing technologies**. It works on the principle of **photopolymerization**, where a **liquid photopolymer resin is cured (hardened) layer by layer using an ultraviolet (UV) laser** to form a solid 3D object.





Main Components of an SLA (Stereolithography Apparatus) 3D Printer

1. **Resin Tank (Vat)**

- ✓ A container that holds the **liquid photopolymer resin**.
- ✓ The resin is sensitive to **ultraviolet (UV) light** and solidifies when exposed to it.

2. **Build Platform (Elevator Platform)**

- ✓ A movable platform where the **3D object is formed layer by layer**.
- ✓ It moves **up or down after each layer is cured** to allow the next layer to be formed.

3. **UV Laser Source**

- ✓ Produces a **focused ultraviolet laser beam**.
- ✓ The laser scans the surface of the resin and **hardens the liquid resin according to the layer pattern**.

4. **Galvanometer Mirrors (Scanning System)**

- ✓ These are **precision mirrors that direct and control the movement of the laser beam** across the resin surface.
- ✓ They help the laser trace the exact shape of each layer.

5. **Recoating Mechanism (Blade or Wiper)**

- ✓ Spreads a **thin and uniform layer of resin** over the previously cured layer.
- ✓ Ensures smooth layer formation.

6. **Computer Control System**

- ✓ Controls the **entire printing process**.
- ✓ Converts the **CAD model (STL file) into layer instructions** and controls laser movement, platform motion, and printing sequence.

7. **Post-Curing Unit (UV Chamber)**

- ✓ Used after printing to **further cure the printed object under UV light**.
- ✓ Improves the strength and stability of the final part.

WORKING PRINCIPLE

The working of an SLA 3D printer involves the following steps:

Design Creation

- ➢ The 3D model is created using **CAD software**.
- ➢ The model is then converted into **STL file format**.

Slicing of the Model

- ➢ The STL file is sliced into **thin layers** using slicing software.
- ➢ Each layer represents a cross-section of the final object.

Initial Positioning

- ➢ The **build platform is positioned just below the surface of the liquid resin** inside the vat.

Laser Curing Process

- ➢ A **UV laser beam scans the surface of the liquid resin** according to the first layer pattern.
- ➢ The resin exposed to the laser **solidifies and forms the first layer** of the object.

Layer Formation

- ➢ After one layer is formed, the **build platform moves slightly downward** (equal to layer thickness).
- ➢ A fresh layer of liquid resin flows over the previously cured layer.

Repeated Curing

- ➢ The laser again scans and **solidifies the next layer**.
- ➢ This process continues **layer by layer until the entire object is formed**.

Post Processing

- ➢ The finished part is removed from the platform.
- ➢ It may be **washed and further cured under UV light** to improve strength.

SLA Advantages

Stereolithography allows manufacturers to quickly develop a new product and reduce the time it takes to bring it to market. Some of the major advantages of this technology are:

■ Very good model accuracy, smooth surface finishes, and the ability to produce large-size prototypes

■ Good quality solid 3D prototypes that can be produced quickly and accurately from a CAD file

■ Ability for designers to see and hold their creation, and revise it if necessary by changing the CAD design file before money is spent on tooling

■ Allows designers to experiment with various designs without spending too much time and money

■ Provides a functional model to see if the designed part will fit and operate properly

■ Lowers developmental costs and improves part quality

■ Reduces time-to-market by as much as 80%

■ Improves overall productivity and competitiveness

■ Produces physical models for market research

SL Applications

Stereolithography is used by designers to quickly translate CAD files into 3-D objects. Examples of uses are:

■ QuickCast patterns for investment casting

■ Epoxy patterns for precision sand casting and soft tooling

■ Medical and dental models

■ Jewelry design

WORKING OF LAMINATED OBJECT MANUFACTURING (LOM) 3D PRINTER

The working of a **LOM 3D printer** involves the following steps:

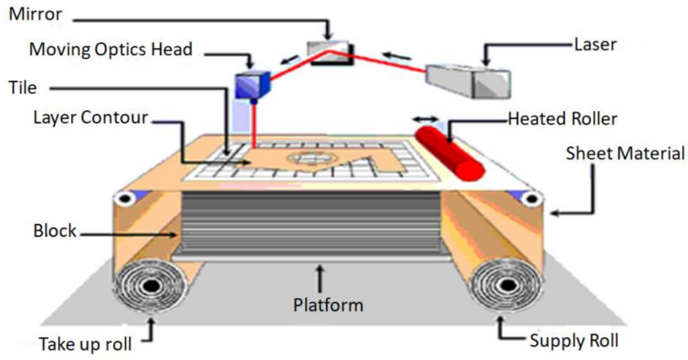
Creation of CAD Model

The 3D model of the part is first designed using **CAD software**.

The model is converted into an **STL file** and then divided into thin layers using slicing software.

Material Feeding

A **roll of sheet material** (paper, plastic, or metal foil) is fed onto the **build platform**.



Layer Bonding

The sheet material passes under a **heated roller**.

The roller **applies heat and pressure to bond the sheet to the previous layer** using adhesive.

Laser Cutting

A **laser beam or knife cutter** cuts the outline of the object for that layer based on the sliced CAD data.

The unwanted material around the object is cross-hatched so it can be easily removed later.

Platform Movement

After one layer is completed, the **build platform moves down by one layer thickness**.

A new sheet of material is fed onto the surface.

Layer-by-Layer Building

The bonding and cutting process is repeated **until the entire object is formed layer by layer**.

Removal of Excess Material

After printing is complete, the **excess laminated material is removed manually**, leaving the final 3D object.

SPECIAL PURPOSE MACHINES

- Special purpose machines (SPM) are those machines which are not available off the shelf and these are not covered in standard manufacturing process; these are designed and tailored made as per the customer specific requirements.

- Special-purpose machines (SPMs) are custom-designed machines used for specific manufacturing tasks that cannot be efficiently performed by standard machines. Unlike general-purpose machines, SPMs are built to handle **repetitive and high-volume production processes** with greater precision, speed, and automation.
- The establishment of a special purpose machine (SPM) unit is a strategic investment aimed at enhancing manufacturing efficiency, precision, and automation in industries requiring high-volume and customized production.
- Unlike conventional machines, SPMs are designed to perform specific tasks with higher accuracy, speed, and cost-effectiveness, reducing reliance on manual intervention and minimizing production downtime. These machines are tailored to meet unique manufacturing requirements, ensuring higher productivity while maintaining quality standards.
- In contrast to general-purpose machines, which are designed to do multiple tasks, SPMs are specifically designed to do one task very quickly, accurately, and reliably.

General Element of SPM

1. Frame and Structure: The frame provides the basic structure and support for the machine. It is designed to withstand the forces and vibrations generated during the operation.

2. Actuators: Actuators are devices that provide controlled movement to different parts of the machine. Examples include hydraulic cylinders, pneumatic cylinders, and electric motors.

3. Control System: SPMs typically have a dedicated control system for managing the machine's operation. This can include PLCs (Programmable Logic Controllers), microcontrollers, or other specialized control units.

4. Sensors: Sensors are used to gather information about the workpiece, tool position, and other relevant parameters. Common types of sensors include proximity, optical, and pressure sensors.

5. Tooling and Fixturing: SPMs often include specialized tooling and fixtures designed for the specific manufacturing process. These ensure accurate positioning and secure holding of the workpiece during machining.

6. Motion Control System: This system controls the movement of various machine components with precision. It includes components like servo motors, stepper motors, and associated controllers.

7. Power Transmission System: The transmission system transfers power from the energy source to different machine components. This can include gears, belts, chains, and other mechanical components.

8. Cooling and Lubrication Systems: SPMs may incorporate systems for cooling and lubricating moving parts to prevent overheating and reduce friction.

9. Human-Machine Interface (HMI): An interface that allows operators to interact with and control the machine. It may include a touchscreen panel, buttons, and other input devices.

10. Safety Features: Special-purpose machines are equipped with safety features such as emergency stops, interlocks, and guards to ensure the safety of operators.

11. Programming Interface: For programmable SPMs, a programming interface allows the user to define and customize the machine's operation.

12. Material Handling Systems: Some SPMs may include automated material handling systems for loading and unloading workpieces.

13. Quality Control Systems: In some cases, SPMs may integrate quality control systems to inspect and verify the produced parts.

These elements work together to create a specialized machine tailored to a specific manufacturing process, providing efficiency, precision, and reliability. The design of Special Purpose Machines is highly application-specific, and each machine may have unique features based on the intended purpose.

<u>Productivity Improvement by SPM</u>

SPMs are engineered to streamline operations, enhance efficiency, and ultimately boost productivity in manufacturing or industrial settings. Here's how they contribute to productivity improvement:

1. Automation: Special-purpose machines are designed to automate repetitive tasks that were previously performed manually or required multiple steps. By automating these tasks, productivity increases as machines can work continuously without fatigue or breaks.

2. Speed and Accuracy: These machines are optimized for speed and precision, performing tasks much faster and with higher accuracy than human labour. This reduces cycle times and minimizes errors, leading to overall productivity gains.

3. Customization: Special-purpose machines are tailored to specific manufacturing processes or operations. This customization ensures that the machine is optimized for the particular task it's designed to perform, leading to improved efficiency and productivity.

4. Reduced Downtime: Special-purpose machines are often engineered for reliability and durability. With fewer breakdowns and maintenance requirements compared to general-purpose machinery, downtime is reduced, allowing for more continuous production and higher overall productivity.

5. Resource Optimization: These machines are typically designed to use resources such as energy, materials, and space more efficiently. By optimizing resource utilization, special-purpose machines contribute to cost reduction and improved productivity.

6. Process Integration: Special-purpose machines can be integrated into existing production lines seamlessly. This integration helps in allowing smoother operations and increased productivity across the entire manufacturing process.

Principles of SPM Design

Designing Special Purpose Machines (SPMs) involves adhering to specific principles to ensure that machine meets its intended purpose efficiently and effectively. While the design principles can vary based on the specific application, here are some general principles that are often followed in SPM design:

1. Understand the Application Requirements: Before starting the design process, a thorough understanding of the specific manufacturing process and its requirements is essential. This includes knowledge of tolerances, production rates, and other critical parameters.

2. Customization for Specific Tasks: SPMs are designed to perform a particular task or set of tasks with high precision and efficiency. The design should be tailored to meet the specific requirements of the intended application.

3. Simplicity in Design: Keeping the design simple helps in minimizing complexity, reducing costs, and enhancing reliability. Unnecessary features that do not contribute to the machine's primary function should be avoided.

4. Modularity: Designing SPMs with modular components allows for easier maintenance, repair, and future modifications. Modularity is the design principle of breaking a system into smaller, independent components/modules—that each handle specific functionalities. Modular designs improve maintainability, reusability, and scalability (the capacity to be changed in size or scale).

5. Optimization of Material and Energy Usage: Efficient use of materials and energy is crucial for cost-effectiveness. This involves selecting materials with the right properties and optimizing the machine's energy consumption.

6. Precision and Accuracy: SPMs are expected to deliver high precision and accuracy in manufacturing processes. The design should focus on minimizing errors, backlash, and other factors that could affect the quality of the end product.

7. Reliability and Durability: Designs should prioritize robustness and durability to ensure continuous and trouble-free operation over an extended period.

8. Ease of Operation and Maintenance: The design should consider the ease of operation for machine operators and maintenance personnel. Intuitive interfaces, clear labelling, and easy access to critical components contribute to efficient operation and maintenance.

9. Safety Considerations: Safety is a top priority in SPM design. Adequate safety features, such as emergency stops, interlocks, and guards, should be integrated to protect operators and prevent accidents.

10. Cost-Effectiveness: SPM design should strike a balance between functionality and cost. The goal is to achieve the required performance at a lower cost, considering factors such as material costs, manufacturing processes, and the overall economic feasibility.

11. Adaptability to Changes: The design should allow for adaptation to changes in production requirements or technological advancements. Flexibility in design can future-proof the SPM to some extent.

12. Environmental Considerations: Where applicable, consider the environmental impact of the machine's operation. This includes energy efficiency, waste reduction, and adherence to environmental regulations.

MAINTENANCE OF MACHINE TOOLS

Maintenance of machine tools is essential to ensure the longevity, reliability, and efficiency of industrial equipment. Machine tools are subjected to wear and tear due to continuous operation, making proper maintenance practices crucial for preventing breakdowns and ensuring smooth production. Maintenance strategies can be categorized into preventive, predictive, corrective, and conditionbased maintenance. Effective maintenance ensures machine tools remain operational, reducing downtime and improving overall productivity.

OBJECTIVES OF MACHINE TOOL MAINTENANCE:

1) The objective of machine tool maintenance is to achieve minimum breakdown end to keep them in good working condition at the lowest possible cost.
2) Machine tools should be kept in such a condition which permits them to be used at their optimum (profit making) capacity without any interruption or hindrance.
3) Maintenance division of the factory ensures the availability of the machines and services required by other sections of the factory.

NEED FOR MACHINE TOOL MAINTENANCE

(i) Machine tools are properly maintained so that they remain in working condition at all the times.

(ii) Their accuracy does not deteriorate.

(iii) They manufacture the components most economically.

For this, machine tools are inspected periodically against

- Use of wrong or inadequate lubrication
- Change in level of the machine tools
- Wrong use and overloading of the machine tools
- Wear of slideways, bearings and other components
- Dust, heat and humidity
- Vibration and Chatter
- Corrosion of some parts due to the use of wrong lubricants etc.
- Productivity, efficiency and capability

TYPES OF MAINTENANCE

Implementing efficient maintenance techniques is crucial for ensuring the reliability, effectiveness, and durability of machine tools across different industrial settings. Organizations can create customized maintenance plans by comprehending several maintenance kinds such as preventive, predictive, reactive, and condition-based, aligning them with their specific needs and operational demands. Firms can boost productivity by implementing proactive maintenance practices and utilizing sophisticated technology to optimize equipment uptime and reduce maintenance expenses.

Given below are the different types of maintenance practices:

a) **REACTIVE MAINTENANCE**
b) **PREDICTIVE MAINTENANCE**
c) **PREVENTIVE MAINTENANCE**
d) **SCHEDULED MAINTENANCE**
e) **ROUTINE MAINTENANCE**

REACTIVE MAINTENANCE

Reactive maintenance, sometimes referred to as breakdown or corrective maintenance, entails dealing with equipment faults as they arise.

This method is used for non-essential equipment or when the expense of preventative actions is more than repair expenses.

Reactive maintenance is characterized by responding to equipment failures as they occur.

• Responding to unexpected equipment malfunctions.

• Immediate repairs to reinstate functionality.

• Performing emergency troubleshooting and diagnostics.

• Inadequate planning and scheduling.

(i) ***corrective maintenance:*** **(**Maintenance performed **after a fault is detected** but **before** it leads to major failure.)

(i) When inspection shows that corrective action is necessary the machine tool should be withdrawn from production.

(ii) As the object of this inspection is to take action before a failure occurs, such action should be taken as quickly as possible.

(iii) Corrective maintenance is a maintenance task performed to identify, isolate, and rectify a fault so that the failed equipment, Machine or system can be restored to an operational condition.

(iv) This type of corrective maintenance only works with non-critical assets that are easily and cheaply repaired or replaced.

Examples:

- Adjusting misalignment
- Fixing vibration issues
- Recalibrating machine settings

(ii) <u>Breakdown maintenance: (</u>Maintenance carried out **only after the machine fails.**)

(i) Breakdown maintenance implies that repairs are made after the equipment is out of order and it cannot perform its normal function any longer, e.g., an electric motor of a machine tool will not start, a belt is broken, etc.

(ii) Under such conditions, production department calls on the maintenance department to rectify the defect. The maintenance department checks into the fault and makes the necessary repairs.

(iii) After removing the fault, maintenance engineers do not attend the equipment again until another failure or breakdown occurs. This type of maintenance may be quite justified in small factories.

(iv) Breakdown maintenance practice is economical for those (non-critical) equipments whose down-time and repair costs are less this way than with any other type of maintenance.

Features:

- Unplanned and emergency-based
- May lead to production loss

Examples:

- Repairing a broken spindle

- Replacing failed motor or components

Typical Causes of Equipment Breakdown

- Failure to replace worn out parts.
- Lack of lubrication.
- Neglected cooling system.
- Indifference towards minor faults.
- External factors (such as too low or too high line voltage, wrong fuel, etc.)
- Indifference towards equipment vibrations, unusual sounds coming out of the rotating machinery, equipment getting too much heated up, etc.

<u>PREDICTIVE MAINTENANCE</u>

Maintenance based on monitoring the actual condition of the machine.

(i) It is comparatively a newer maintenance technique.

(ii) It makes use of human senses or other sensitive instruments such as Audio gauges, Vibration analyzers, Amplitude meters, Pressure, temperature and resistance strain gauges, sensors etc., to predict troubles before the equipment fails.

(iii) Predictive maintenance uses data analysis and monitoring methods to anticipate when equipment failure is probable. Early detection of potential faults is possible through the collection and analysis of data from different sensors and monitoring systems, enabling prompt intervention and maintenance actions.

(iv) Unusual sounds coming out of rotating equipment predict a (coming) trouble; an electric cable excessively hot at one point predicts a trouble. Simple hand touch can point out many unusual (equipment) conditions and thus predict a trouble.

Important components of predictive maintenance are:

• Continuous monitoring of machine performance.

• Conducting data analysis to detect changes and defects.

• Predictive modeling to estimate remaining usable life.

• Instant alerts and notifications in real-time.

• Combining sensors and IoT technologies.

<u>**PREVENTIVE MAINTENANCE**</u>

Maintenance carried out before failure occurs to avoid breakdowns.

Preventive maintenance is the practice of taking proactive steps to avoid equipment breakdown. This maintenance type focuses on detecting and resolving possible problems by doing routine inspections, lubrication, calibration, and replacing components. Following a predetermined maintenance schedule helps reduce machine downtime and prolong the equipment's lifespan. Preventive maintenance involves scheduled examinations and servicing.

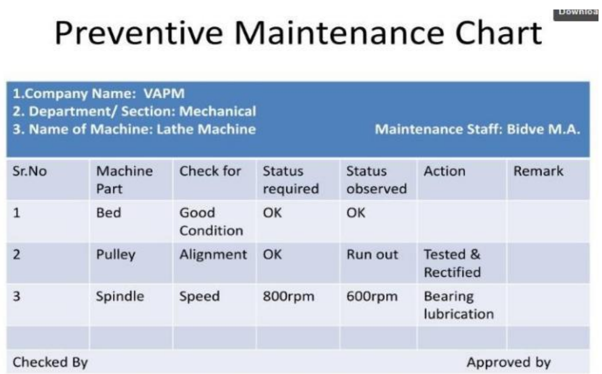
• Scheduled inspections and servicing.

• Lubrication of moving parts.

• Adjusting machine parameters precisely.

• Replacing worn-out parts

• Implementation of condition monitoring techniques.



Preventive Maintenance Chart

1.Company Name: VAPM 2. Department/ Section: Mechanical 3. Name of Machine: Lathe Machine					Maintenance Staff: Bidve M.A.	
Sr.No	Machine Part	Check for	Status required	Status observed	Action	Remark
1	Bed	Good Condition	OK	OK		
2	Pulley	Alignment	OK	Run out	Tested & Rectified	
3	Spindle	Speed	800rpm	600rpm	Bearing lubrication	
Checked By					Approved by	

Objectives of Preventive Maintenance (PM)

a) To minimize the possibility of unanticipated production interruption or major breakdown by locating or uncovering any condition this may lead to it.

b) To make machine tools always available and ready for use.

c) To maintain the optimum productive efficiency of the machine tools.

d) To maintain the operational accuracy of the machine tools.

e) To reduce the work content of maintenance jobs.

f) To achieve maximum production at minimum repair cost.

g) To ensure safety of life and limb of the machine tool operators.

h) To maintain value of machine tools (by periodic inspections, repairs, overhauls)

Advantages:

- ✓ Less production down time.
- ✓ Repairs of parts are avoided.
- ✓ Life of components increases.

<u>SCHEDULED MAINTENANCE</u>

Maintenance planned at specific time intervals based on usage or manufacturer guidelines.

(i) When maintenance is carried out as per the time table prepared in advance for the machine tool, it is known as scheduled maintenance. e.g. Cleaning of water tank, checking of pressure vessel, refilling of CO_2 in fire extinguisher, calibration of measuring instruments, etc.

(ii) Scheduled maintenance is a stich-in-time procedure aimed at avoiding breakdowns. Breakdowns can be dangerous to life and as far as possible should be minimized.

(iii) Inspection, lubrication, servicing, etc., of these equipments are included in the predetermined schedule.

(iv) Scheduled maintenance is the maintenance activity that is **planned and carried out at predetermined time intervals** based on machine usage, manufacturer recommendations, or past experience.

Key Features:

- Performed at **fixed intervals** (daily, weekly, monthly, yearly)
- **Pre-planned and systematic** approach
- Helps **prevent unexpected breakdowns**
- Based on **time or operating hours**
- Usually documented in maintenance schedules or charts

Activities Involved:

- Inspection of machine components
- Lubrication of moving parts
- Tightening of bolts and fasteners
- Replacement of worn-out parts
- Calibration and alignment checks
- Cleaning and coolant replacement

Examples:

- ✓ Daily cleaning and lubrication of lathe machine
- ✓ Weekly inspection of belts and gears
- ✓ Monthly alignment check of CNC machines
- ✓ Annual overhaul of machine tool

Advantages

- · Reduces chances of sudden failure
- · Increases machine life and efficiency
- · Improves production quality
- · Helps in better planning of maintenance work

Routine Maintenance

Basic maintenance done **regularly by operators**.

Features:

- Simple and frequent tasks
- Helps prevent major issues

Examples:

- Cleaning chips and dust
- Checking coolant levels
- Visual inspection

Repair cycle analysis

- ❖ Repair Cycle Analysis in machine tools is a systematic approach used to examine and enhance the efficiency and efficacy of repairs carried out on machine tools after equipment breakdowns or failures. The analysis seeks to **decrease downtime, lower maintenance expenses, and improve equipment reliability.**
- ❖ Repair Cycle Analysis is the study of the **time required to detect, diagnose, repair, and restore equipment** to its normal working condition after a failure.
- ❖ Repair Cycle Analysis is a vital tool in maintenance management that focuses on reducing downtime by analyzing each stage of the repair process. Efficient repair cycles lead to improved productivity, reduced costs, and higher machine reliability.

The repair cycle typically consists of the following stages:

1. **Failure Occurrence Time** : The moment when the machine stops functioning.
2. **Detection Time** : Time taken to identify that a failure has occurred.
3. **Diagnosis Time:** Time required to locate the exact fault or cause.
4. **Repair Time:** Actual time spent fixing the fault or replacing components.
5. **Testing & Adjustment Time:** Ensuring the machine works properly after repair.
6. **Return to Service Time:** Machine is restored to normal operation.

Repair cycle analysis involves:

1. **Locating Breakdowns in Equipment:** The procedure begins by realizing and documenting occurrences of equipment failures or breakdowns. Possible issues may involve problems in different parts including motors, bearings, control systems, or structural elements of the machine tool.
2. **Documentation of Repair Activities:** Each repair performed on the machine tool is meticulously documented. The information required includes the specific day and time of the failure, the type of failure, any parts or components that were replaced, the repair methods employed, and the length of time taken for the repair.
3. **Downtime Analysis:** An analysis is conducted on the duration of downtime caused by equipment breakdowns. This involves **keeping track of the duration** from the moment of failure to the point when the machine tool was restored to full functionality.
4. **Root Cause Analysis:** Root Cause Analysis is performed to identify the fundamental reasons for equipment malfunctions. This includes investigating problems such as mechanical breakdown, lack of proper servicing, insufficient operator training, low-quality components or materials, environmental factors, or design deficiencies.

5. **Repair Time Analysis:** The amount of time required to finish each individual repair task is evaluated. The amount of time spent diagnosing the problem, placing orders for new parts, carrying out the repair, and performing post-repair testing and validation is included in this measurement.
6. **Cost Analysis:** The costs related to repairs are evaluated, including both direct and indirect expenses. Direct costs includes the expenditures for replacement parts, labour, and specialized repair services outsourced. Indirect costs may include losses from production halts, overtime pay, and effects on consumer satisfaction.
7. **Identification of Improvement Opportunities:** Based on the analysis results, possible actions include optimizing repair procedures, introducing preventative maintenance strategies, strengthening maintenance staff training programs, improving spare parts inventory management, or updating equipment components to enhance reliability.
8. **Implementation of Corrective Actions:** Tasks may include adjusting maintenance schedules, acquiring sophisticated diagnostic tools, improving inventory management systems, or offering extra training to maintenance personnel.
9. **Performance Monitoring:** The efficacy of the corrective measures is continually assessed. Key performance indicators like mean time between failures (MTBF), mean time to repair (MTTR) and overall equipment effectiveness (OEE) are monitored to evaluate the effects.
10. **Continuous Improvement:** Repair cycle analysis is a continual procedure focused on enhancing performance.

Repair Complexity

Repair complexity refers to the **degree of difficulty involved in diagnosing, repairing, and restoring a failed machine or component** to its normal working condition.

Factors Affecting Repair Complexity

Repair complexity depends on several technical and operational factors:

1. **Design Complexity** : Machines with intricate designs, tight tolerances, or compact assemblies are harder to repair.
2. **Accessibility of Components** : If parts are difficult to reach or require disassembly of multiple components, repair becomes complex.
3. **Fault Diagnosis Difficulty** : Hidden or intermittent faults increase complexity.

4. **Skill Requirement** : Highly specialized skills or trained personnel may be needed.
5. **Availability of Tools & Equipment** : Lack of proper tools or diagnostic instruments increases difficulty.
6. **Spare Parts Availability** : Non-availability or long lead time of spares adds complexity.
7. **Technology Level** : CNC machines, automated systems, and electronics increase repair complexity.

Levels of Repair Complexity

Repair complexity is often categorized into levels:

1. **Low Complexity**

- Simple faults, easy access, quick repair
- Example: Replacing a worn belt

2. **Medium Complexity**

- Requires some disassembly and skilled labor
- Example: Bearing replacement

3. **High Complexity**

- Involves advanced diagnostics and major disassembly
- Example: CNC control system failure

Repair complexity plays a crucial role in maintenance planning. Lower repair complexity leads to faster repairs, reduced downtime, and improved system reliability, making it an important consideration in machine design and maintenance strategies.

Overall, repair complexity in machine tools is a complicated term driven by a variety of elements such as the nature of the problem, component accessibility, technical documentation availability, maintenance personnel skill level, and resource requirements. Understanding and measuring these aspects allows firms to better manage repair procedures, reduce downtime, and improve equipment reliability.

Maintenance manual

- A maintenance manual for machine tools is a thorough document issued by the manufacturer to guide users, technicians, and maintenance professionals through the correct care, maintenance, and troubleshooting of a specific machine tool.
- A **maintenance manual** is a detailed document that provides **instructions, procedures, and guidelines** for the proper maintenance, inspection, troubleshooting, and repair of machines or equipment.
- These manuals are invaluable resources, precisely prepared to provide users with the knowledge and instructions required to ensure the equipment's peak performance, longevity, and safety.

The Fundamental Elements of a Maintenance Manual are:

1. Introduction: The manual usually starts with an introduction that explains its objective, scope, and target audience. This section may also offer a summary of the machine tool, highlighting its main characteristics and uses.

2. Safety precautions: The incorporation of safety precautions and instructions into any maintenance handbook is an essential component that must be there in order to guarantee the health and safety of staff. Within this section, possible risks that are related with maintenance chores are brought to light, and recommendations for reducing those dangers are provided.

3. Procedures for preventive maintenance: For the purpose of completing routine preventive maintenance tasks, such as lubrication, cleaning, inspection, and calibration, detailed instructions are supplied. It is imperative that these procedures be followed in order to avoid early wear, preserve accuracy, and make the most of the machine tool's lifespan.

4. Troubleshooting guidelines: A comprehensive set of troubleshooting techniques is included in the handbook, which is designed to assist users in identifying and resolving common problems or malfunctions that may occur while the machine is being operated. The purpose of this section is to assist in the process of problem-solving by providing flowcharts, checklists, or troubleshooting trees.

5. Repair and replacement of parts: The manual includes detailed instructions that can be followed in order to replace or repair particular machine tool components in the event that a component fails or is damaged. Disassembly, reassembly, adjustment, and alignment techniques, as well as recommendations for spare parts, are all included in this.

6. Maintenance schedule: Users can plan and schedule routine maintenance tasks with the help of the offered recommended schedules and intervals. Maintenance is done proactively when following these schedules, which minimizes downtime and maximizes equipment performance.

7. Technical specifications: The user is provided with comprehensive technical specifications, diagrams, and schematics of the machine tool components in order to facilitate their comprehension of the machine's functioning and configuration responsibilities. This information is necessary for precisely identifying problems and carrying out maintenance in an efficient manner.

8. Maintenance records: Provisions for maintaining maintenance records may be included in certain manuals. These provisions could enable users to document maintenance activities, dates, tasks accomplished, as well as any observations or problems that may have been encountered. The machine tool's maintenance history may be tracked with the use of this documentation, which also assists in identifying patterns or problems that keep occurring.

- ✓ A maintenance manual is an essential document in any industrial setup, providing systematic instructions for maintaining equipment efficiently. It helps improve reliability, reduce failures, and ensure safe operation of machines.
- ✓ Finally, a machine tool maintenance manual helps users maintain, diagnose, and optimize their equipment. Operators and maintenance staff can maximize productivity and minimize downtime by following the manual's guidelines and procedures to maintain machine tool reliability, longevity, and safety. Thus, the maintenance manual is crucial for machine tool maintenance management.

Maintenance records

- ✧ Maintenance records in machine tools are detailed documentation which records all maintenance actions carried out on a specific machine tool during its operational lifecycle.
- ✧ Maintenance records are **systematic documents that contain the history of maintenance activities** performed on machines or equipment, including inspections, repairs, replacements, and servicing.
- ✧ These records are essential for monitoring equipment maintenance history, assessing equipment health, and making educated decisions about maintenance practices and future investments.

Objectives of Maintenance Records

- Track maintenance history of equipment
- Identify recurring faults and failure patterns
- Plan preventive maintenance effectively
- Improve reliability and performance
- Support decision-making (repair or replacement)

Maintenance records usually contain the following details:

a. **Date and time:** When each maintenance activity or inspection was carried out, including the date and time of the event. This assists in the establishment of a chronological record of the activities related to maintenance.

b. **Maintenance task:** A description of the particular maintenance task that was carried out, which may include lubrication, cleaning, inspection, calibration, component repair, or replacement.

c. **Task details:** Information about the maintenance task, such as the particular components or systems that are being maintained, the tools or equipment that are being utilized, and any observations or discoveries that were made while the maintenance activity was being carried out.

d. **Technician or operator:** Identification of the technician or operator who is responsible for carrying out the maintenance task, including their name or identification. It is easier to assign responsibility and keep track of the persons who are participating in maintenance operations when this is done.

e. **Duration:** The amount of time needed to finish the repair job. This gives information about how well maintenance methods work and helps plan when to do future maintenance tasks.

f. **Condition assessment:** Any evaluations or assessments of the machine tool's state, that were done during the maintenance task, such as notes on wear, damage, abnormalities, or signs of possible problems.

g. **Maintenance Recommendations:** Recommendations or follow-up activities that are a result of the maintenance activity, such as extra repairs, changes, or additional inspections that are required to solve the issues that were detected.

h. **Parts and materials used:** The records of any components, materials, lubricants, or consumables that were utilized in the course of the maintenance task, including the part numbers, quantities, and suppliers of those components.

i. **Equipment calibration:** Documentation of equipment calibration conducted during maintenance, detailing calibration dates, results, and any modifications made.

j. **Signature and approvals:** Signatures or permissions from authorized people are required to verify the performance of maintenance tasks and ensure compliance with maintenance processes and standards.

HOUSEKEEPING

Housekeeping refers to the systematic practice of maintaining cleanliness, order, and safety in and around machine tools. It plays a vital role in ensuring efficient machine performance, longer service life, and a safe working environment.

Good housekeeping is an integral part of machine tool maintenance. It not only ensures smooth functioning of machines but also promotes a safe, organized, and productive workplace.

To maintain the highest standards of cleanliness in a machining setting, you need to adhere to these basic steps:

1. Cleanliness of Machines

Regular cleaning of machine tools is essential to remove chips, dust, coolant, and oil deposits. Accumulation of dirt on guideway, slides, and spindles can affect machining accuracy and lead to premature wear.

2. Proper Lubrication Practices

Housekeeping ensures that lubrication points are clean before applying oil or grease. Excess oil should be wiped off to prevent contamination and slipping hazards. Proper lubrication reduces friction and wear of moving parts.

3. Organization of Tools and Equipment

Cutting tools, gauges, fixtures, and accessories should be stored in designated locations such as tool racks or shadow boards. Proper organization reduces search time and prevents damage or loss of tools.

4. Waste and Scrap Disposal

Metal chips, scrap materials, and used coolant should be disposed of properly using designated bins. This prevents clutter, reduces accidents, and maintains a clean working environment.

5. Floor and Workplace Maintenance

Floors around machine tools should be kept clean and dry. Oil or coolant spills must be cleaned immediately to avoid slips and falls. Walkways should remain free from obstructions.

6. Safety and Accessibility

Safety guards, emergency switches, and fire extinguishers should be easily accessible and kept clean. Adequate lighting and ventilation must be maintained for safe operation.

7. Routine Inspection and Checks

Housekeeping includes regular inspection of machines for loose bolts, leaks, abnormal noise, and misalignment. Early detection helps in preventing major breakdowns.

Importance of Housekeeping

- Improves machine efficiency and accuracy
- Reduces maintenance cost and downtime
- Enhances safety of workers
- Increases productivity
- Ensures better quality of finished products

There are several signs which reflect poor housekeeping and cleanliness at the workplace in the organization. Some of these signs are (i) cluttered and poorly arranged work areas, (ii) untidy or dangerous storage of materials (such as materials stuffed in corners and overcrowded shelves etc.), (iii) dusty and dirty floors and work surfaces, (iv) items lying on the shop floor which are in excess or no longer needed, (v) blocked or cluttered aisles and exits, (vi) tools and equipment left in work areas instead of being returned to proper storage places, (vii) broken containers and damaged materials, (vii) overflowing waste bins and containers, and (viii) spills and leaks etc.

TOTAL PRODUCTIVE MAINTENANCE

Total Productive Maintenance (TPM) is a maintenance philosophy aimed at maximizing equipment effectiveness by involving all employees—from operators to top management—in maintaining and improving equipment. It focuses on achieving zero breakdowns, zero defects, and zero accidents.

TPM is a comprehensive approach that integrates maintenance with production processes. By involving all employees and focusing on continuous improvement, TPM enhances productivity, quality, and equipment reliability, making it essential for modern manufacturing systems.

TPM in machine tools emphasizes proactive maintenance strategies, involving both operators and maintenance personnel, to ensure the equipment's optimal performance, reliability, and longevity.

Objectives of TPM

- Maximize Overall Equipment Effectiveness (OEE)
- Achieve zero equipment breakdowns
- Eliminate defects and rework
- Improve workplace safety
- Increase productivity and equipment life

Key Elements / Pillars of TPM

1. **Autonomous Maintenance (AM)**

➢ Operators are provided with training and authority to carry out regular maintenance duties on the machine tools, including but not limited to cleaning, lubrication, inspection, and small adjustments.

➢ The primary objective of AM is to mitigate the degradation of machine conditions, promptly detect any irregularities, and ensure that equipment remains in an optimal operational state.

➢ By actively engaging operators in the maintenance process, machine tools are effectively maintained, resulting in enhanced reliability and decreased periods of inactivity.

2. **Planned Maintenance (PM)**

➢ Maintenance activities are scheduled based on time or condition to prevent unexpected failures. Some repairs are aligning, calibrating, replacing worn parts, and planning maintenance based on monitoring the health of the equipment.

➢ If maintenance is done ahead of time, unexpected breakdowns are less likely to happen and the machines last longer generally.

3. **Quality Maintenance**

Ensures machines produce defect-free quality products by maintaining proper conditions. This involves fixing any problems that may arise with the machine's accuracy, repeatability, and stability, all of which have the potential to impact the quality of the product.

4. **Training and Education**

Enhances skills of operators and maintenance staff for better equipment handling.

- It is vital for both operators and maintenance people to participate in appropriate training and education programs in order to ensure that they possess the information and abilities necessary to accurately carry out their respective tasks.
- Training may cover topics such as technique for troubleshooting, maintenance processes, safety protocols, and the functioning of various pieces of equipment.
- Employees who have received enough training are in a better position to recognize possible problems at an earlier stage, carry out maintenance activities in the appropriate manner, and contribute to the overall success of TPM programs.

5. **Early Equipment Management**

Considers maintenance aspects during design and installation of new equipment.

- During the phases of design, procurement, and installation of new machine tools, EEM requires taking into consideration the maintenance requirements that are necessary.
- It is possible to lower overall life cycle costs and maintenance requirements by selecting equipment that has a high level of maintainability, reliability, and ease of serviceability.
- Furthermore, using the appropriate processes for installation and commissioning ensures that the machine tools get off to a good start, hence reducing the number of problems that arise while they are in operation.

6. **Safety, Health, and Environment**

Maintains a safe and healthy workplace with zero accidents.

7. **Office TPM**

Applies TPM principles to administrative and support functions.

8. **Focused Improvement (Kaizen)**

Continuous improvement activities to eliminate losses and improve efficiency.

Benefits of TPM

- Reduced machine breakdowns
- Improved product quality
- Increased equipment efficiency
- Reduced maintenance cost
- Better employee involvement and morale
- Safer working environment

G.P KANDHAMAL

MECHANICAL DEPARTMENT

QUESTION BANK

ADVANCE MANUFACTURING PROCESSES, 6^{TH} SEMESTER

MODULE 1

Modern Machining Processes

SHORT ANSWER TYPE QUESTIONS (2 MARKS AND 5 MARKS)

1. Explain the need for the use of unconventional machining processes compared to the conventional ones.
2. Explain the reasons why the unconventional machining processes are used.
3. Explain why the tool shape in EDM should be complementary to the final form.
4. What are the functions served by the dielectric fluid in EDM?
5. Give examples of dielectric fluid used in EDM.
6. What are the characteristics required for a good electrode material in EDM?
7. State various electrode materials for EDM.
8. Explain the application of the following electrode materials in EDM: (a) Copper (b) Graphite
9. What are the important parameters that control the material-removal rate in EDM? Briefly explain any two factors.
10. Explain the advantages and disadvantages of EDM.
11. Write a short note on wire-EDM process.
12. Write down various application areas of EDM.
13. Explain the principle of ECM with a neat sketch.
14. What are the functions served by the electrolyte in ECM?
15. Give examples of electrolytes used for ECM.
16. Describe the factors that should be considered in selecting an electrolyte in ECM.

17. What factors should be considered in selecting the tool materials in ECM?
18. What are the various tool materials used in ECM?
19. Briefly explain the various process parameters that affect the material-removal rate in ECM.
20. Explain the advantages and disadvantages of ECM.
21. Write down various application areas of ECM.
22. Explain how material is removed in USM.
23. Briefly explain about the functions of transducer and tool cone in USM.
24. What is the function of abrasive slurry in USM? Explain how the abrasive selection is made.
25. State about MRR and factors affecting it in USM.
26. Explain the advantages and disadvantages of USM.
27. Write down various application areas of USM.
28. Give a short note on LBM.
29. What are the types of lasers that are generally used in LBM? Explain their significance.
30. State about MRR and factors affecting it in LBM.
31. Write down various application areas of LBM.
32. Explain the advantages and disadvantages of A]M.
33. Describe the factors that should be considered in selecting the abrasive in AJM.
34. Give examples of abrasives used in AJM.
35. Explain how material is removed in AJM.
36. State about MRR and factors affecting it in AJM.
37. Write down various application areas of AJM.
38. Explain the advantages and limitations of electron-beam machining.
39. State about MRR and factors affecting it in EBM.
40. Give the applications of plasma-arc machining.
41. Explain the advantages and limitations of plasma-are machining.
42. State about MRR and factors affecting it in PAM.

LONG QUESTIONS (8 MARKS)

1. Give a comparison of the unconventional processes in terms of process, material-removal rate and applications.
2. Explain the working principle of EDM with a neat sketch.
3. Briefly explain the working of an EDM machine showing important elements.
4. Briefly explain the working of an ECM machine showing important elements.
5. Briefly explain the working of an USM machine showing important elements.
6. Briefly explain the working of an LBM machine showing important elements.
7. Explain the working principle of AJM with a neat sketch. State its advantages and disadvantages.
8. Briefly explain the equipment and working principle used for electron beam machining. Give the applications of electron-beam machining.
9. Briefly explain the working principle plasma-arc machining process with neat sketch.

MODULE 2

Plastic Processing

SHORT ANSWER TYPE QUESTIONS (2 MARKS AND 5 MARKS)

1. Differentiate between thermoplastic and thermosetting polymers with suitable examples.
2. Write down common properties of plastics.
3. List out the basic moulding methods for plastics.
4. Briefly mention the criteria for selecting plastic processing methods.
5. Write a short note on casting processing method.
6. Explain the process calendaring.
7. Briefly explain blow moulding method for making a plastic water bottle.
8. What do you mean by vacuum forming?
9. Explain pressure bag moulding process.
10. Write down the methods for laminating plastics.

11. Write a short note on low pressure laminates.
12. Write down the applications of plastics in engineering fields.

LONG QUESTIONS (8 MARKS)

1. What are the various materials added to polymers during polymerization? Briefly mention their roles with examples.
2. What is compression moulding? Briefly explain the process with a neat sketch. Write down the advantages and applications of compression moulding.
3. Explain (i) flash type (ii) positive type (iii) landed positive type (iv) semi positive type compression moulding.
4. What is transfer moulding? Briefly explain the process with a neat sketch. Write down the advantages and applications of transfer moulding.
5. What is injection moulding? Briefly explain the process with a neat sketch. Write down the advantages, limitations and applications of injection moulding.
6. What is extrusion moulding? Briefly explain the process with a neat sketch. Write down the advantages and applications of extrusion moulding.
7. Explain the methods for manufacturing plastic laminating sheets, plastic rods and tubes.

MODULE 3

Additive Manufacturing Process

SHORT ANSWER TYPE QUESTIONS (2 MARKS AND 5 MARKS)

1. How would you define prototype in the context of modern product development?
2. What are the main roles and functions for prototypes? How do you think rapid prototyping satisfies these roles?
3. What are the fundamentals of additive manufacturing?
4. What is the *Rapid Prototyping Wheel?* Describe its four primary aspects.
5. Write down the limitations of additive manufacturing.
6. What are the other terms used in place of additive manufacturing? Justify.

7. What is your favorite term (AM, Freeform Fabrication, RP, etc.) for describing this technology and why?
8. How do you classify rapid prototyping systems?
9. Name three Rapid Prototyping Systems that are liquid-based.
10. How can the liquid form be converted to the solid form as in these liquid-based Rapid Prototyping Systems?
11. In what form of material can Rapid Prototyping Systems be classified as solid-based? Name three such systems.
12. What is the method used in powder-based Rapid Prototyping Systems?
13. Briefly explain various fundamental automated processes.
14. Briefly explain other technologies that are related to AM.
15. Which step in the entire process chain is, in your opinion, the shortest? Most tedious? Most automated? Support your choice.
16. What are the finishing processes that are used for RP models and explain why they are necessary?
17. What are the typical RP applications in design?
18. What are the typical RP applications in engineering and analysis?
19. Explain how RP systems can be applied to traditional industries like the jewelry industries.
20. What are the typical RP applications in medicals and bioengineering?
21. What are the typical RP applications in aerospace engineering?
22. What are the typical RP applications in automotive industries?
23. What do you mean by concurrent engineering? Explain briefly.
24. Write a short note on capstan and turret lathe.
25. What do you understand by the term flexible manufacturing system?
26. Explain the needs for flexible manufacturing syatem?
27. Write down the advantages of FMS.
28. List down the various components of FMS.
29. Write a short note on concurrent engineering.

LONG QUESTIONS (8 MARKS)

1. Describe the advantages of Rapid Prototyping in terms of its beneficiaries such as the product designers, tool designer, manufacturing engineer, marketeers and consumers?
2. Differentiate between CNC and AM.
3. Broadly classify rapid prototyping systems.
4. Describe the steps involved in a general RP process chain.
5. Distinguish cleaning, post curing and finishing which are the various tasks of post processing. Name two RP processes that do not require post curing and one that does not require cleaning.
6. Explain the components of FMS: Processing Station, Material handling & storage and Computer Control System.
7. Describe the process flow of Cubic's Laminated Object Manufacturing.
8. Describe the process flow of Stratasys' Fused Deposition Modeling.
9. Describe the process flow of the 3D System Stereolithography Apparatus.

MODULE 4
SPECIAL PURPOSE MACHINES (SPM)

1. Define special purpose machine.
2. State the objectives of SPM.
3. Discuss about general elements of SPM in detail.
4. Explain productivity improvement by SPM.
5. Discuss principles of SPM design in detail.

MODULE 5
MAINTENANCE OF MACHINE TOOLS

1. Define maintenance and explain any two types of maintenance.
2. Differentiate between preventive and corrective maintenance.
3. What is predictive maintenance? State its advantages.
4. Explain breakdown maintenance with examples.
5. What is repair cycle analysis?
6. State the importance of repair cycle analysis in maintenance.
7. Define repair complexity.
8. What factors affect repair complexity?
9. How does repair complexity influence maintenance planning?
10. What is a maintenance manual?
11. List the contents of a maintenance manual.
12. State the importance of maintenance manuals in industry.

13. What are maintenance records?
14. List types of maintenance records.
15. State the benefits of maintaining proper records.
16. Define housekeeping in machine maintenance.
17. List key elements of housekeeping.
18. State the importance of housekeeping.
19. What is Total Productive Maintenance (TPM)?
20. State the objectives of TPM.

10-Mark Questions

1. Explain various types of maintenance with suitable examples.
2. Compare preventive, predictive, and breakdown maintenance.
3. Discuss the advantages and limitations of different maintenance strategies.
4. Explain repair cycle analysis with stages and its significance.
5. Discuss how repair cycle analysis helps in reducing downtime.
6. Explain repair complexity and factors affecting it in detail.
7. Explain the structure and contents of a maintenance manual.
8. Discuss the importance of maintenance manuals in machine tool maintenance.
9. Explain housekeeping in machine tool maintenance and its importance.
10. Discuss the role of housekeeping in improving safety and productivity.
11. Explain Total Productive Maintenance (TPM) and its objectives.
12. Describe the pillars of TPM in detail.

RAPID PROTOTYPING METHODS

The various RP technologies differ from the way the cross-setions are produced as well as the material that can be used. The most common rapid prototyping processes are Stereolithography, Selective Laser Sintering, and Laminated Object Manufacturing.

STEREOLITHOGRAPHY

Stereolithography (SL), the first and most widely used rapid prototyping and manufacturing technologies (RP&M), can literally go from art to part. It can quickly and accurately take a CAD or CAM design or a computer-scanned image, and produce solid three-dimensional objects in a matter of hours. This technology allows manufacturers to reduce time-to-market by as much as 80%, reduce product development costs, and respond quickly to market changes, while improving product quality.

The Stereolithography Process

1. CAD Design

■ Stereolithography begins with data from a CAD system.

■ A good CAD designer or engineer is very important to successful prototyping.

■ A good CAD system is a must to ensure success.

2. Translation

The CAD file must be translated into a file that the SLA system can read.

■ The STL file format appears to be the standard use for RP&M.

3. Process

■ The SLA builds physical models a layer at a time.

■ The CAD data of the product design is first sliced into very thin cross-sections.

■ The slice unit is the value that the software program uses in place of CAD units, and can range in thickness from 0.07 mm to 0.38 mm.

■ A laser beam of ultraviolet light is then focused onto the surface of a vat of liquid photopolymer.

■ The laser beam traces the thin cross-section of the part, turning a thin layer of liquid plastic to solid.

■ The layer thickness (slice units) can range from 0.07 mm to 0.38 mm; however, if a very accurate form is required, layers of 0.13 mm or less are recommended.

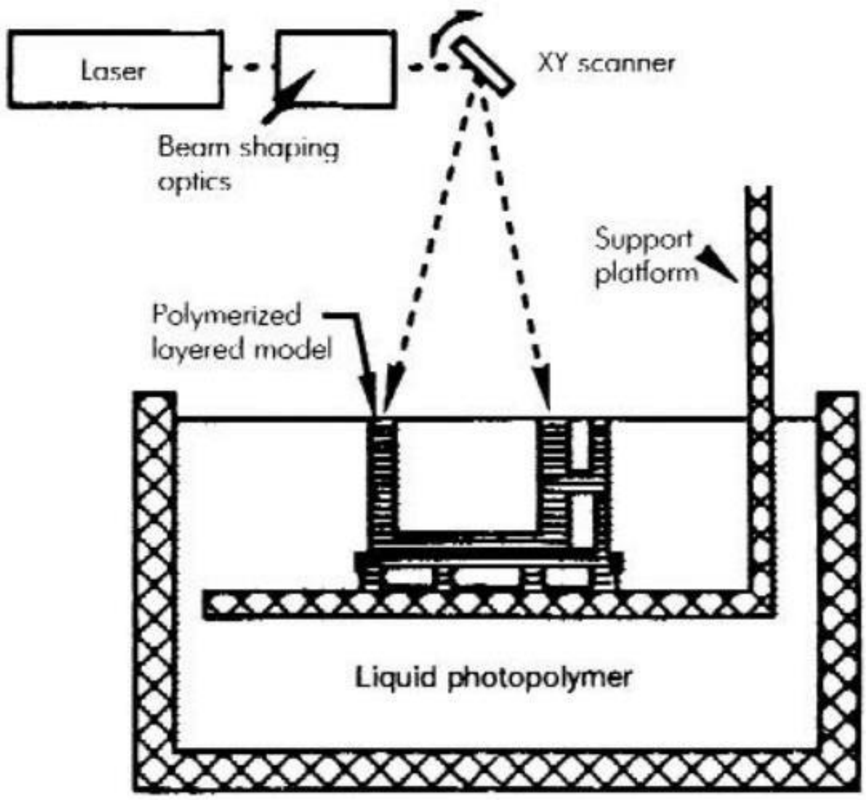
■ The model is then lowered in the vat and recoated with liquid photopolymer and the laser traces the next layer on top of the previous one.

■ The process continues layer by layer until the part is complete.

■ Unattended SLA systems work around the clock, without tooling, machining, or cutting, and a three-dimensional part is built within a few hours.

■ The final part is removed from the vat and is treated in a final curing process.

■ The SLA prototype can be used in secondary manufacturing processes to produce the final product.



Process variables:

2. **Finished Part Size** - SLA systems can only handle parts within a specific size, however, it is possible to make parts in sections and bond them together.
3. **Volume** - RP&M systems must be used frequently to justify the expense.
4. **Speed** - Most systems take about a minute to produce each layer, and parts can be built overnight, making this method extremely fast compared to most traditional methods for producing a prototype.
5. **Part Finish** - Slice thickness used to make the model will determine the surface finish. If a fine finish is required, the slice thickness should be small, and will take

longer to produce. If surface finish is not too important, larger slice thickness can be used.

6. **Materials** - If a model must only last for a few hours to show and tell, it can be made from relatively weak materials. If it must undergo rigorous testing, it requires stronger material, especially where temperature is a prime consideration. The best materials can withstand a constant temperature of 392°F (200°C).

7. **Cost** - The cost of the SLA machine is only one factor. therefore, when considering this type of equipment, consider how the system will improve your operation and product quality. Despite the high up-front cost, the long-term savings from design and production improvements can be as high as 30%.

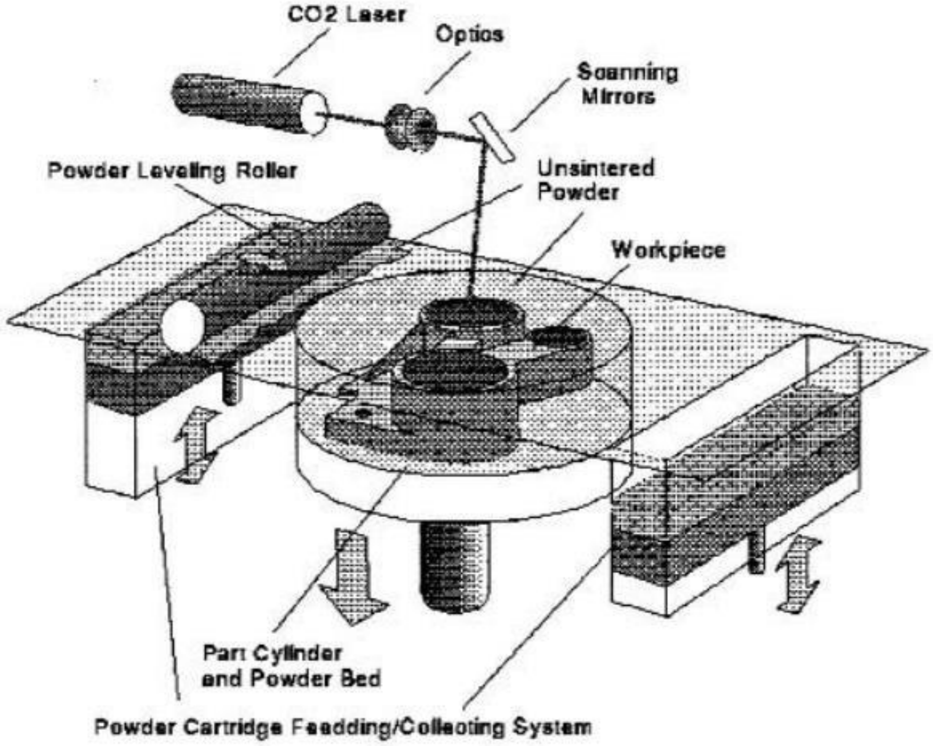
SELECTIVE LASER SINTERING (SLS)

- Laser Sintering (SLS), a powder-based fabrication technology, uses a CO2 laser beam to fuse (sinter) layers of plastic, metal, ceramic, and composite powdered materials into 3D parts.
- By mixing powder particles with thermal binders, a wide variety of materials such as polycarbonate, nylon, polystyrene, sand, and direct metal powders can be used. The powders offer several key advantages over resin-based technologies as well, including higher strength and durability.
- This process is used for building functional parts that are extremely durable and accurate, have high tensile strength, and are resistant to many chemicals. The SLS process provides almost unlimited materials and applications flexibility because of its ability to work with a variety of powdered materials. Selective Laser Sintering can work with almost any type of material, providing it is available in a powder form. Any powder material that is capable of being fused is capable of being transformed into a model and can be used as a true prototype component.

The SLS Process

The prime requirements for the SLS process are the 3D dimensional CAD design in the industry-standard STL format and a Selective Laser Sintering station.

1. CAD files are transferred to the SLS machine where they are sliced into thin cross-sections.
2. A thin layer of heat-fusible powder is deposited across the build chamber.
3. An initial cross-section of the object under construction is drawn on the powder with a C02 laser.
4. The laser heats only the powder defined by the object’s geometry at the cross-section to the melting point, causing the powder particles to fuse and form a solid mass.
5. Another layer of powder is deposited on top of the previous layer by a roller system,
6. The process is repeated, with each layer fusing to the one below it.
7. Successive layers of powder are deposited and the process repeated until the part is completed.
8. After processing, the part is removed and loose powder is removed and recycled. Parts may require some post-processing depending on their application.



Advantages

■ It is a leading rapid prototyping technology, providing more choices of materials for flexibility, and more applications than other technologies.

■ A manufacturing process can be verified before expensive tooling is purchased.

■ The SLS process quickly creates parts strong enough to be used as functional prototypes and end-use parts.

■ A limited number of parts can be produced for testing and early market introductions.

■ Tooling and pattern prototypes can be produced quickly with a minimum amount of steps. In some cases, the final tooling may be produced.

Disadvantages

■ The part size is limited by the size of the build chamber.

■ Part surfaces have a granular texture because the powder particles are relatively large (.003 to .005 or 80 to 120).

■ Crystalline powders such as wax and nylon liquefy and are smoothed by surface tension; the surface may show pitting.

■ The capital costs could be high if the volume does not justify the expenditure.

■ The energy costs could be high (not higher than other RP systems).

Applications

Primary applications of SLS technology include functional modeling, prototype manufacturing, and direct manufacturing. Specific application segments include functional modeling, patterns masters for investment casting, cores and molds for sand casting, and metal molds for injection molding or die casting. For typical applications, SLS can be used to build prototype assemblies that can be powered and tested under actual working conditions. From aerospace to consumer electronics, automobiles to appliances, manufacturers have been able to shorten design, development, and time-to-market of new products.

LAMINATED OBJECT MANUFACTURING (LOM)

In the Laminated Object Manufacturing (LOM) process, a computer image of the solid object is sliced out of inexpensive paper, plastic film, ceramic, or composite sheet-form material, into parallel, two-dimensional cross sections with a laser. The sheet-form material is laminated (layered) together to form the 3-D model. LOM is similar to SLA (stereolithography) in that it slices a three-dimensional CAD electronic file from the computer to the LOM machine to produce parts for design purposes, visualization models, patterns or molds, casting, rotational molding, blow molding, and rubber molding.