E-Learnig Materials
On

Advanced Manufacturing Technology

Branch –Mechanical
6th Semester

Preapared
By

Mr. Deepak Ranjan Pattnaik
Lecturer in Mechanical Engg. Department
Govt. Polytechnic, Nabarangpur
At-Agnipur 764059

CH-01 →→ Nonconvectional M/C Process ←←

→ Two types of Maching process.
① Convectional
② Non convectional

→ convectional → Workpiece touches the tool.
→ Drilling, Maching, grinding, lathe etc.
→ Low surface finish, larger man power more time consumption, low tool life.

→ Nonconvectional → W/P is not touch the tool
→ for ex: electro chemical M/C Process
Electro discharge
plasma arc
Leaser beam
abrasive Jet
electron beam.
→ Low surface finish.
Lesser power required.
Aparantely using time requires.
Long tool life.

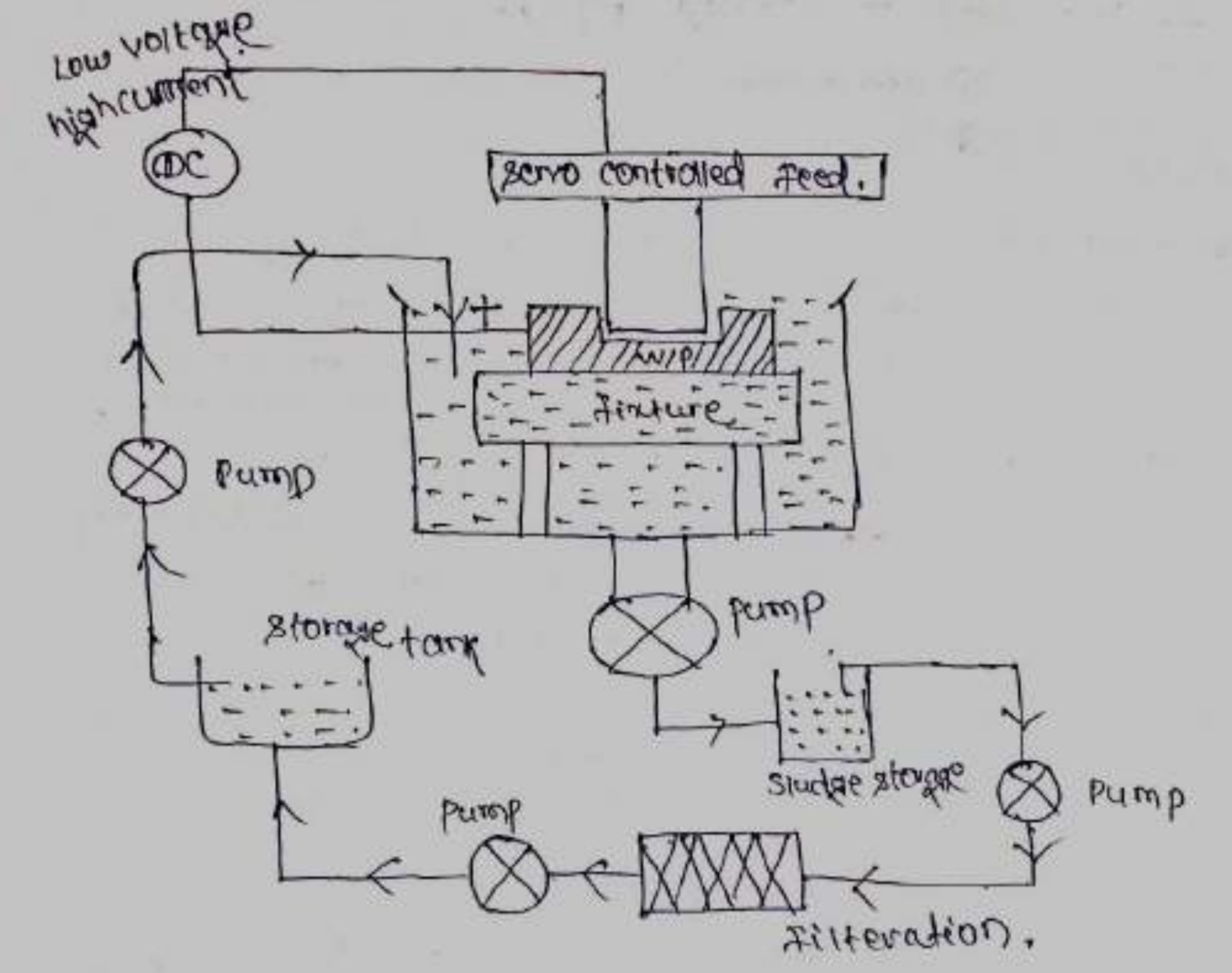
Non convectional :-

→ Those energy source which are renewable & ecological safe that is called nonconvectional machining process.

→ It is a special type of Machining process in which there is no direct contact betn the tool & the workpiece.

→ In non-convectional m/c process It is a form of energy is used to remove unwanted material from a given w/p.

→ Electro chemical Machining Process :-



*> Working Process :-

→ First the workpiece is assembled in the fixture tool & tool is brought close to the workpiece. The tool & w/p is immersed in a suitable electrolyte.

→ After that, potential difference is applied across the workpiece (anode) & tool (cathod). The removal of material is starts. The material is removed as in the same manner as we have discussed above in the working principle.

→ Tool feed system advances to the tool towards

the workpiece & always keeps a required gap in bet^n them. The material from the workpiece is comes out as possible ions & combine with the lines present in the electrolyte & precipitates as as sludge.
, Hydrogen gas is libarated at cathode during the machining process.

→ Since the dissocitation of the material from the workpiece takes place at atomic level, so it gives excellent surface finish.

→ The sludge from the tank is taken out & separated from the electrolyte. The electrolyte after filtration again trasported to the tank of the ECM process.

→ Application :-

→ The ECM process is used for die sinking operation, profiling & contouring, drilling, grinding, trepanning & Micro machining.

→ It is used for machining steam turbine blades within closed limits.

→ Advantages :-

→ Negligible tool wear.

→ Complex & concave curvature parts can be produced easily by the use of convex & concave tools.

→ No forces & residual stress are produced, because there is no direct contact bet^n tool & w/P.

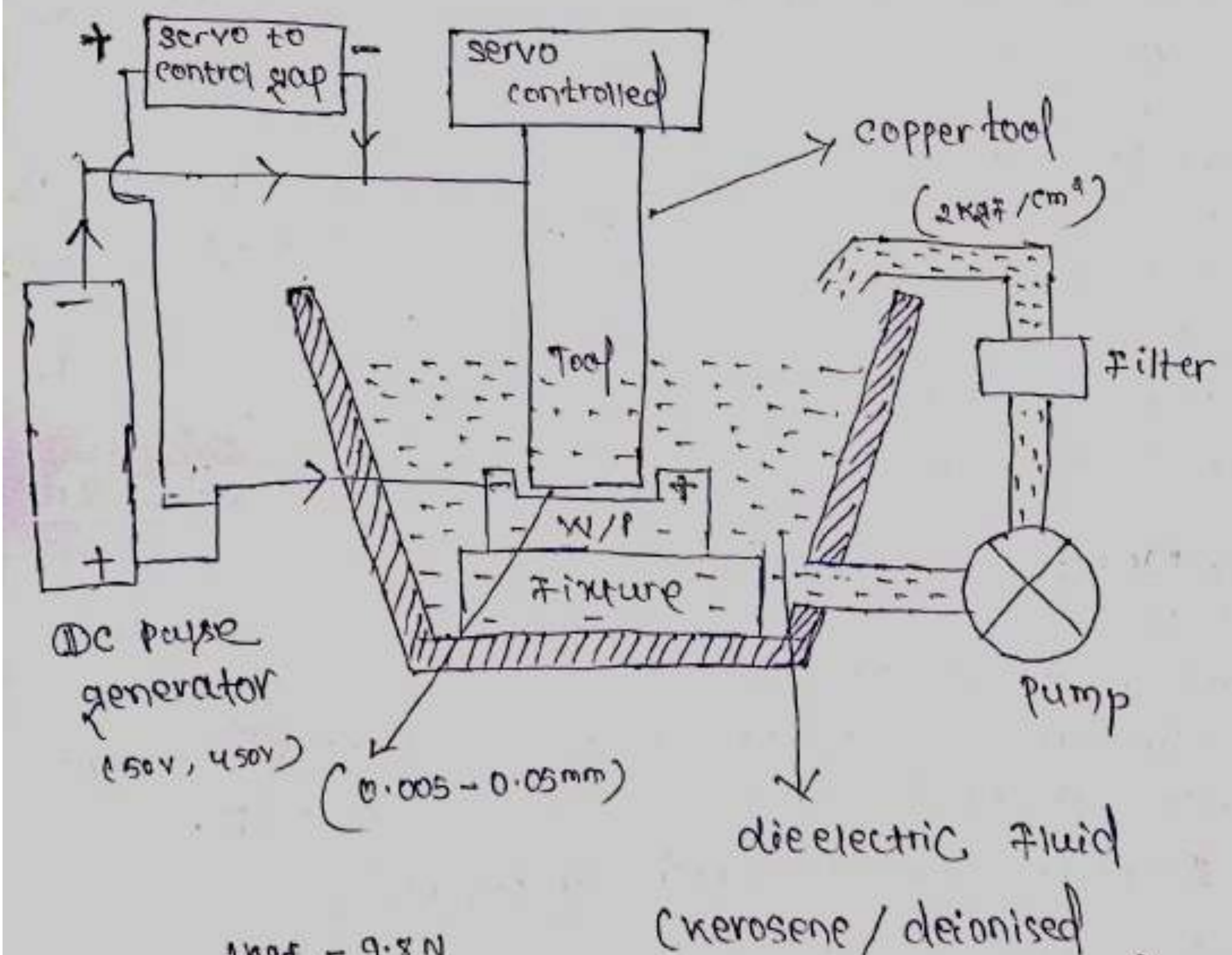
→ Excellent surface finish is produced.

→ Less heat is generated.

Disadvantages :-

→ The risk of corrosion for tool, workpiece & equipment increases in the case of saline & acidic electrolyte.
→ Electrochemical machining is capable of machining electrically conductive materials only.
→ High power consumption.
→ High initial investment cost.

② Electro discharge Machining process :(EDM) :-



1kgf = 9.8 N

→ **Equipment** :- The various equipment used in electro discharge machining are

① Dielectric reservoir, pump & circulating system :-
→ Pump is used to circulate the dielectric medium betn the two electrodes. Kerosene or deionized water is used as dielectric medium.

② Power generator & control unit :-
→ Generator is used to apply potential difference. The voltage used in this machining process is not constant but it is applied in pulse form.

③ Working tank with work holding device :-
→ It has working tank with a work holding device. The workpiece is hold in the work holding devices. The tank contains dielectric medium.

④ Tool holder :- It is used to hold the tool.

⑤ Servosystem :- A servosystem is used to control the tool. It maintains the necessary gap betn the electrodes.

Working of EDM :-

1 → First the tool & w/P is clamped to the m/c. After that with the help of servo mechanism a small gap is maintain in betn the tool & workpiece.

2 → The tool & w/P is immersed in dielectric medium.

3 → A potential difference is applied across the electrode. An electric spark is generated in betn the tool & w/P. The spark generates a heat about 10000 degree celsius & due to this heat the material from the w/P starts to vaporize & melts.

4 → The spark generates in electrical discharge machining

is not contineous. As the voltage breaks, the dielectric fluid flushes away the molten materials leaving behind a crater.

→ This process keep continue & machined the w/p.

***> Advantages :-**

→ Less time required as compared to convectional machining.
→ Metals having high melting point temp. can be easily machined.
→ Excellent surface finish can be obtained.
→ Complex shapes & corners can be machined.
→ Burrface machining surface.

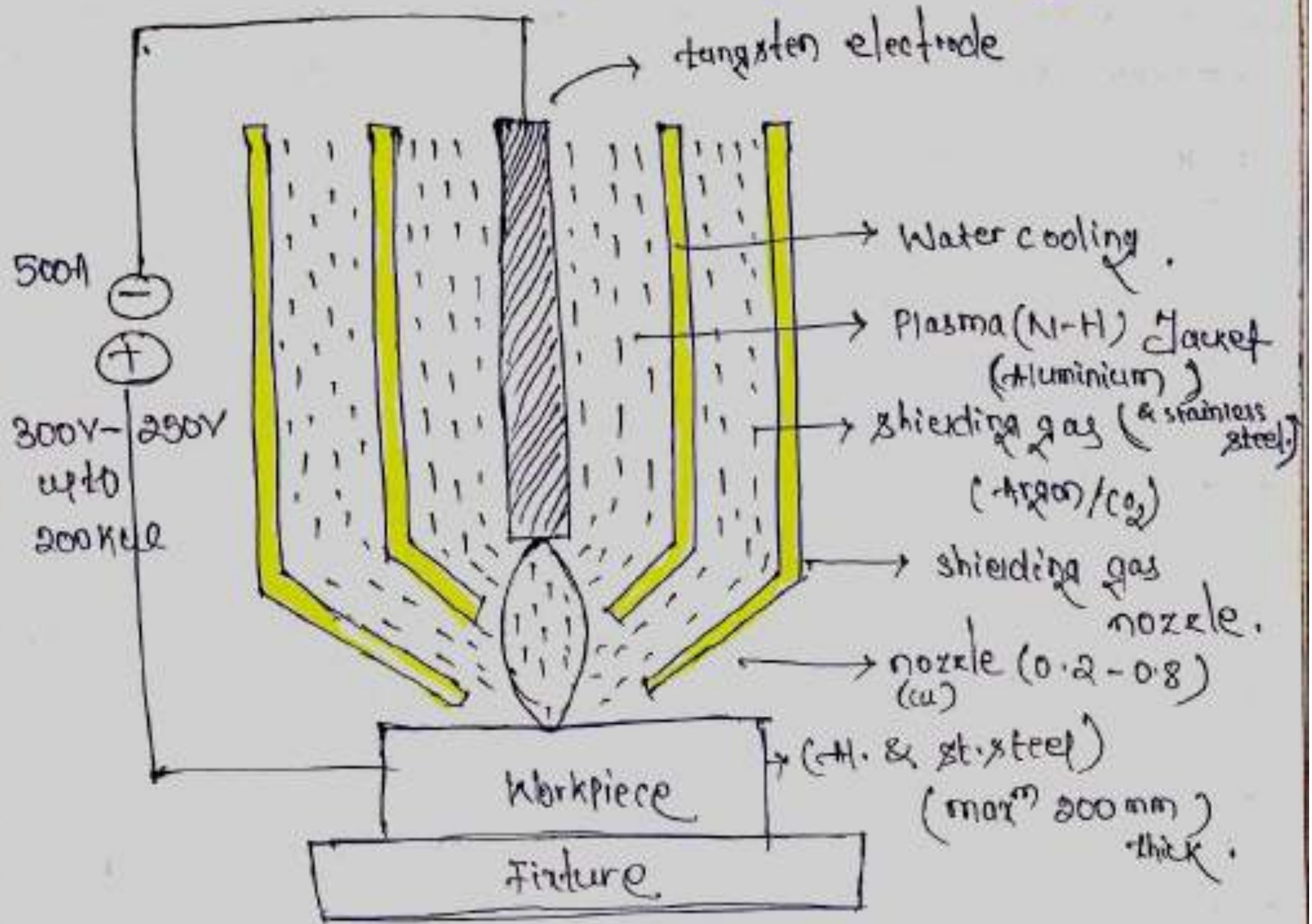
***> Disadvantages :-**

→ Only electrical conductive materials can be machined.
→ High voltage required.
→ High initial cost.
→ High maintanance.
→ More time required for machining.
→ Thin materials can't be machine.

***> Appl^n / uses :-**

→ It is mostly used by mold making & dies industries.
→ It is used for coinage die making.
→ It also used in aerospace Industries.
→ It use to creat small holes in variety of application.

* PLASMA ARC Machining Process :- (PAM)



→ **Equipments required :-**

1. DC electric Supply.
2. Tungsten electrodes.
3. Nozzle.
4. plasma & Shielding gas.
5. W/P & Fixture.

→ **What is plasma :-**

→ When a gas or air heated at high temps, the number of collisions betn atoms increases.

→ When you heat the gas above 5500°C, it partially ionizes into +ve ions, negetive ions & neutral ions,

→ When you further heat the gas above 11000°C then, it completely ionises.
→ Such a completely ionised gas is called plasma.
→ Plasma states lies in bet^n temp 11000°C to 28000°C.

Working of PAM:-

→ It consist of a plasma gun.
→ Plasma gun has an electrode made up of tungsten situated in the chamber.
→ Here this tungsten electrode is connected to the -ve terminal of DC power supply thus the tungsten acts as cathod.
→ While the +ve terminal of DC power supply is connected to the nozzle thus the nozzle of the plasma gun acts as anode.
→ As we give the power supply to the system, an electric arc develops bet^n the cathodic tungsten electrode & an anodic nozzle.
→ As the gas comes in contact with the plasma, there is a collision bet^n the atoms of gas & electrons of an electric arc & as a result, we get an ionized gas, that means we get the plasma state that we wanted for PAM.
→ Now this plasma is targeted towards the workpiece with a high velocity & the machining process starts.
→ In the whole process, high temp cond^{n}s are required, as a hot gasses come out of nozzle there are chances of over heating.
→ In order to prevent this over heating, a water Jacket is used.

Advantages:-

→ In PAM hard as well as brittle metals can be easily machined.

→ We get a better dimensional accuracy.
→ It is a simple process to carry out & a very efficient process.
→ It takes a big part in automobile repair of Jet engine blades.

Disadvantages :-

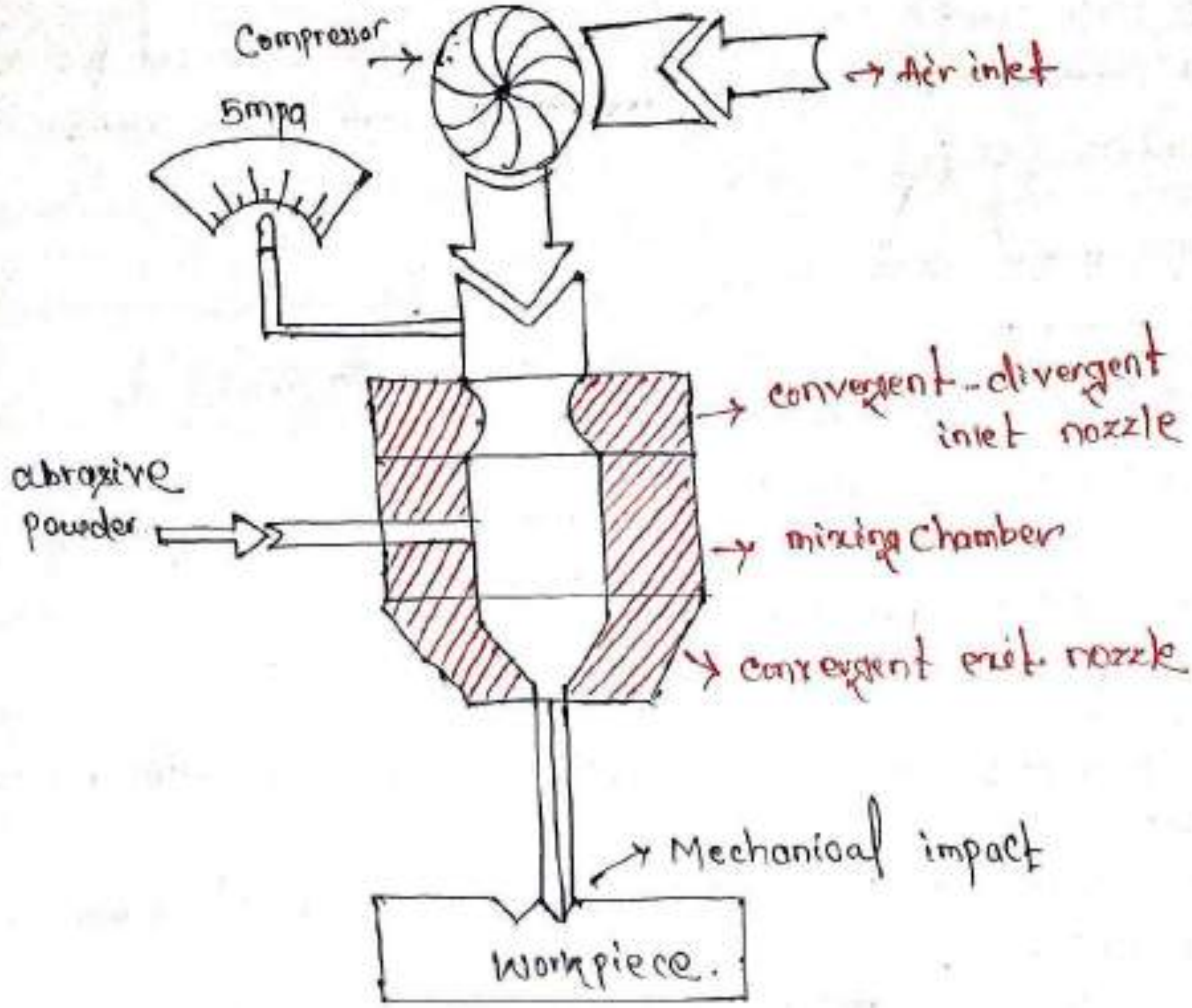
→ Its initial cost is very high.
→ It is uneconomical for bigger cavities to be machined.
→ Inert gas consumption is high.
→ This process can affect human eyes so a proper goggles or helmet must be worn by an operator.
→ Take proper precaution for whole process.

Application :-

→ It is mostly used for cryogenic, high temp corrosion resistance alloys.
→ It is also used in case of titanium plate upto 8 mm thickness.
→ It is used in nuclear submarine pipe system & for welding steel rocket motor case.

*) Abrasive Jet Machining Process :- (AJM)

→ Equipments are used in AJM are as follows.
① Gas propulsion system
② Abrasive feeder.
③ Abrasive
④ Cutting nozzle.
⑤ Machining chamber
⑥ Compressor
⑦ Air inlet.



Working principle :-

→ The basic concept of AJM is abrasive erosion or metal cutting by high velocity abrasive particle. Its working process can be easily summarized into following point.

① 1st gas or air compressed into gas compressor. There the density & pressure of gas increases.

② Now this compressed gas send to filtration unit, where dust & othere suspended particle removed from it.

③ This clean gas sends to drier, which absorb moisture from it. It is used to avoid water or oil contamination of abrasive power.

④ Now this clean & dry gas sends to mixing chamber where abrasive particle is about 50 micro meter grit size.

(5) The high pressuring abrasive carried gas send to nozzle where its pressure energy Converted into kinetic energy. The velocity of abrasive particle leaving the nozzle is about 200m/s.

(6) The standoff distance betn workpiece & nozzle is about 2mm.

(7) Now these high velocity abrasive particles impinge on the w/p. These high velocity abrasive particles remove the material by micro cutting action as well as brittle fracture of the work material.

Advantages :-

→ High surface finish.
→ It can machine heat sensitive material.
→ It is free from vibration.
→ Initialization cost is low.
→ Thin section can be machined easily.

Disadvantages :-

→ Low metal remove rate.
→ Abrasive particle can embedded into w/p mostly in soft metals.
→ Nozzle life is limited so it needs frequently replacement.
→ Abrasive particle can't be reuse in this process.
→ It can't use for m/c soft & ductile material.

Application / uses :-

→ It is used in drilling & cutting of hardened metals.
→ It is used for machining brittle & heat sensitive material like glasses, quartz, sapphire, mica, ceramic etc.
→ It is used for manufacturing electronics devices.

*) Leaser Beam Machining process :-

*) Main parts :- The various main parts used in the LBM are

1) A pump medium :- A pump medium is needed that contains a large number of atoms. The atoms of the media are used to produce leasers.

2) Flash lamp :- It is used to provide the necessary energy to the atoms to excite their electrons.

3) Power supply :- A high voltage power source is used to produce light in the flash tube.

4) capacitor :- It is used to operate the leaser beam machine at pulse mode.

5) Reflecting Miror :- There are two types of miror is used first one is 100% reflecting & others is partially reflecting.

→ 100% reflecting miror is kept at one end & partially reflecting Miror is at another end.

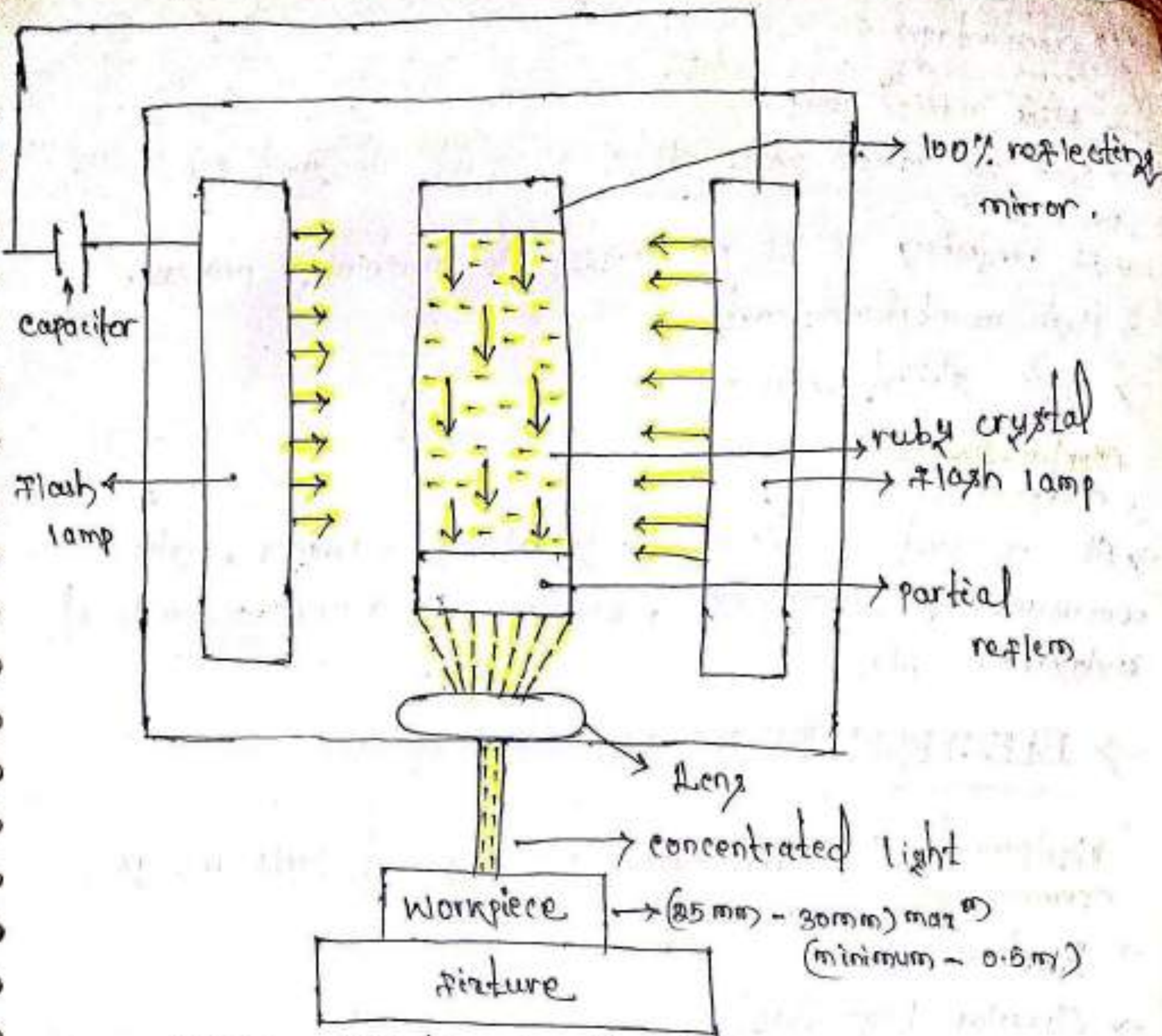
→ The leaser beam comes out wher partially reflecting miror is kept.

→ Working of Leaser Beam Machining :-

→ A very high energy leaser beam is produced by the laser m/c. This leaser beam produced is focused on the workpiece to be machined.

When the leaser beam strikes the surface of the workpiece, the thermal energy of the leaser beam is transferred to the surface of the workpiece. This heats, melts, vaporizes & finally removes the material from the workpiece.

→ In this way leaser be machining works.



Laser (Light amplification by stimulated emission of radiation)

Advantages:- It can be focused to a very small diameter.

→ low maintenance cost.

→ It produces a very high amount of energy, about 100 mkJ per square mm of area.

→ It is capable of producing very accurately placed holes.

→ There is no physical contact betn the tool & w/p.

→ Very high precision work.

Disadvantages :-

→ High initial cost.
→ Low production rate since it is not designed for mass production.
→ It requires a lot of energy for machining process.
→ High maintenance cost.
→ High skilled trainer.

Application :-

→ It is used in heavy manufacturing industries, light manufacturing industries, electronic industries, medical industries etc.

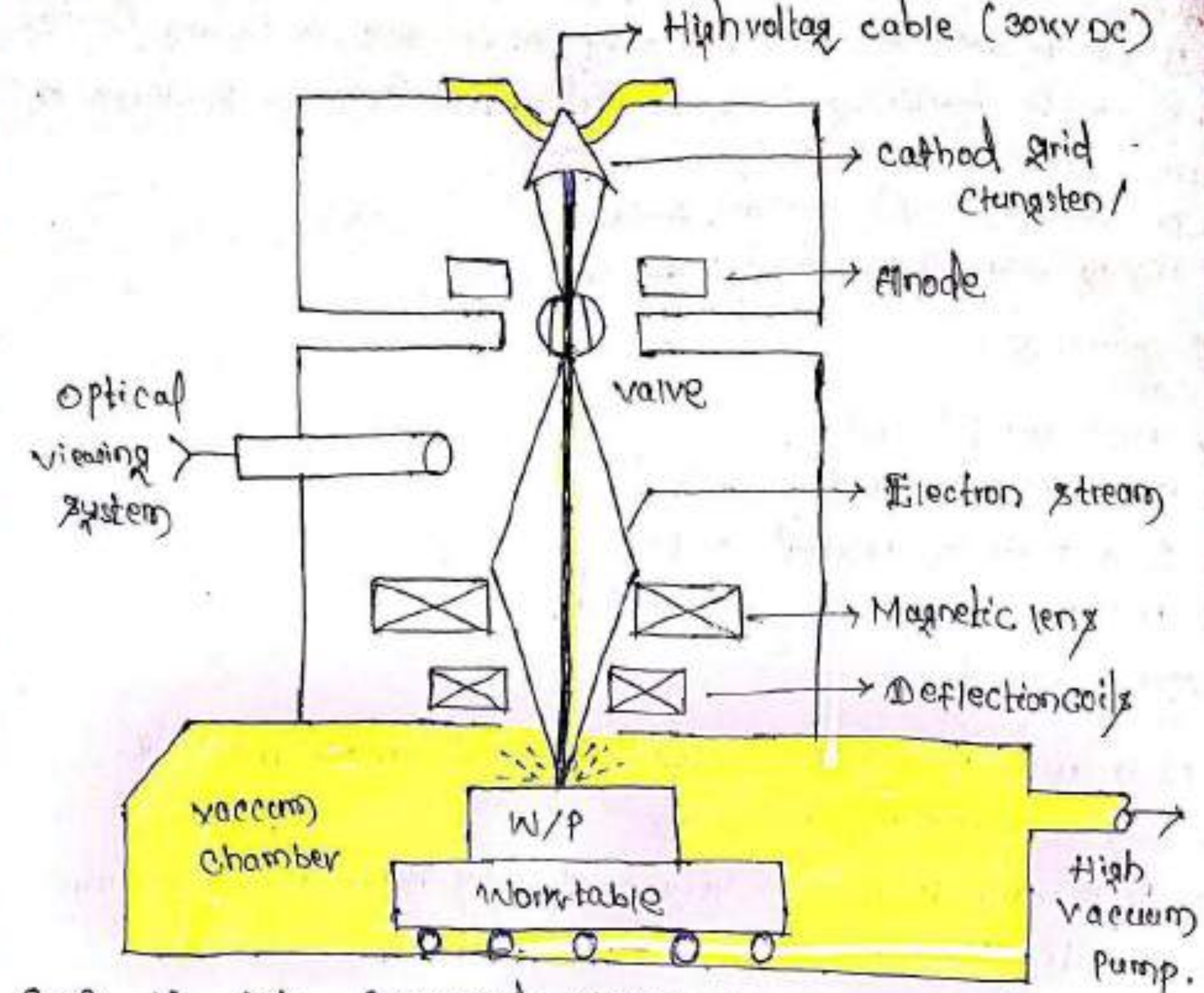
→ ELECTRON BEAM Machining process :-

Equipments :- There are some important parts are as follows

→ Electron Gun.
→ Annular Bias Grid.
→ Magnetic Lenses.
→ Electromagnetic lens & deflection coil.
→ W/P & work holding device.

→ WORKING :- The EBM works same as laser beam machining. Its working can be summarize into following points.

① 1st electron gun produces high velocity electron particles. These electron particles move towards anode which is placed after cathod table.



Core of only convergent electron passes through it. It absorb all divergent electron & low energy electron. It provide a high quality electron beam.

③ The electron beam now passes through electromagnetic lens & deflecting coil. It focus the electron beam at a spot.

④ The high intense electron beam impinges on the w/p where kinetic energy of electrons convert into thermal energy.

⑤ The material is removed from contact surface by melting & vaporization due to this high heat generated by conversion kinetic energy of electrons convert into thermal energy. This whole process take place in a vaccum chamber otherwise there electron collide with air particle betn path & loses its kinetic energy.

Advantages :-

→ It can be used for produce very small size hole in any shape.
→ It can be machining any material irrespective its hardness & other mechanical properties.
→ It provide good surface finish.
→ Highly reacting material can be easily.

Disadvantages :-

→ High capital cost.
→ High skilled operator required.
→ Low material removal rate.
→ Regular maintenance is required.

Application :-

→ It is used to produce holes in diesel injection nozzle.
→ used in aerospace industries
→ It is used to provide very small size holes about 100 mm to 8 milimeter.

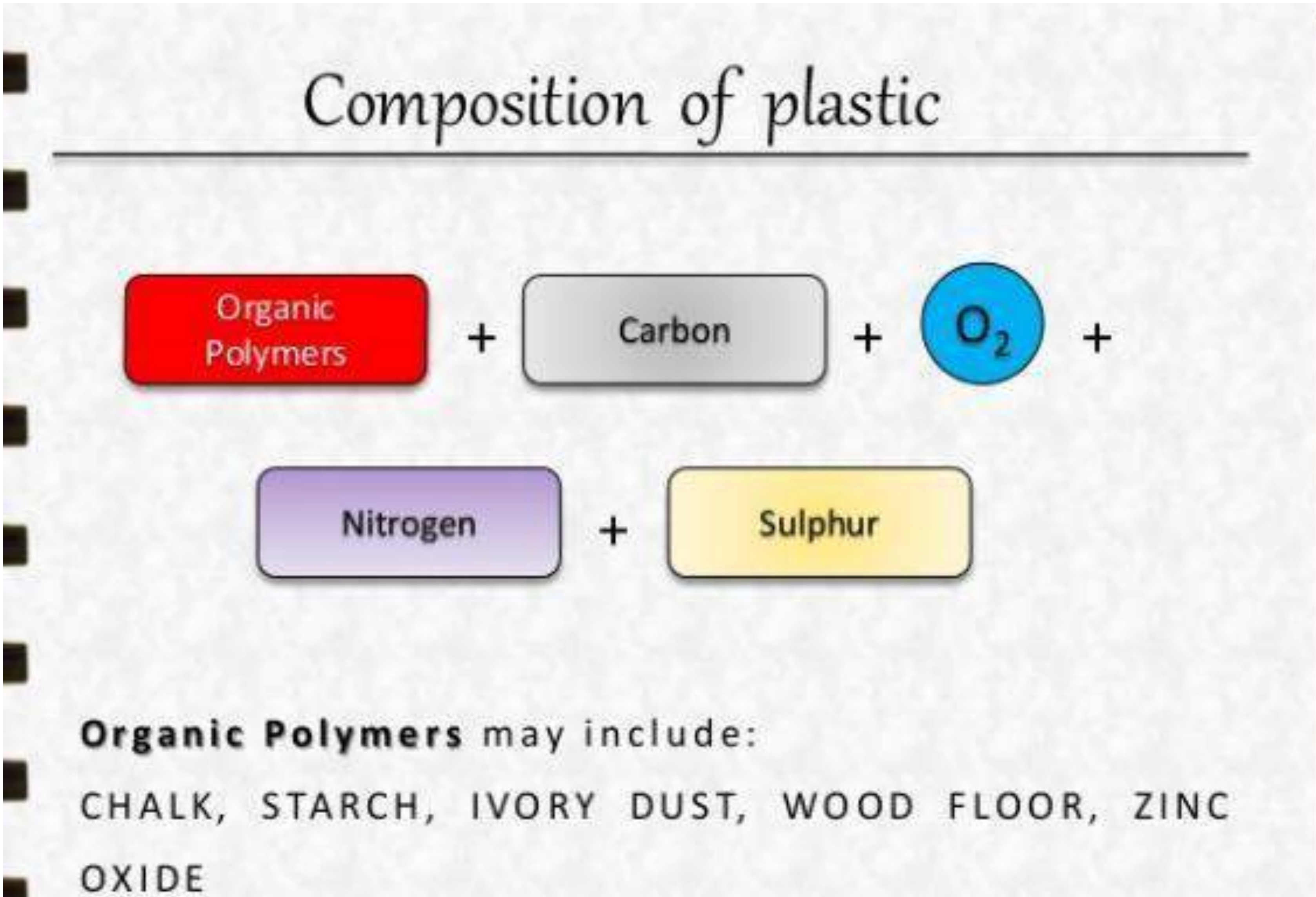
MODULE 2

Plastic Processing


plastic

plastic

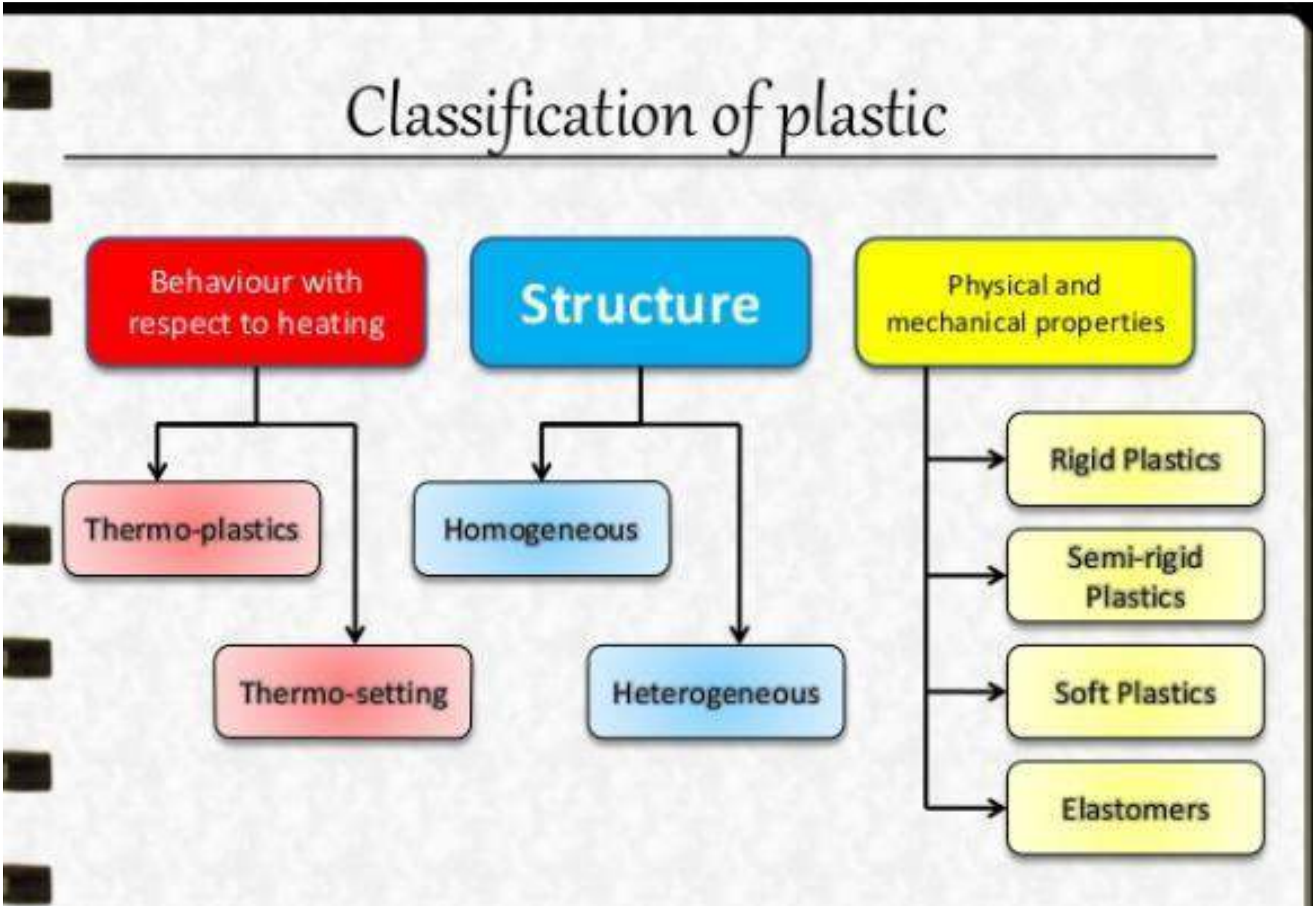
Plastic is a synthetic material made from a wide range of organic polymers such as polyethylene, PVC, nylon, etc., that can be moulded into shape while soft, and then set into a rigid or slightly elastic form.


Composition of plastic
Organic Polymers
+
Carbon
+
O_2
+
Nitrogen
+
Sulphur
Organic Polymers may include:
CHALK, STARCH, IVORY DUST, WOOD FLOOR, ZINC OXIDE

Classification of plastic

There are many ways of classifying plastics. They can be classified considering various aspects, as according to their:

1. Behaviour with respect to heating,
2. Structure, and
3. Physical and mechanical properties.


Classification of plastic
Behaviour with respect to heating
Structure
Physical and mechanical properties
Thermo-plastics
Thermo-setting
Homogeneous
Heterogeneous
Rigid Plastics
Semi-rigid Plastics
Soft Plastics
Elastomers

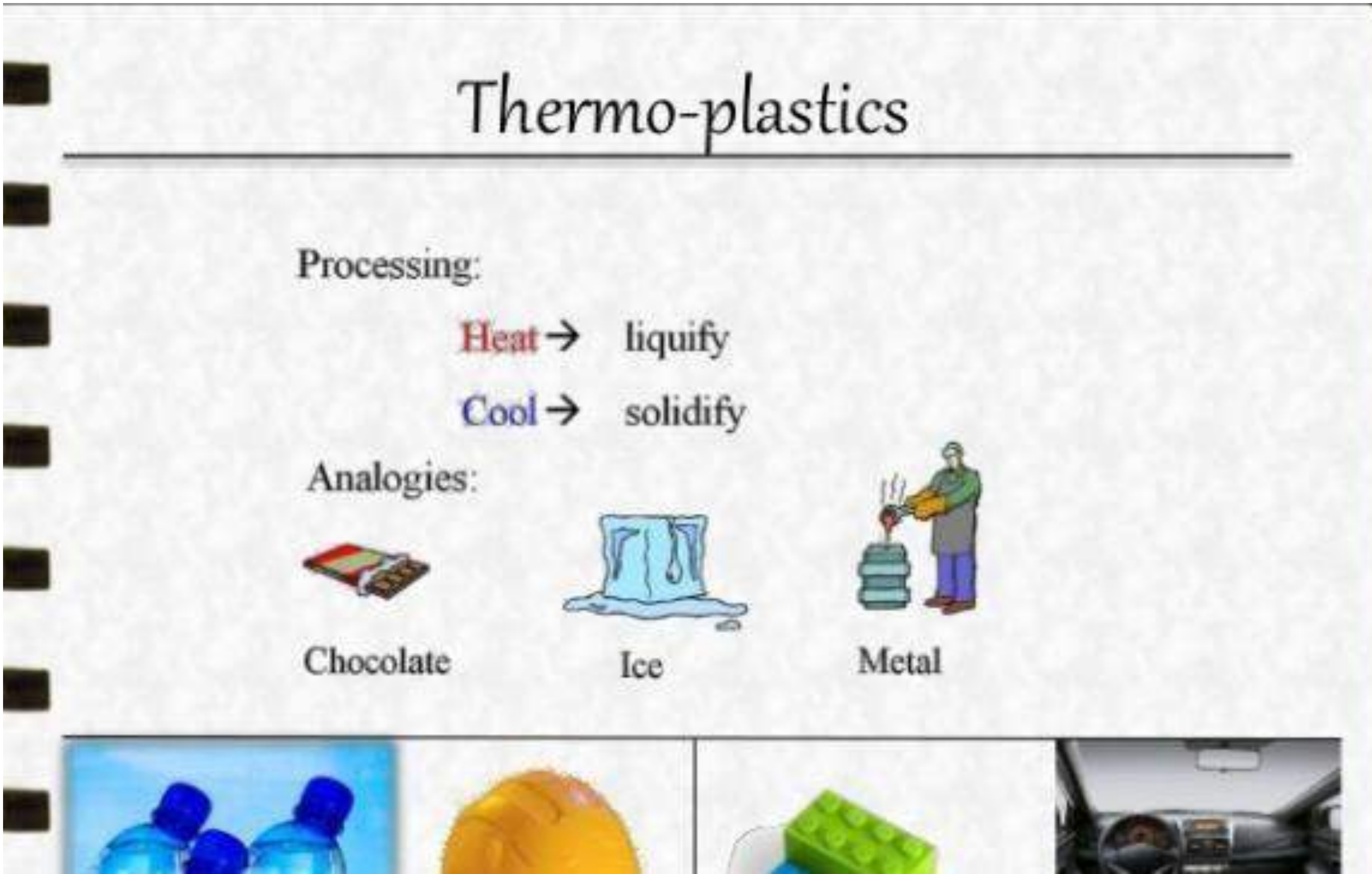
Themoplastic & thermosetting

Basic difference between Thermoplastics and Thermosetting plastics

THERMOPLASTICS	THERMO-SETTING PLASTICS
Thermoplastics variety softens by heat and hardens when cooled down. It can be used by remolding as many times as required.	Thermosetting plastics can not be reused .This variety requires a great pressure and momentary heat during molding which hardens on cooling.

Thermo-plastics

- The thermo-plastic or heat non-convertible group is the general term applied to the plastics which becomes soft when heated and hard when cooled.
- Thermoplastic materials can be cooled and heated several times.
- They can be recycled.
- When thermoplastics are heated, they melt to a liquid. They also freeze to a glassy state when cooled enough.
- Thermoplastic can be moulded into any shape.

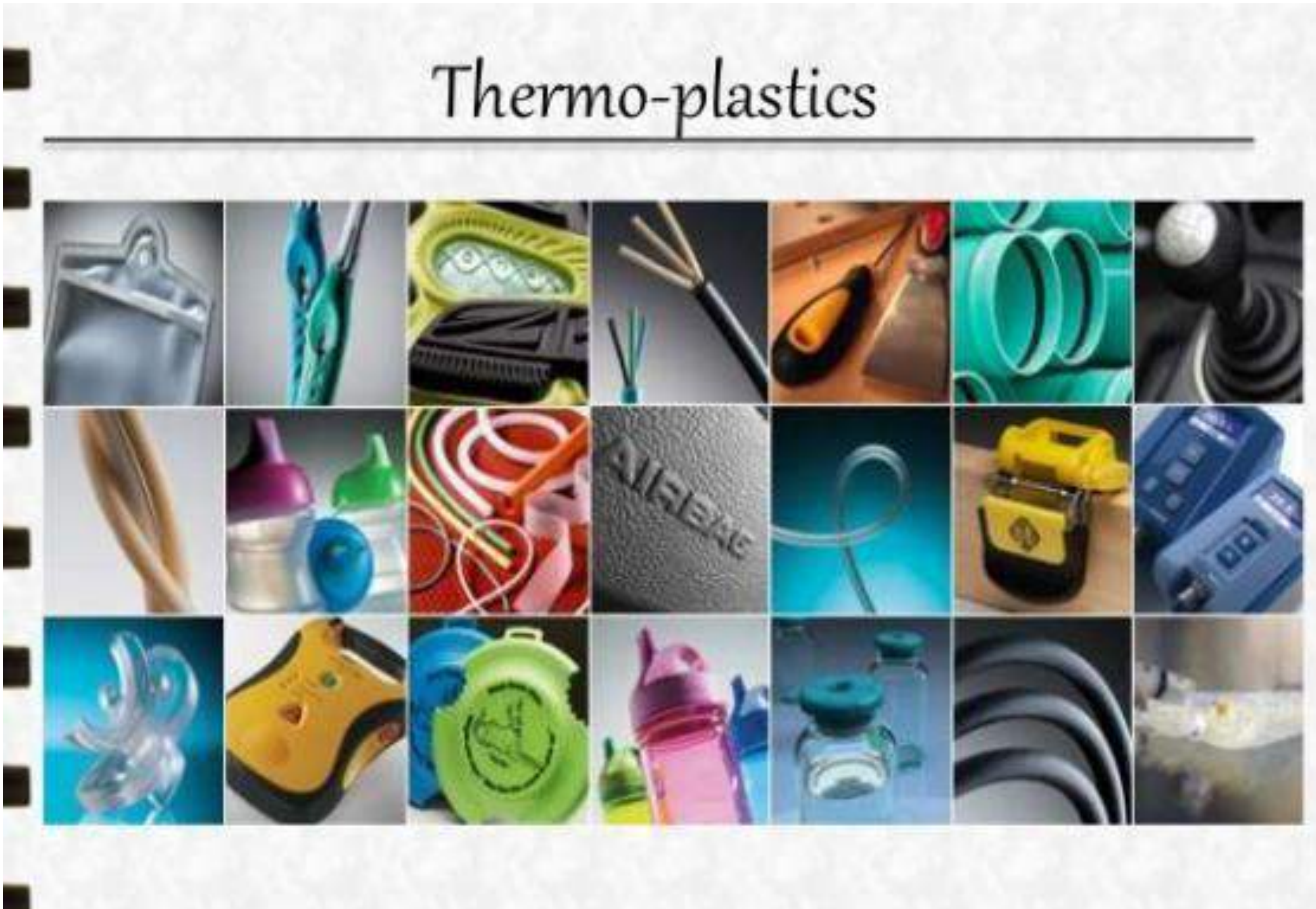

Thermo-plastics
Processing:
Heat → liquify
Cool → solidify
Analogies:
Chocolate
Ice
Metal


Thermo-plastics
PROPERTIES
➢ It may melt before passing to a gaseous state.
➢ Allow plastic deformation when it is heated.
➢ They are brittle and glossy.
➢ They are soluble in certain solvents.
➢ Swell in the presence of certain solvents.
➢ Good resistance to creep.

Thermo-plastics

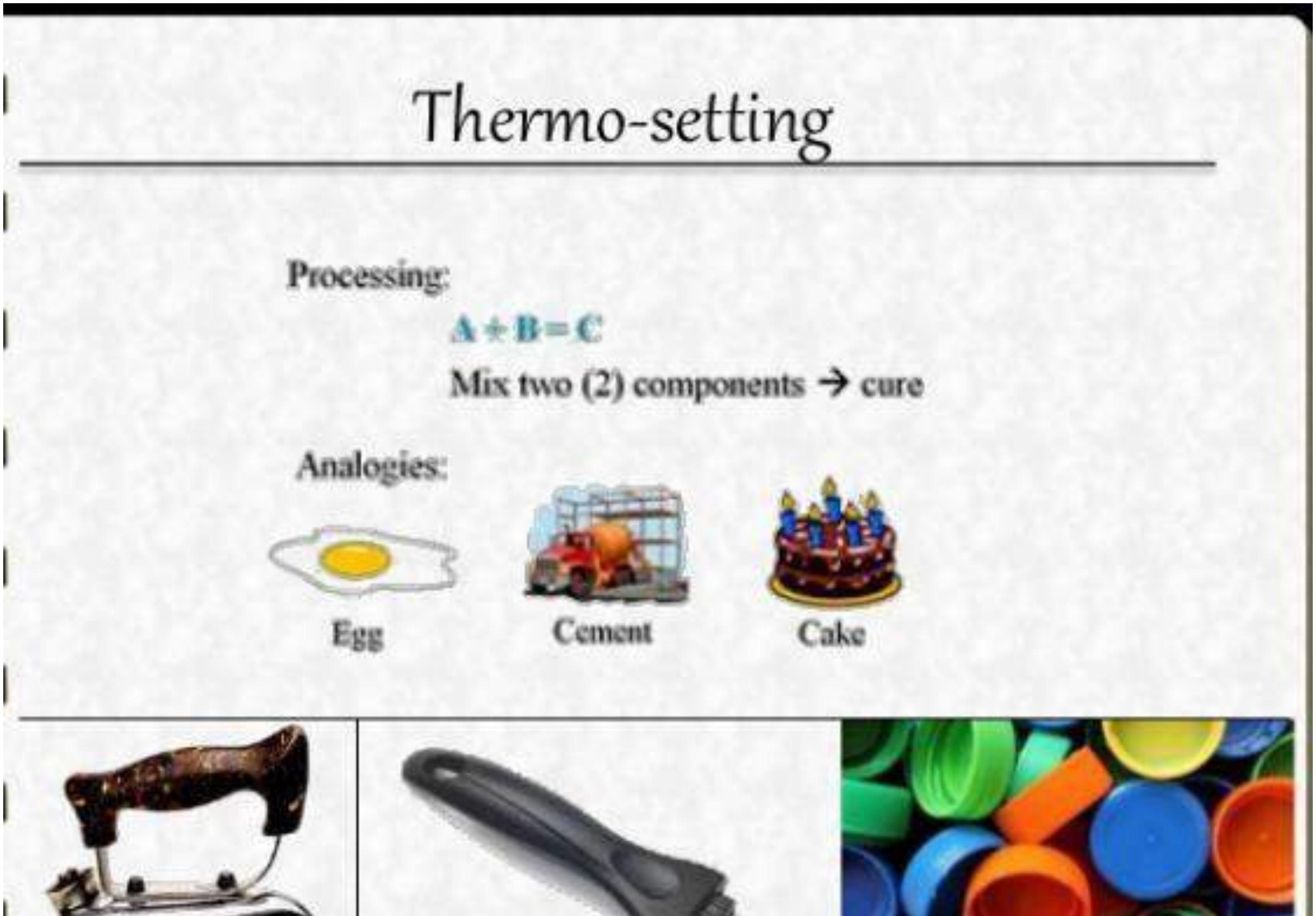
Examples and applications of thermoplastic plastic materials

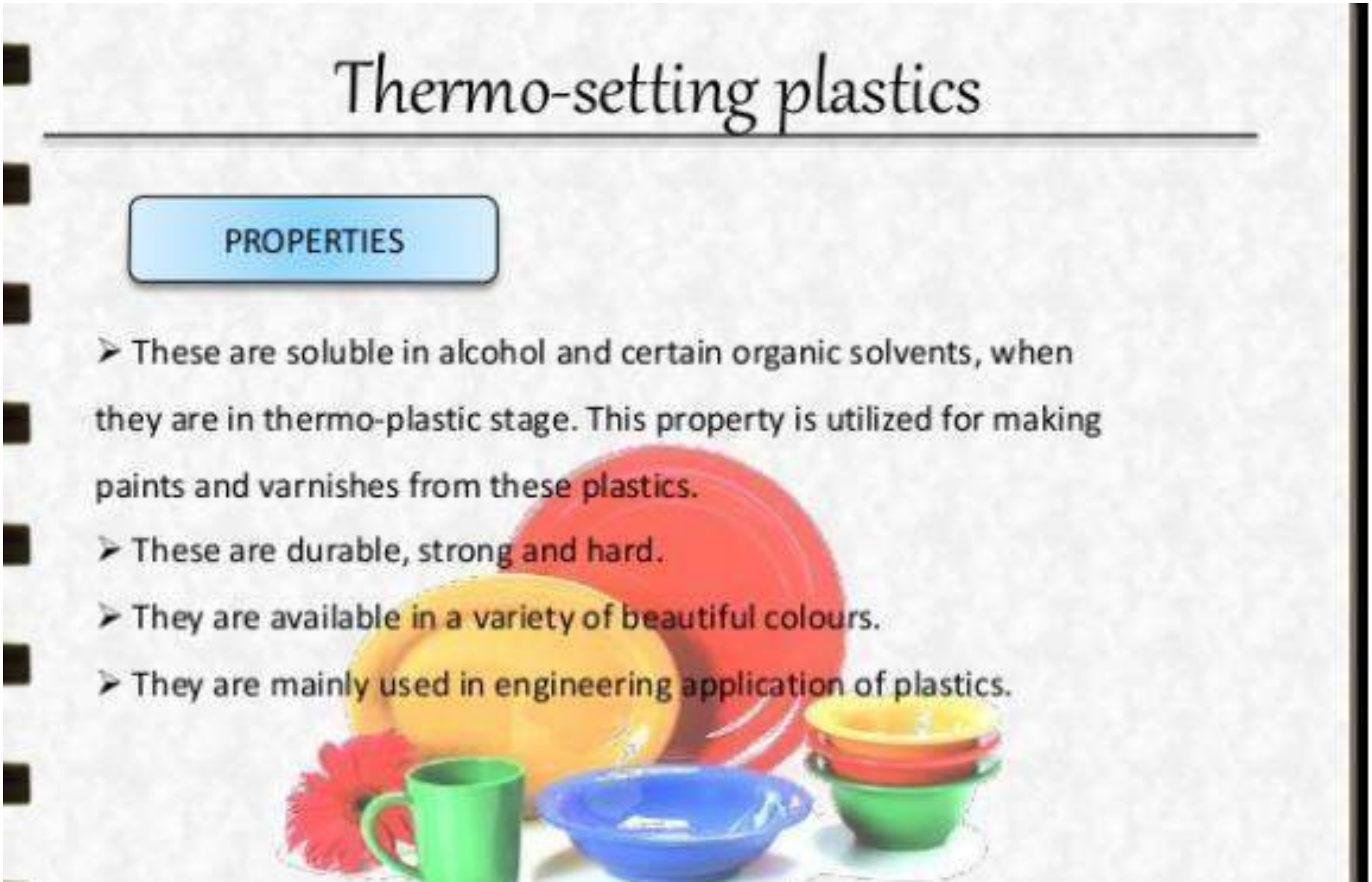
- Thermoplastic materials have many features. Some products made from thermoplastic materials are used for **electronic applications**. They protect against electrostatic discharge and radio frequency interference.
- High pressure polyethylene as applied to rigid material covered with **electrical machines, tubes**, etc...
- Low pressure polyethylene elastic material used for **insulation of electrical cables,** etc...
- Polystyrene applied for **electrical insulation, handles of tools**...
- Polyamide used for **making ropes, belts**, etc...
- PVC or polyvinyl chloride for the manufacture of **insulation materials, pipes, containers**, etc...


Thermo-plastics

Thermo-setting plastics

- The thermo-setting or heat convertible group is the general term applied to the plastics which become rigid when moulded at suitable pressure and temperature.
- This type of plastic passes originally through thermo-plastic stage. When they are heated in temperature range of 127°C to 177°C, they set permanently and further application of heat does not alter their form or soften them.
- But at the temperature of about 343°C, the charring occurs. This charring is a peculiar characteristic of the organic substances.


Thermo-setting
Processing:
A + B = C
Mix two (2) components → cure
Analogies:
Egg
Cement
Cake


Thermo-setting plastics
PROPERTIES
➢ These are soluble in alcohol and certain organic solvents, when they are in thermo-plastic stage. This property is utilized for making paints and varnishes from these plastics.
➢ These are durable, strong and hard.
➢ They are available in a variety of beautiful colours.
➢ They are mainly used in engineering application of plastics.

Thermo-setting plastics

APPLICATIONS

Epoxies

Properties: good dimensional stability, excellent mechanical and electrical properties, good resistance to heat and chemicals

Applications: electrical components requiring strength, tools and dies, fiber reinforced epoxies are used in structural components, tanks, pressure vessels, rocket motor casing

Phenolics

Properties: good dimensional stability, rigid, high resistance to heat, water, electricity, and chemicals

Applications: laminated panels, handles, knobs, electrical components; connectors, insulators

Thermo-setting plastics

APPLICATIONS

Polyesters (thermosetting, reinforced with glass fibers)

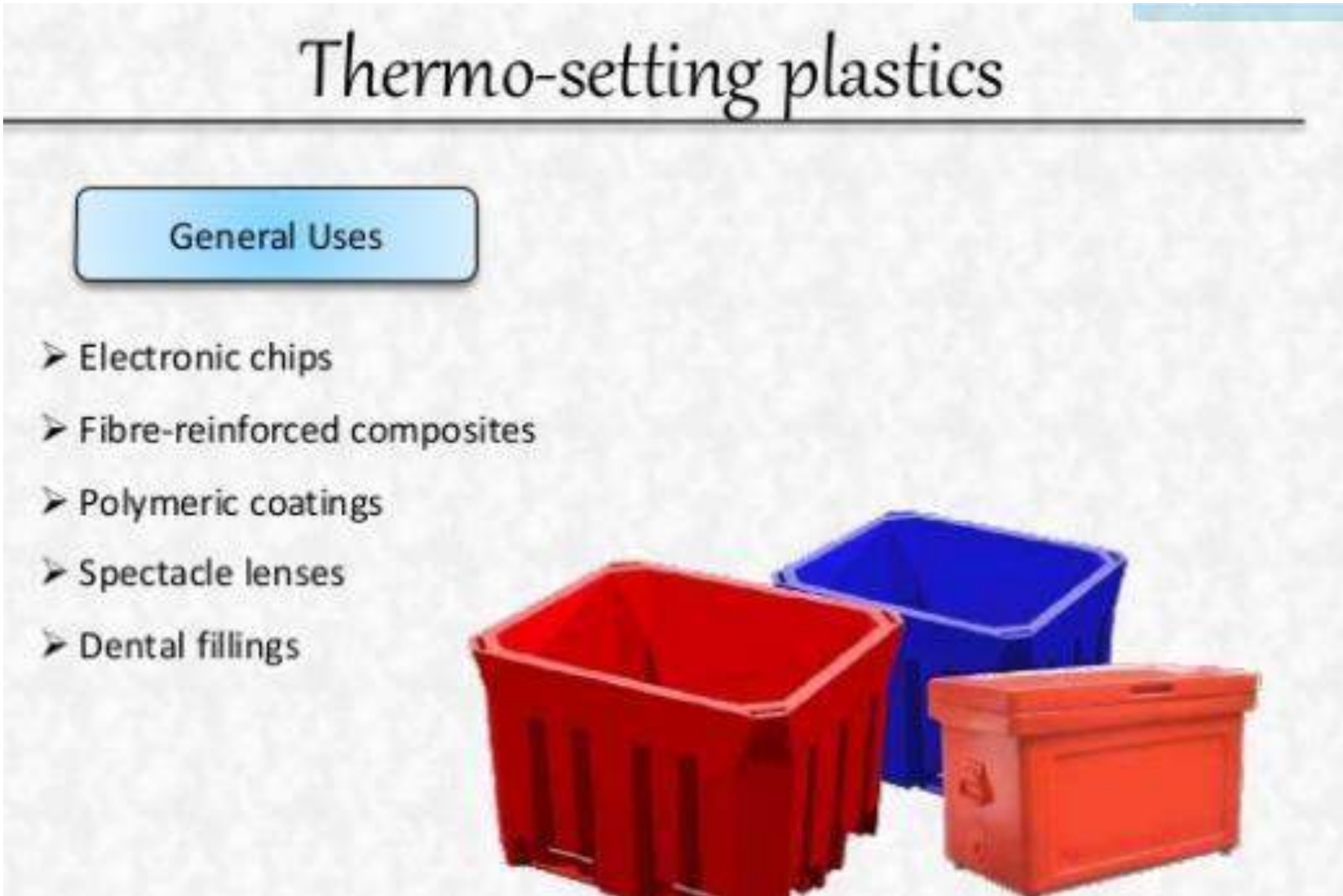
Properties: good mechanical, electrical, and chemical properties, good resistance to heat and chemicals

Applications: boats, luggage, swimming pools, automotive bodies, chairs

Silicones

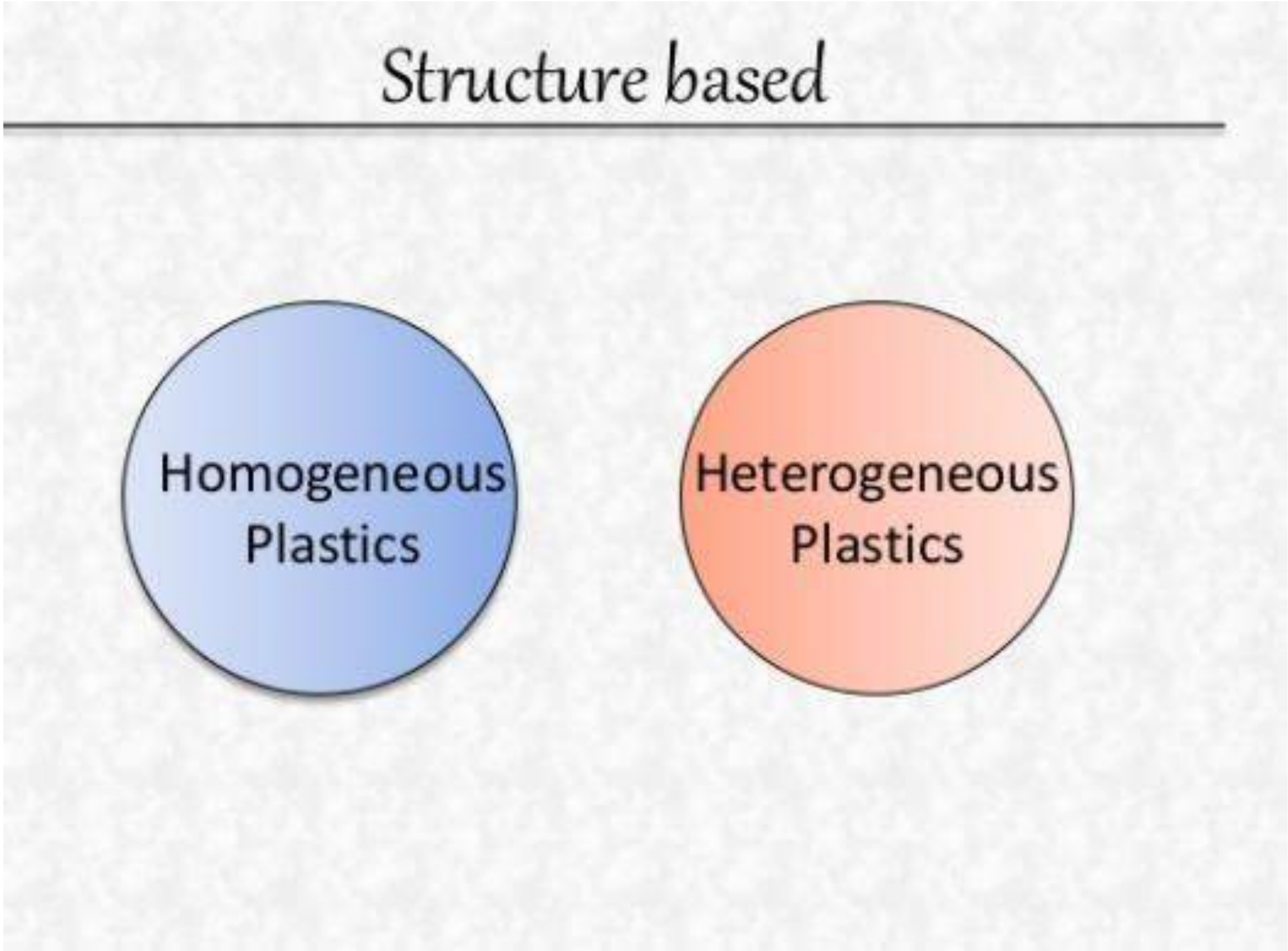
Properties: excellent electrical properties over a wide rang of temperature and humidity, good heat and chemical properties

Applications: electrical components requiring strength at high temp., waterproof materials, heat seals


Thermo-setting plastics
General Uses
➢ Electronic chips
➢ Fibre-reinforced composites
➢ Polymeric coatings
➢ Spectacle lenses
➢ Dental fillings

Natural vs. synthetic polymers

NATURAL POLYMERS	SYNTHETIC POLYMER
Thermoplastic polymer (Chemical composition do not change on heating)	Thermosetting polymer (Irreversible chemical process)
Remouldable Polymers	Non-remouldable Polymers
These are brittle, glossy, elasticity, flexible	They possess matt effect, elasticity, and are flexible
Eg: Polyethylene, Polypropylene, Polystyrene, PVC	Eg: Rubber, Nylon, Glass Fibre, Cork

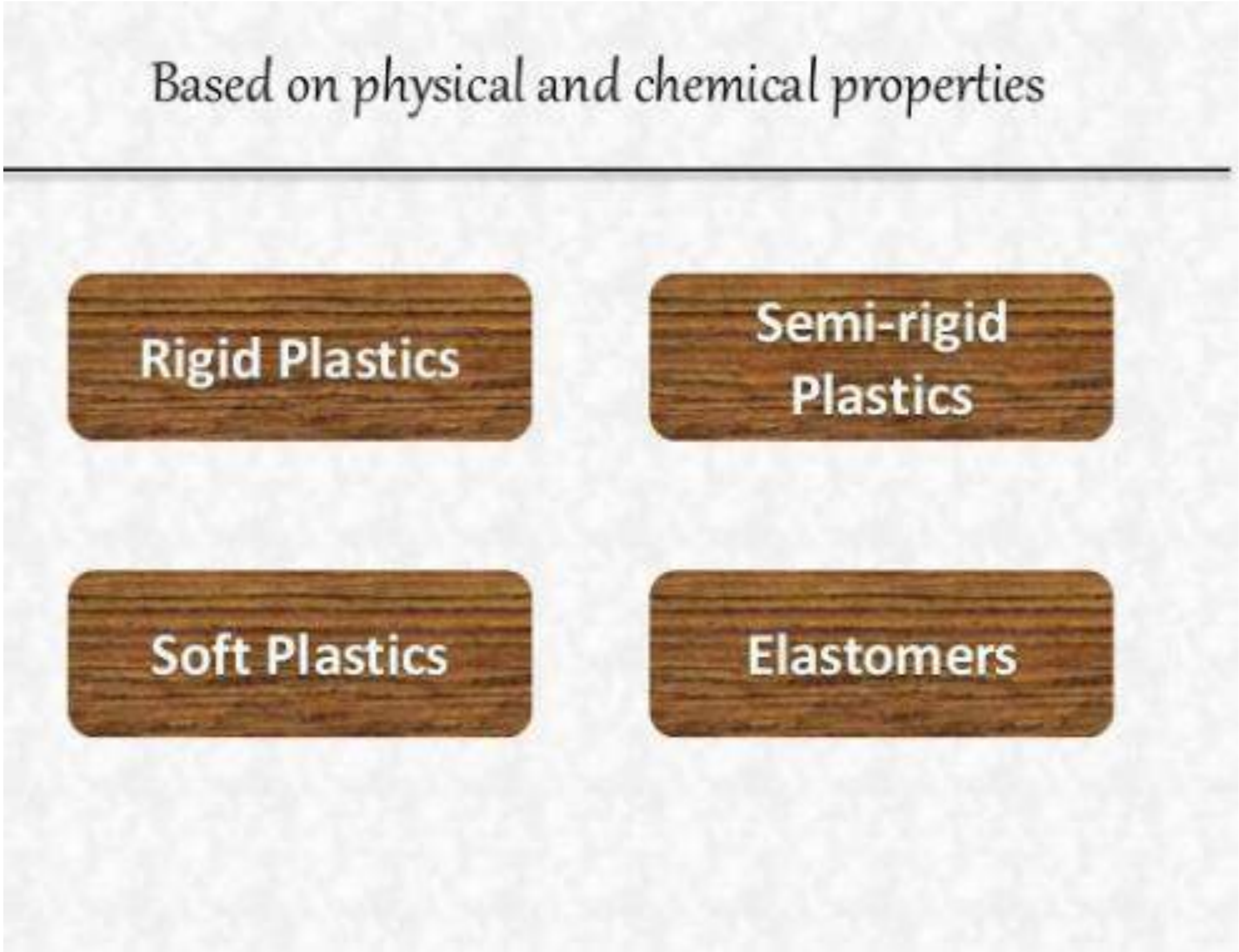

Structure based
Homogeneous Plastics
Heterogeneous Plastics

Homogeneous plastics

This variety of plastic contains carbon chain i.e. the plastics of this group are composed only of carbon atoms and they exhibit homogeneous structure.

Heterogeneous plastics

This variety of plastic is composed of the chain containing carbon and oxygen, the nitrogen and other elements and they exhibit heterogeneous structure.


Based on physical and chemical properties
Rigid Plastics
Semi-rigid Plastics
Soft Plastics
Elastomers

Rigid plastics

These plastics have a high modulus of elasticity and they retain their shape under exterior stresses applied at normal or moderately increased temperatures.

Semi-Rigid plastics

These plastics have a medium modulus of elasticity and the elongation under pressure completely disappears, when pressure is removed.

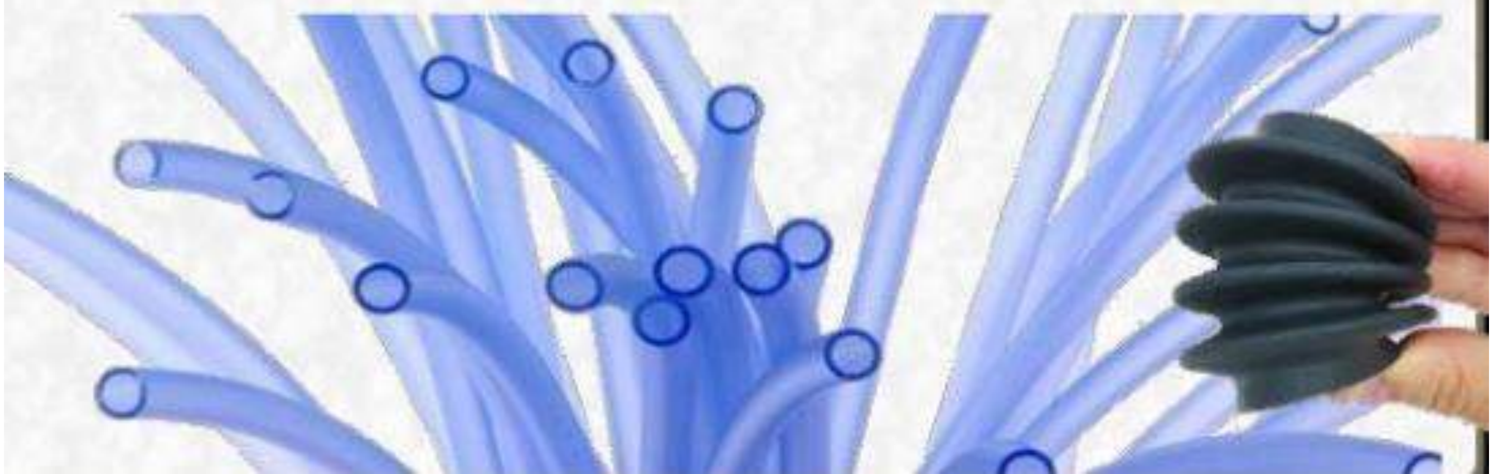
soft plastics

- These plastics have a low modulus of elasticity and the elongation under pressure disappears slowly, when pressure is removed.
- Soft plastics are available in a large range of colours, sizes and particularly shapes.

USES: Used in making children's toys eg: rattles etc., fishing baits.

Elastomers

These plastics are soft and elastic materials with a low modulus of elasticity. They deform considerably under load at room temperature and return to their original shape, when the load is released. The extensions can range upto ten times their original dimensions.



Clip slide

Bio-degradable Plastics

- Biodegradable plastic decomposes in the natural environment. It is produced from biopolymers called polyhydroxyalkanoate (PHA). This material is completely biodegradable.
- Biodegradation of plastics can be achieved by enabling microorganisms in the environment to metabolize the molecular structure of plastic films to produce an inert humus like material that is harmful to environment.
- The use of bio-active compounds compounded with swelling agents ensures that, when combined with heat and moisture, they expand the plastic's molecular structure and allow the bio-active compounds to


Bio-degradable Plastics
1. Buy
Goody products
Need for strong waste management
2. Place
In Organics Bin/ Green Waste
UV light
Oxygen
Aerobic Composting
Bio-degrades
3. Composts
In industrial composting
Saves water
Conditions soil

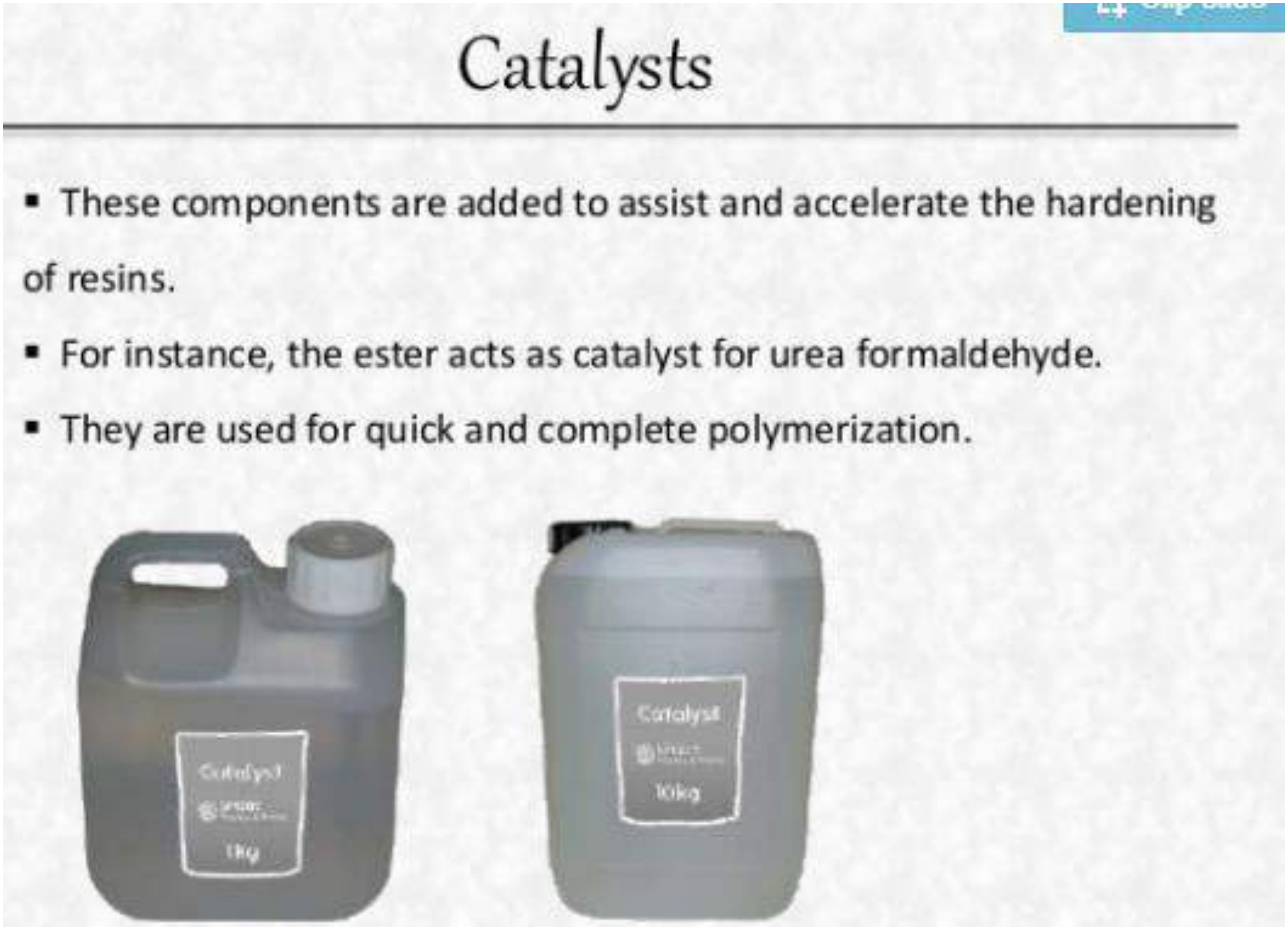
Advantages & disadvantages

- Under proper conditions biodegradable plastics can degrade to the point where microorganisms can metabolize them.
- This reduces the problems with litter and reduces harmful effects on wildlife.
- However degradation of biodegradable plastic occurs very slowly.
- Proper composting methods are required to degrade the plastic, which may actually contribute to carbon dioxide emissions.

Moulding compounds

Some of the moulding components are:

- Catalyst
- Fillers
- Hardeners
- Lubricants
- Pigments
- Plasticizers
- Solvents


Catalysts
▪ These components are added to assist and accelerate the hardening of resins.
▪ For instance, the ester acts as catalyst for urea formaldehyde.
▪ They are used for quick and complete polymerization.
Catalyst
1kg
Catalyst
10kg

fillers

- The fillers are inert materials and they impart strength, hardness and other properties to the plastic.

- The choice of filler should be carefully made.
- It should be confirmed that the addition of a filler does not have detrimental effect on other properties of plastic.
- The filler may be used in the following forms-
  - Fibrous fillers
  - Laminated fillers
  - Power fillers

hardeners

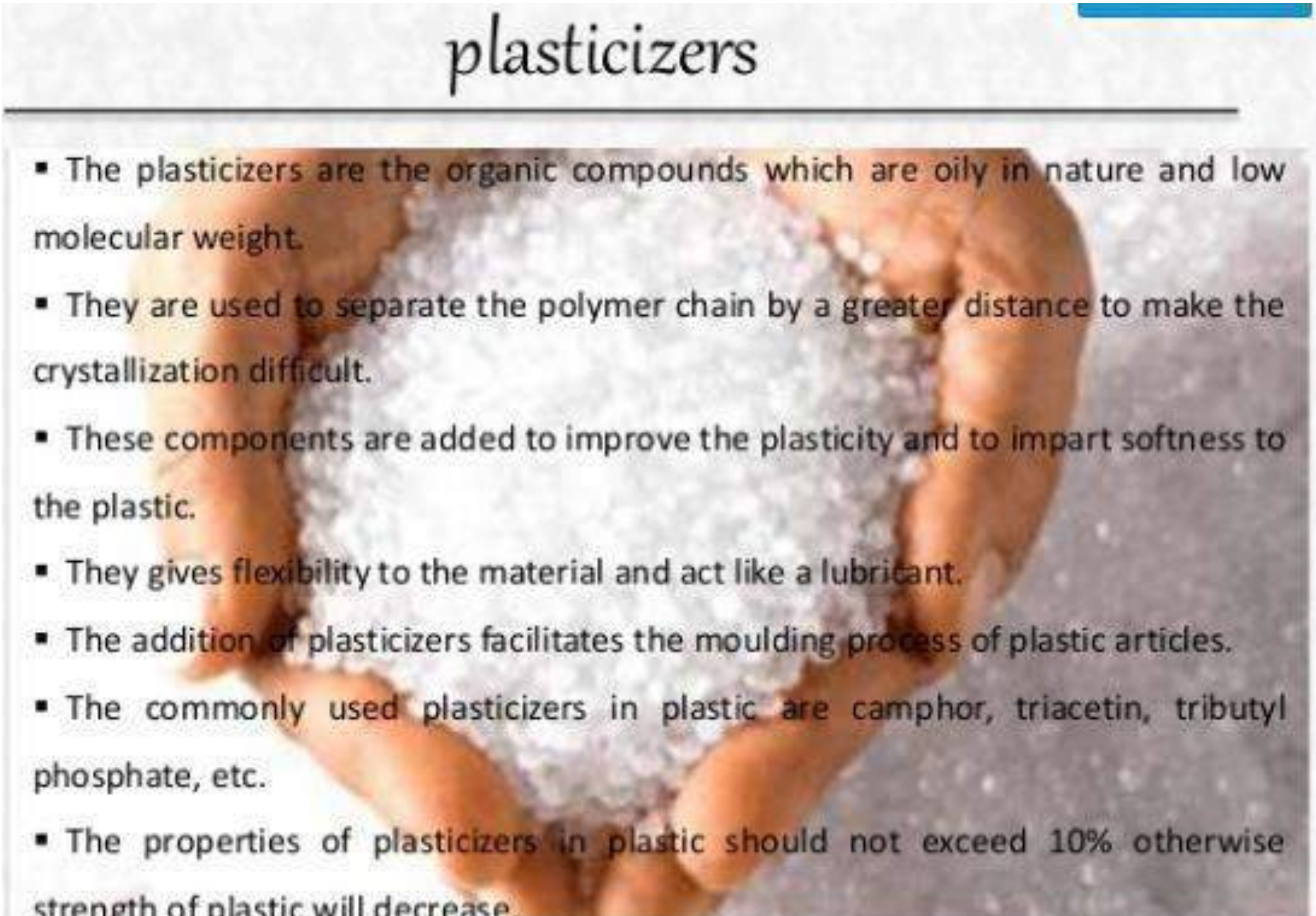
- These compounds are added to increase the hardness of resin.
- For instance, the hexamethylene tetramine acts as hardeners for phenol formaldehyde.

lubricants

- The lubricants are applied on the surface of moulds so that the articles of plastic do not stick to the moulds.
- The application of lubricants on surface of moulds allows easy removal of articles of plastic from the moulds.
- The commonly used lubricants are graphite, parafine, wax, etc.

pigments

- The addition of dyes and pigments helps in two ways, namely, they act as fillers an they impart desired colour to the plastic.
- They should be durable and adequately fast to light.
- The commonly used pigments are zinc oxide, barytes, etc.
- The selection of pigments should be done in such a way that their addition does not alter or affect the other properties of plastic.


plasticizers
▪ The plasticizers are the organic compounds which are oily in nature and low molecular weight.
▪ They are used to separate the polymer chain by a greater distance to make the crystallization difficult.
▪ These components are added to improve the plasticity and to impart softness to the plastic.
▪ They gives flexibility to the material and act like a lubricant.
▪ The addition of plasticizers facilitates the moulding process of plastic articles.
▪ The commonly used plasticizers in plastic are camphor, triacetin, tributyl phosphate, etc.
▪ The properties of plasticizers in plastic should not exceed 10% otherwise strength of plastic will decrease.

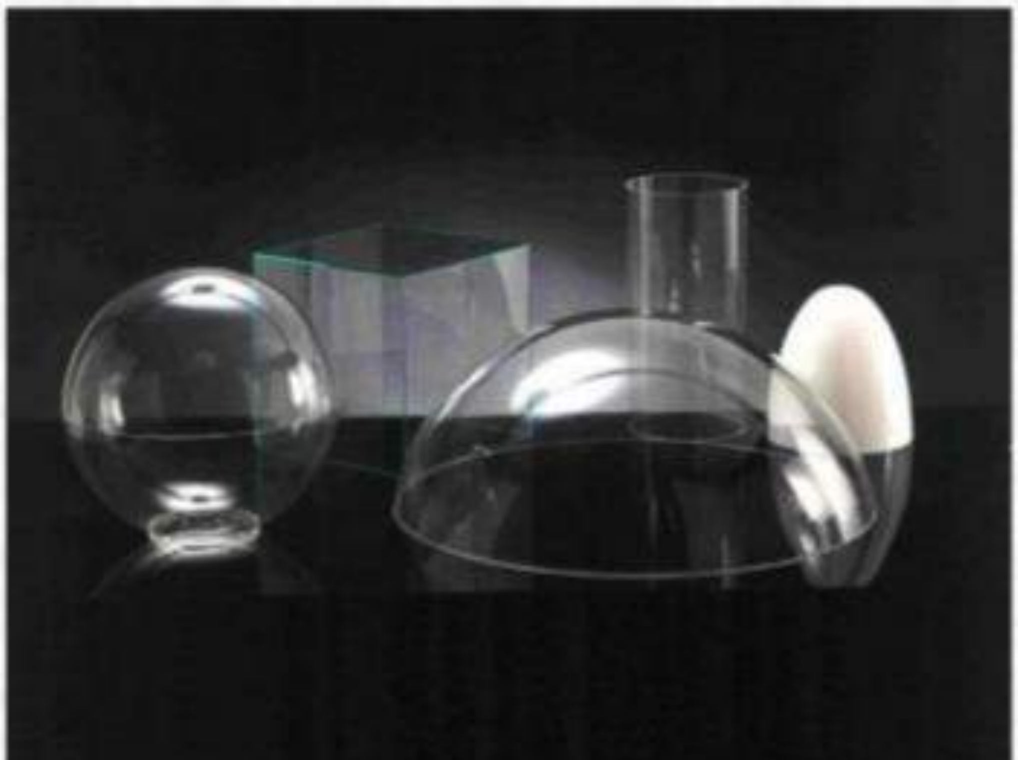
solvents

- These components are added to dissolve the plasticizers.
- For instance the alcohol is added in cellulose nitrate plastics to dissolve camphor.

Fabrication

Following are the process involved in the fabrication of articles of plastics:

- Blowing
- Calendering
- Casting
- Laminating
- Moulding



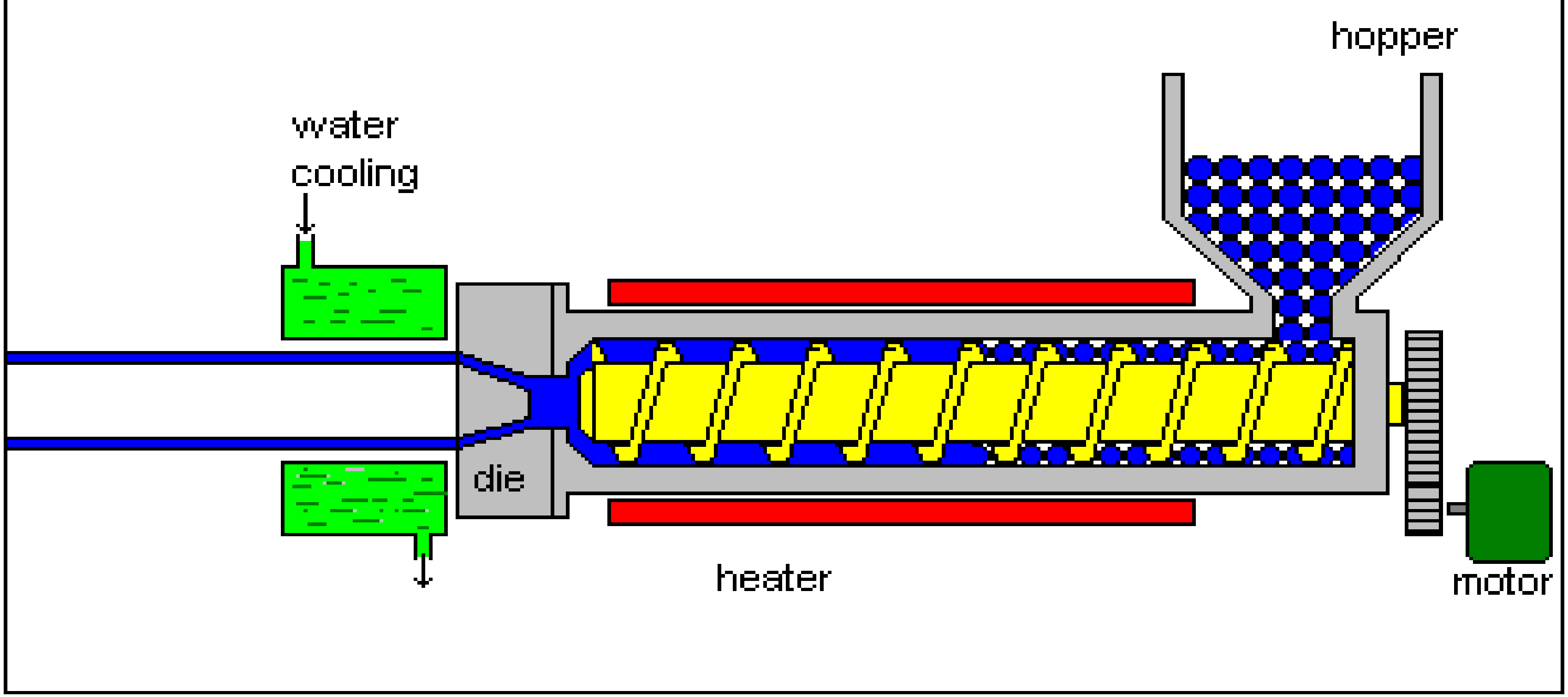
Common Plastic Production Processing

MAE 250L

Common Plastic ProductionProcessing

- **Extrusion**
- **Injection Moulding**
- **Blow Moulding**
- **Vacuum Forming**
- **Compression Moulding**
- **Rotational Moulding**

Extrusion



Extrusion

Continuous process used to produce both solid and hollow productsthat have a constant cross-section. E.g. window frames, hose pipe, curtain track, garden trellis.

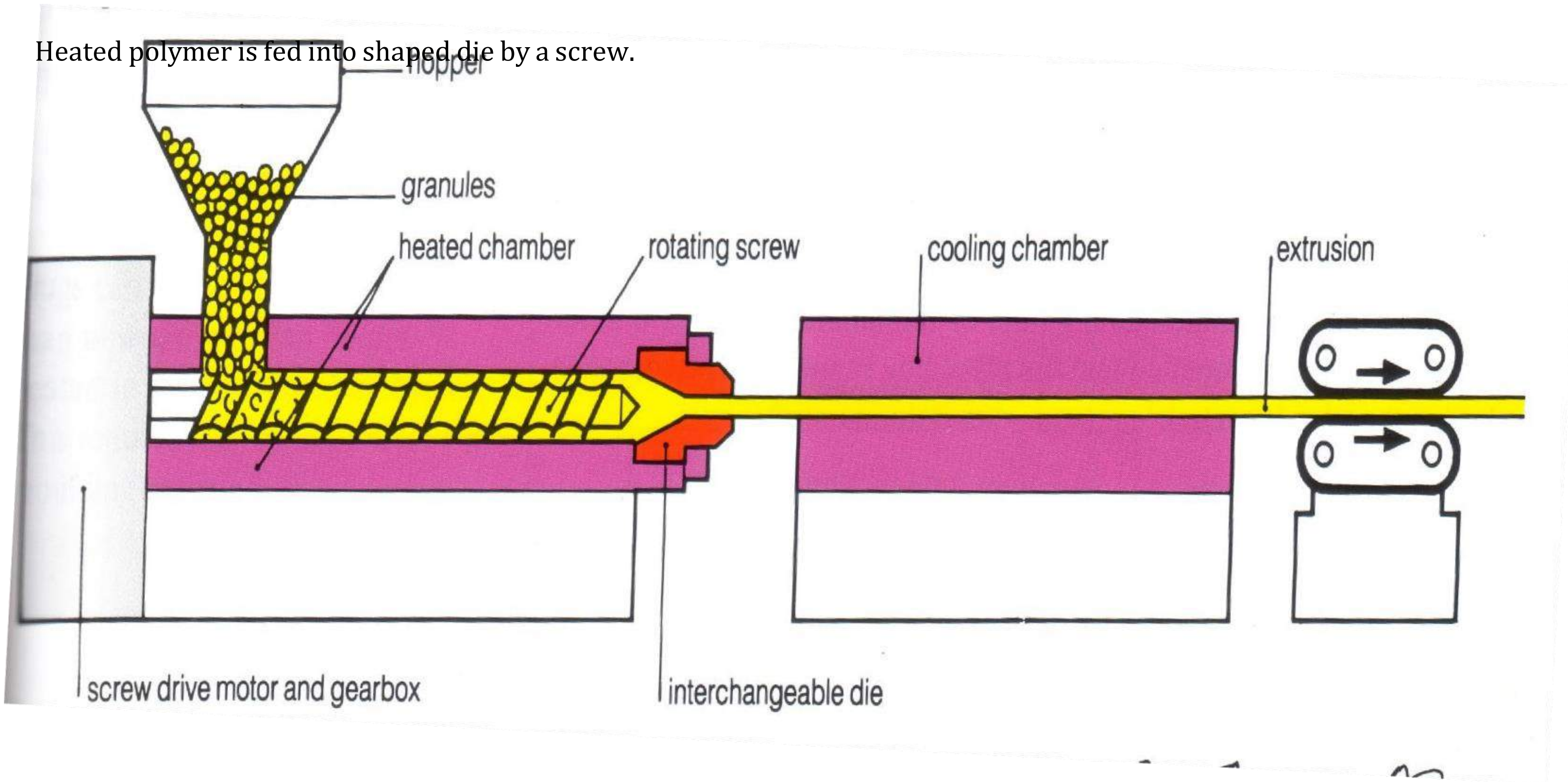
Thermoplastic granules are fed from a hopper by a rotating screw(auger) through a heated cylinder.

The tapered screw compacts the plastic as it becomes heated andelasticised. The die which is fitted to the end of the extruder barrel determines the cross-section of the extrusion.

Thicker cross-sections are extruded more slowly as more time is required for the initial heating and subsequent cooling of the larger quantities of material which are involved. As the extrusion leaves the die it is cooled by passing through a cooling trough (below) containing cold water.

Extrusion

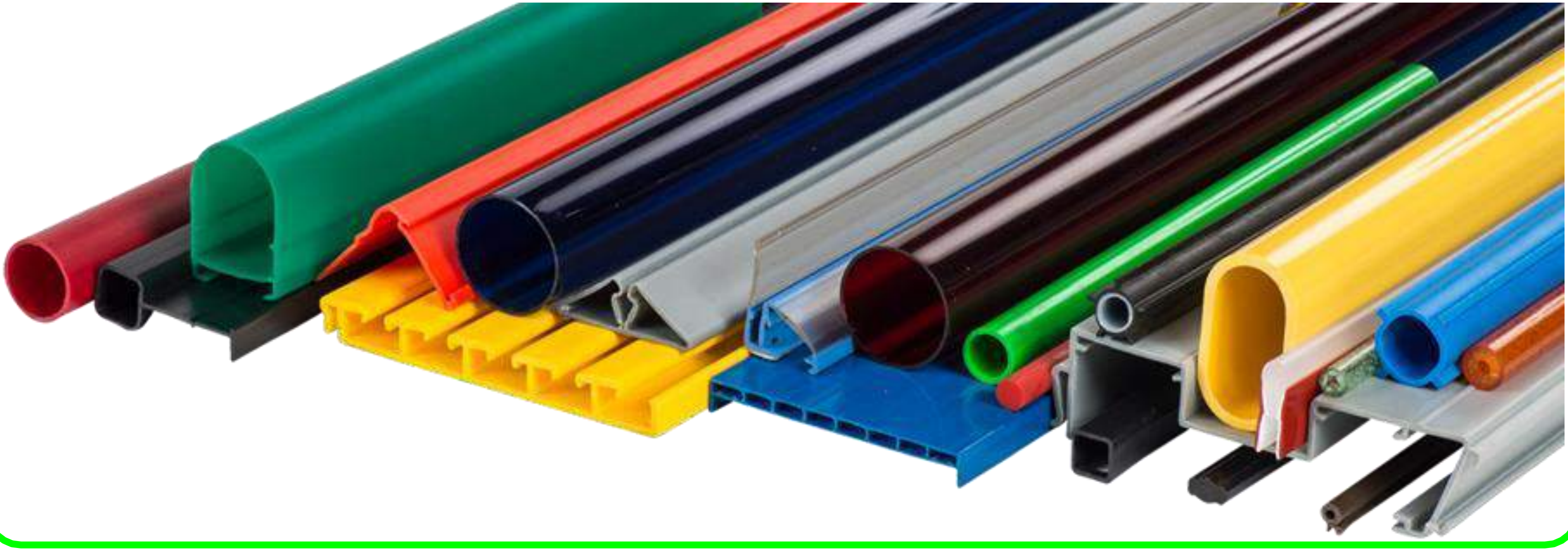
- Produces tubes, rods and other shaped continuousform lengths.
- Heated polymer is fed into shaped die by a screw.



Materials used in Extrusion

This extrusion is part of a window seal made fromthermoplastic elastomer (TPE).

Typical extruded plastic parts.



Common extruded products

pipe/tubing, weatherstripping, fencing,deck railings, window frames, plastic films and sheeting, thermoplastic coatings, and wire insulation…

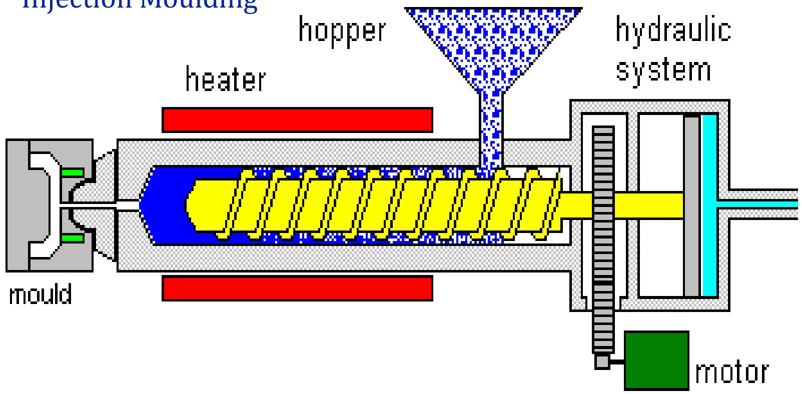
Common Extuded Plastic Materials

Polyethylene (PE), Polypropylene, Acetal (Delrin), Acrylic (plexiglass), Nylon (polyamides), Polystyrene, PolyVinyl Chloride (PVC), Acrylonitrile Butadiene Styrene (ABS),Polycarbonate

Injection Moulding Video

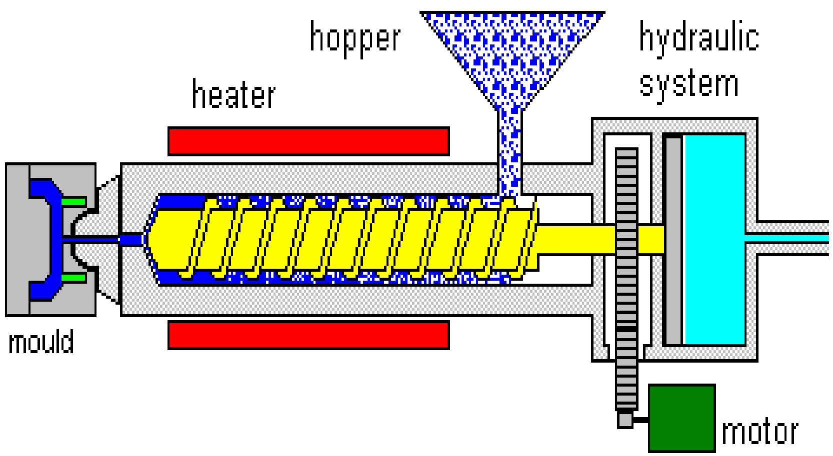
https://upload.wikimedia.org/wikipedia/commons/transcoded/6/62/Plastic_Injection_Molding.webm/Plastic_Injection_Molding.webm.480p.vp9.webm

Injection Moulding



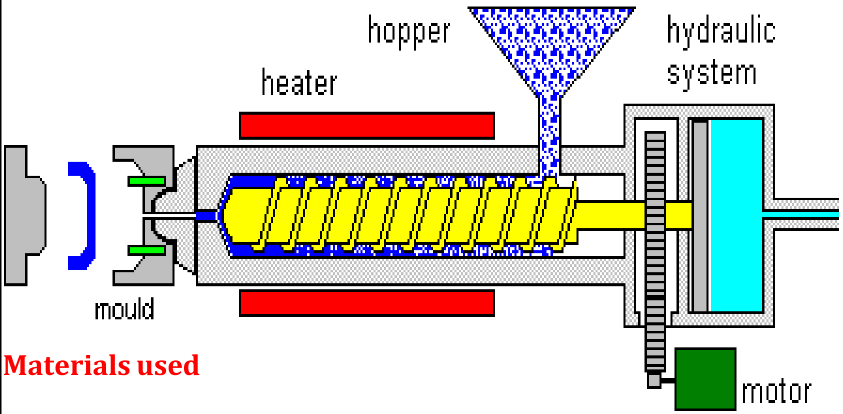
Powder or granules from a hopper feed into a steel barrel with a rotating screw. The barrel is surrounded by heaters. The screw is forced back as plastic collects at the end of the barrel.

Once a sufficient charge of melted plastic has accumulated a hydraulic ram forces the screw forward injecting the thermoplastic through a sprue into the mouldcavity.



Thermoplastic resin pellets for injection moulding.

Injection Moulding



Pressure is kept on the mould until the plastic has cooled sufficiently

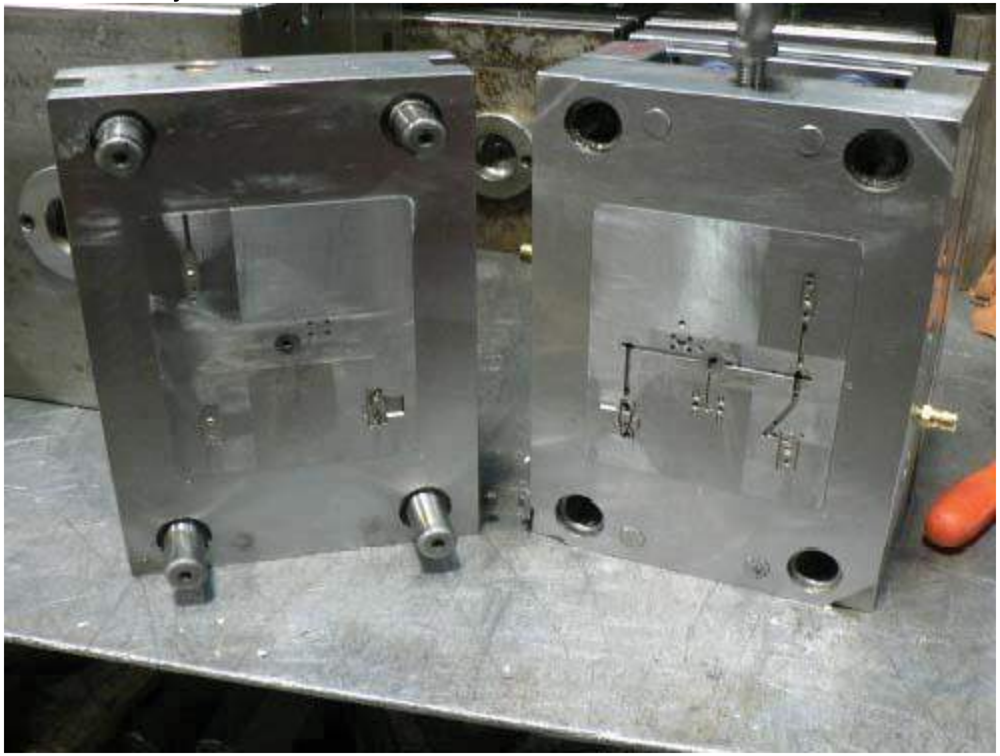
for the mould to be opened and the component ejected.

Materials used

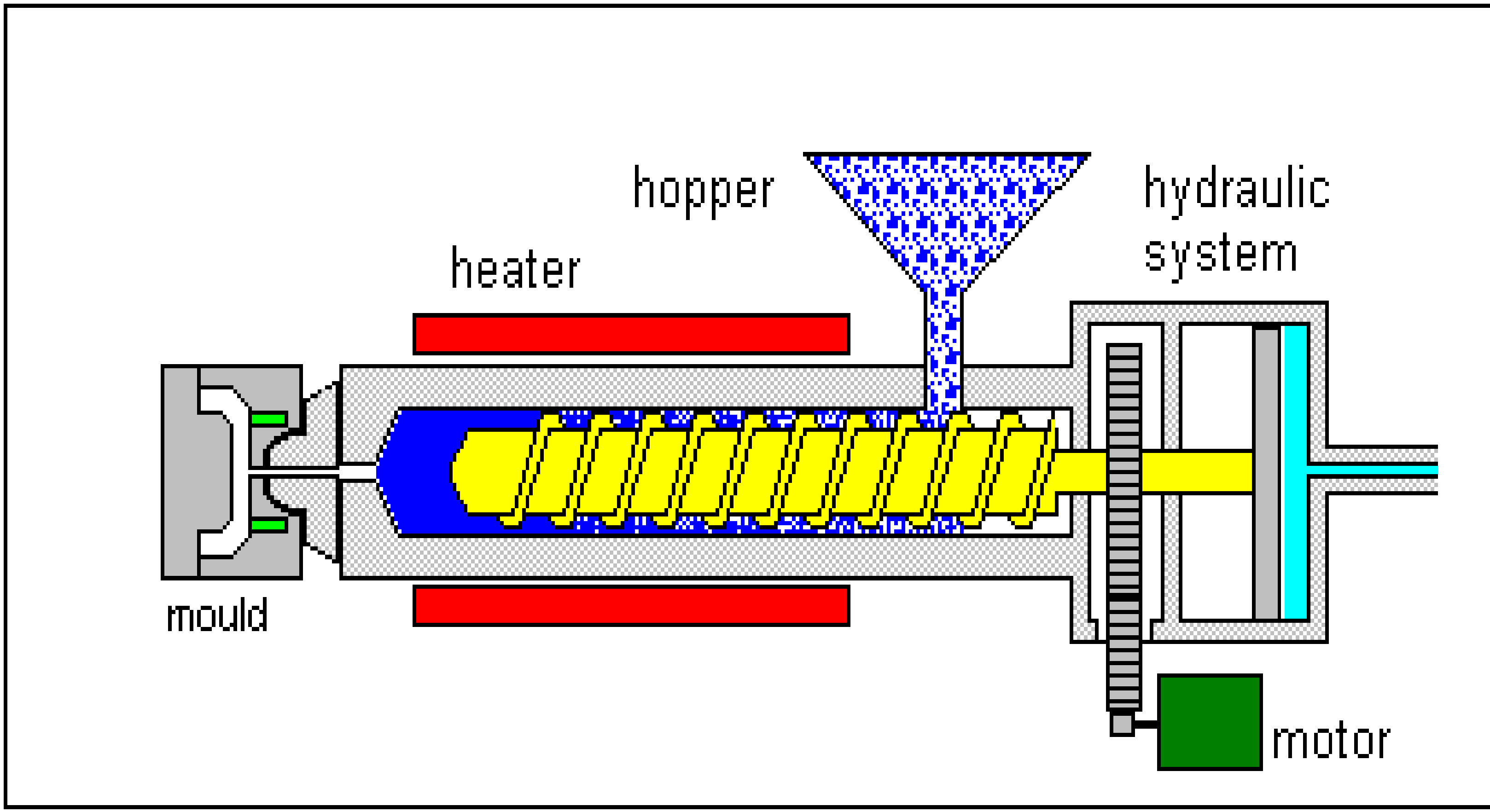
Normally thermoplastics are used in this process although a few thermosetting plastics can also be injection moulded.

Toy made from high impact polystyrene (HIPS).

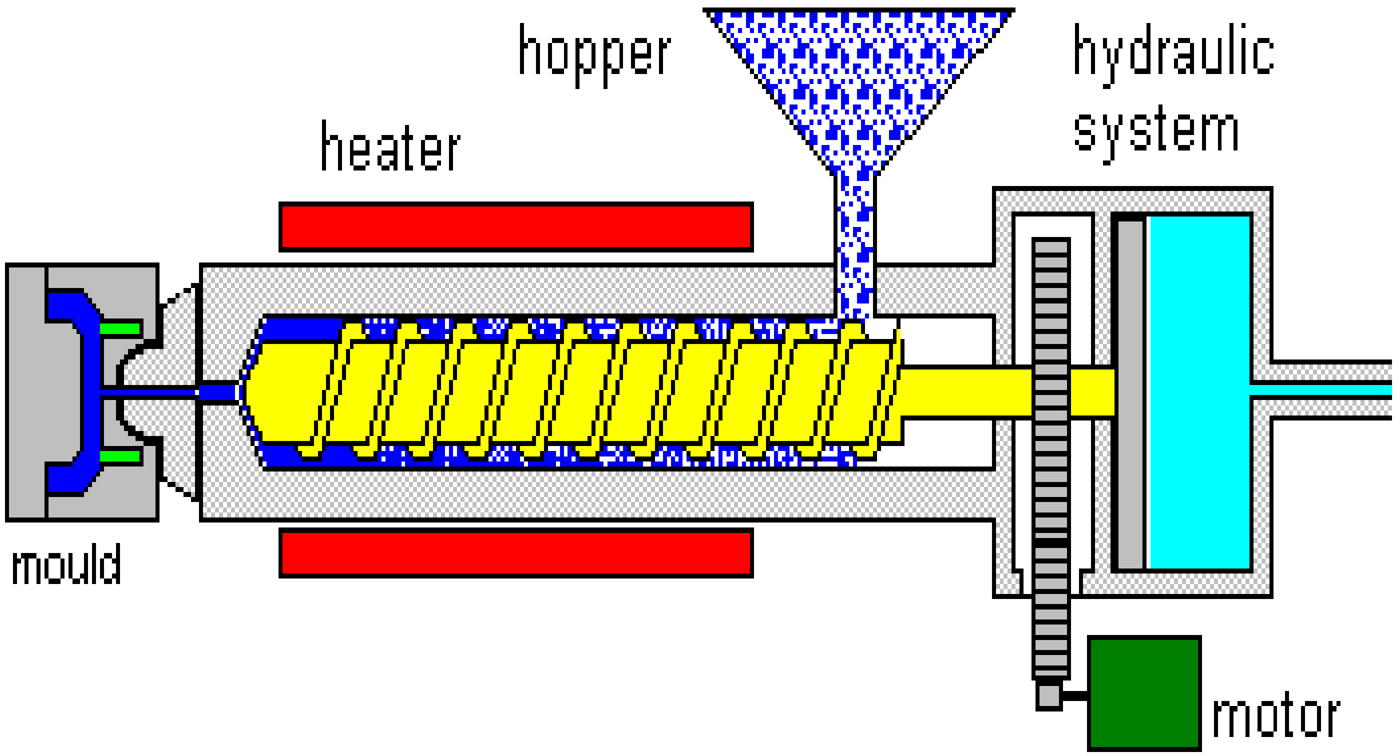
Standard two plates tooling – core and cavity are inserts in a mould base.



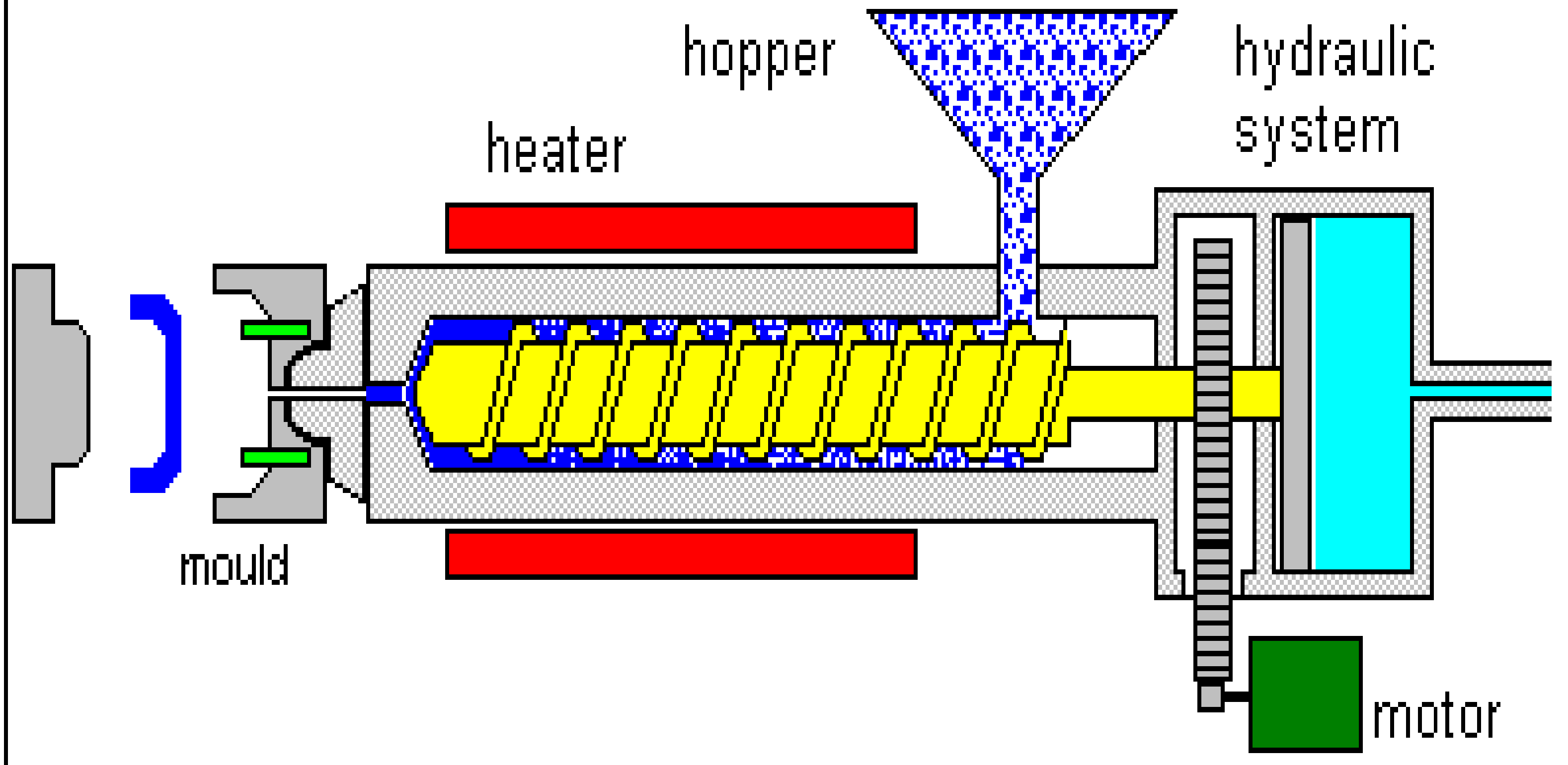
Feed screw filled



Polymer Injection

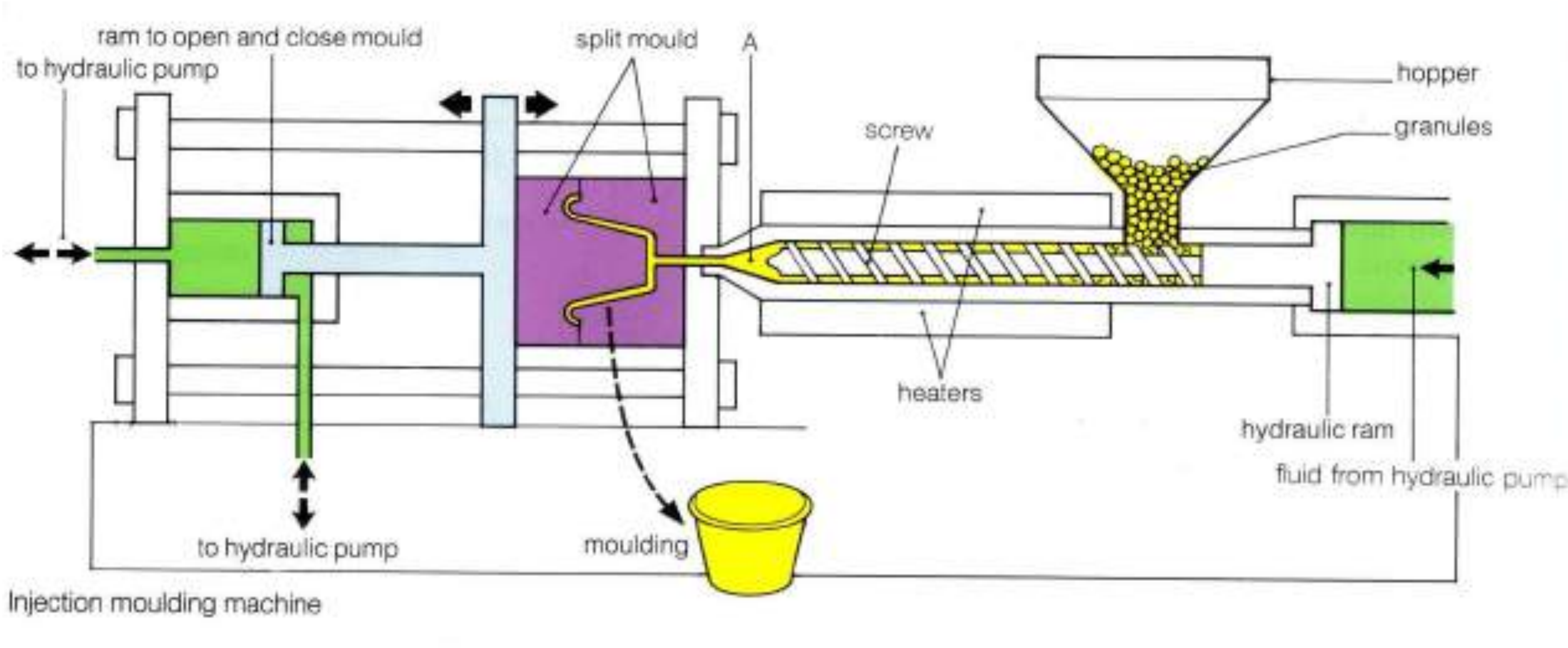


Component Ejected

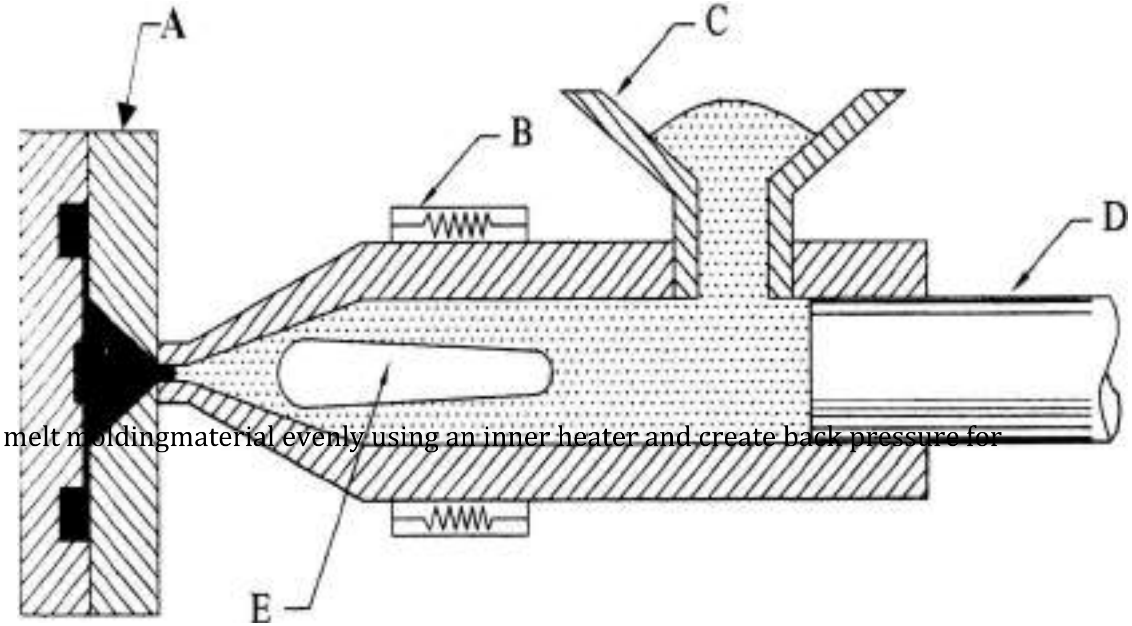


Injection Moulding

- Ameasured amount of molten thermoplastic is drivenby a ram past a heating system into the mould.
- The mould is split to allow finished object to beremoved after cooling.



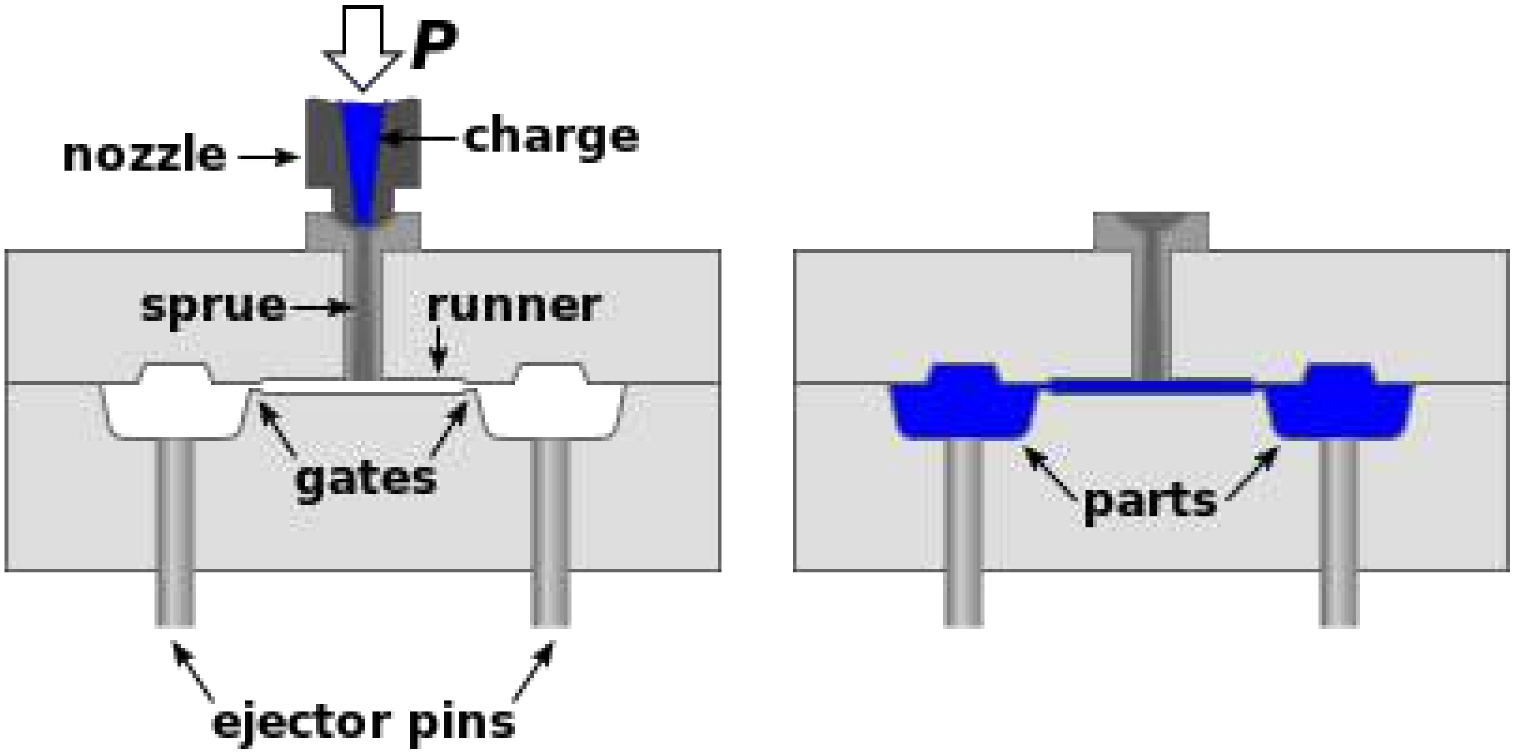
Parts of Injection Moulding Machine



- A– split mould
- B – heater
- C – hopper
- D – hydraulicram
- E – torpedo(spreader)

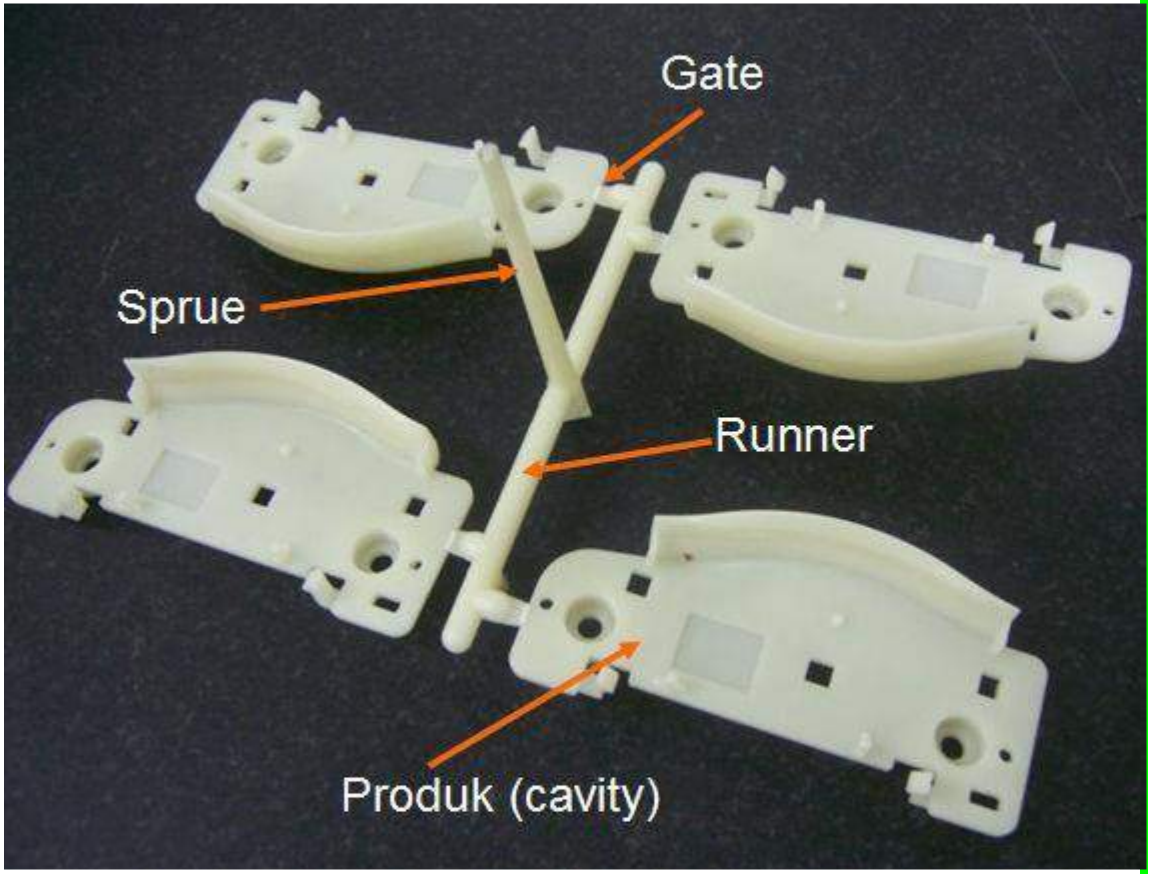
The function of the torpedo is to heat and melt moldingmaterial evenly using an inner heater and create back pressure for better mixing.

Simplified Diagram of theProcess at the Mould



Injection Moulded Parts

- Sprue, runner and gates in actual injection moulding product



Materials for Injection Moulding

- Both thermoplasticand thermosetting polymers are used

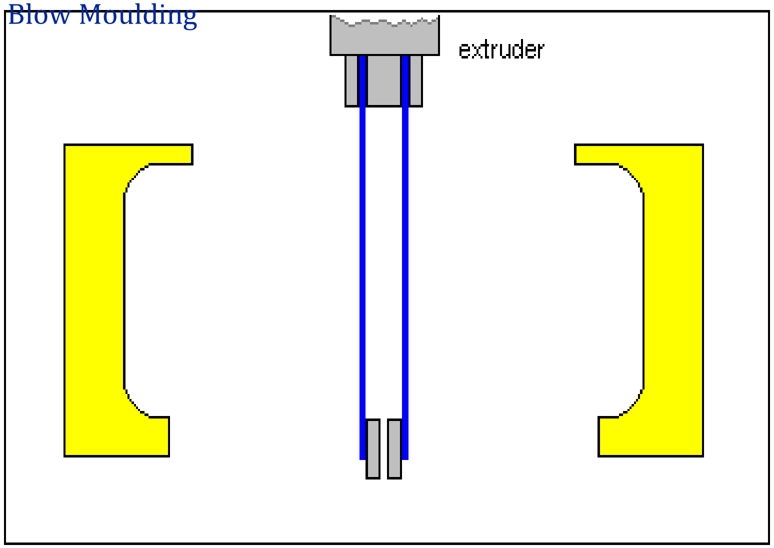
Common polymers

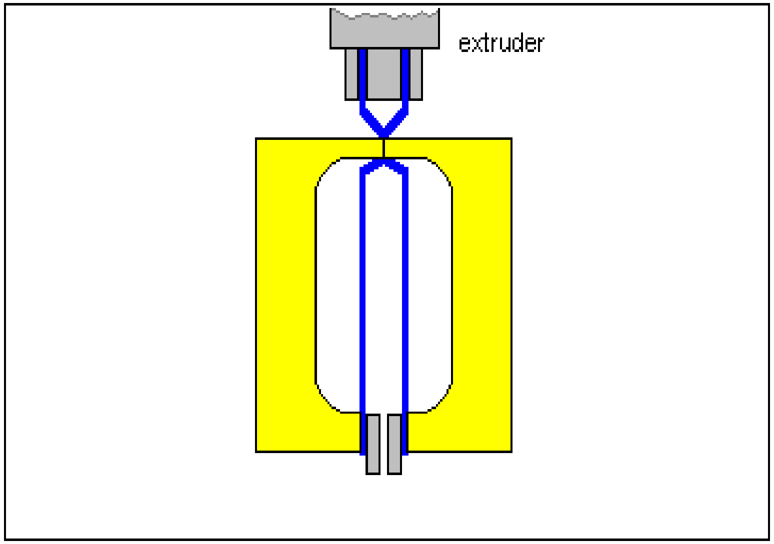
- Epoxy
- Phenolic
- Nylon
- Polyethylene
- Polystyrene

Injection Moulding

- Injection moulding produces accurate andcomplex products with high quality finish.
- Production is fast with little waste.
- Wide range of products including bowls, buckets, containers, toys, electrical parts andcar parts.
- Injection moulded parts can be recognised by the distinctive circular marks (5-10mm) causedby pins used to remove object from it’s mould.

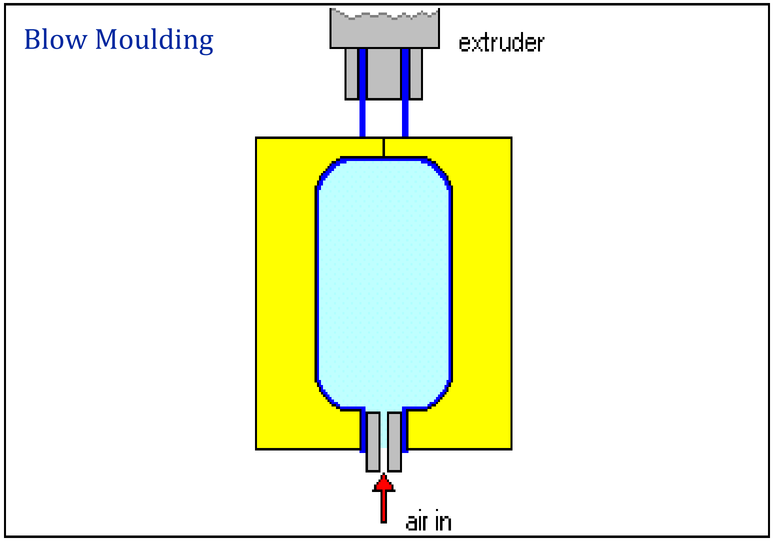
Blow Moulding

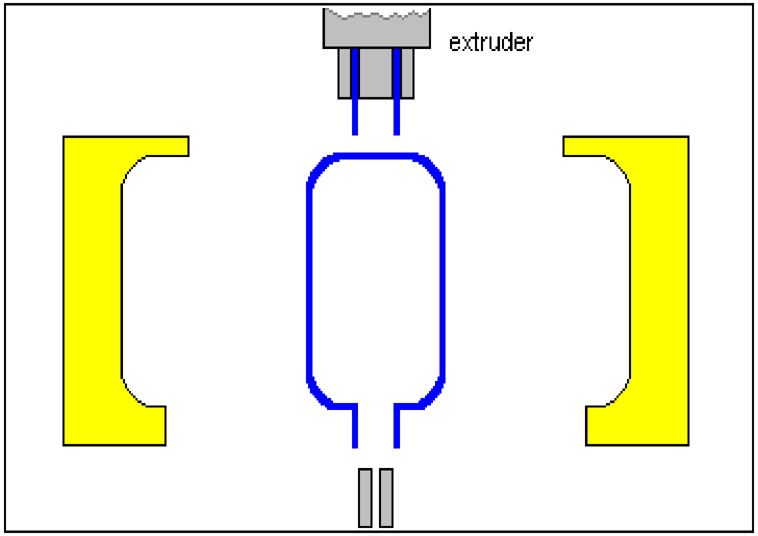




1. A hollow length of plastic, called a parison, is extruded downbetween the two halves of the mould.

2. The mould closes.





3. Compressed air is blown into the inside of the parison which inflates it, pushing the soft plastic hard against the cold surfaces of the mould.

4. The mould is then opened the moulding ejected and the waste(called flash) is trimmed off with a knife.

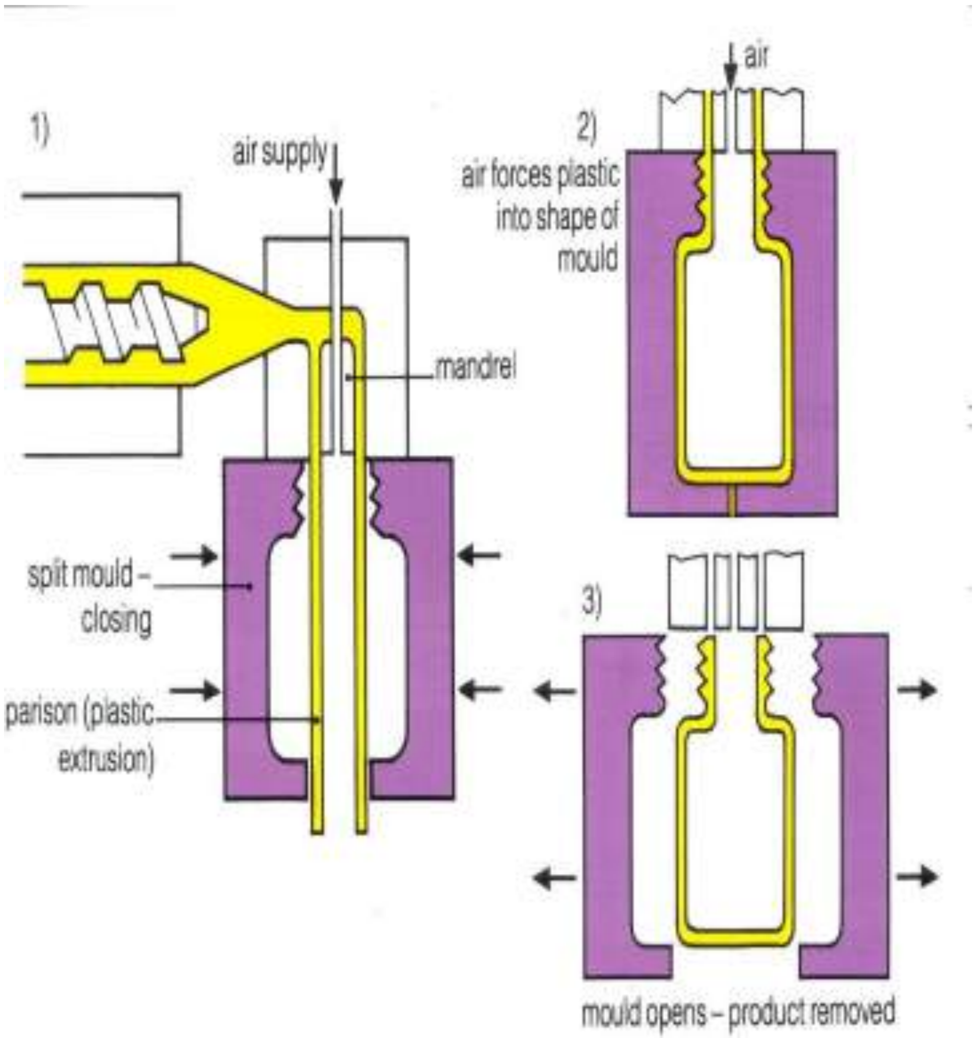
Materials used in blow moulding

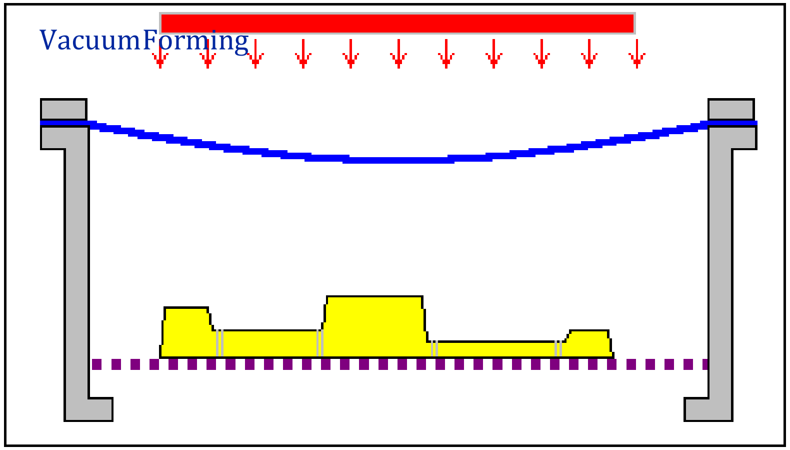
High density polyethylene (HDPE) and low density polyethylene (LDPE) are both commonly used for blow moulding as are other types of thermoplastics. The thermoplastic used in blow moulding needs to bemore viscous (flow less easily) than that used for injection moulding as the parison must retain its form before the mould closes around it.

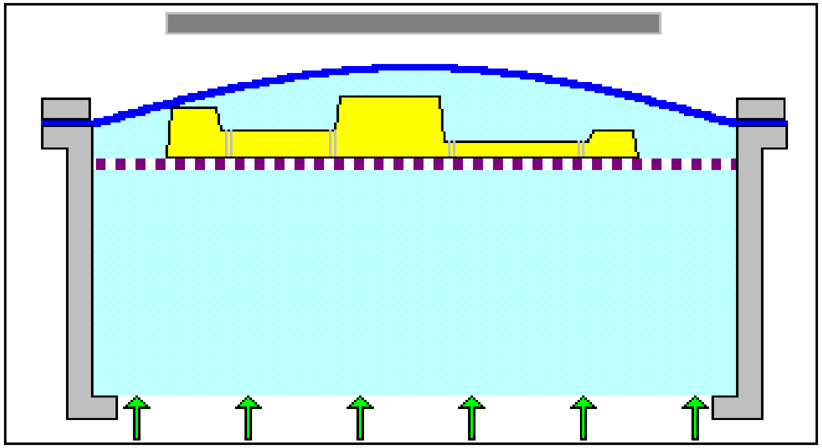
Used extensively to make bottles and other lightweight , hollow parts

Blow Moulding

- Used to make bottles and hollowtoys.
- Air is blown into a plastic tube, called aparison, to take the shape of the mould.
- PVC and polytheneare often used.

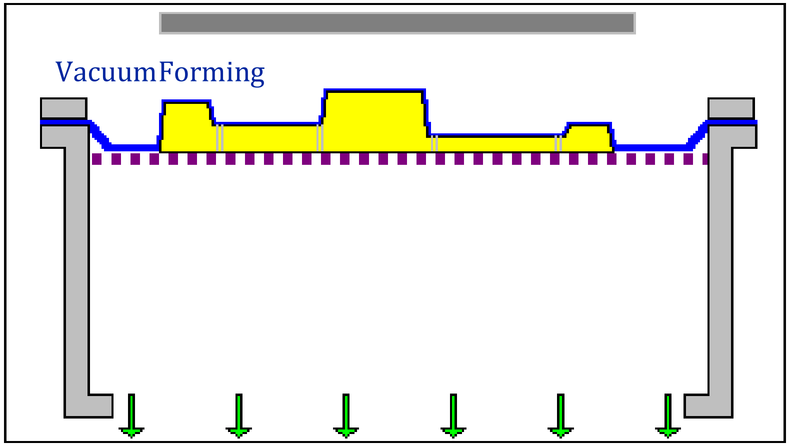


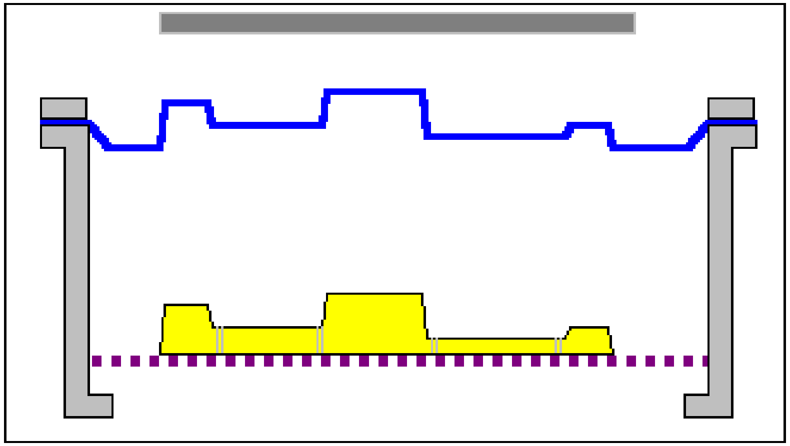




1. Mould is attached to a platen (support plate). The platen and mould are then lowered and a rigid thermoplastic sheet material is clamped onto an air tight gasketand usually heated from above.

2. Once the thermoplastic sheet is softened enough (reaches a plastic state) then air is blown in to raise the sheet in a slight bubble before the platen is raised bringing the mould into contact with the plastic.





3. trapped air remaining between the platen and the heated plastic sheet is then evacuated by a vacuum pump. Atmospheric pressure acting over the top surface completes the forming process by pressing the plastic sheet onto the mould.

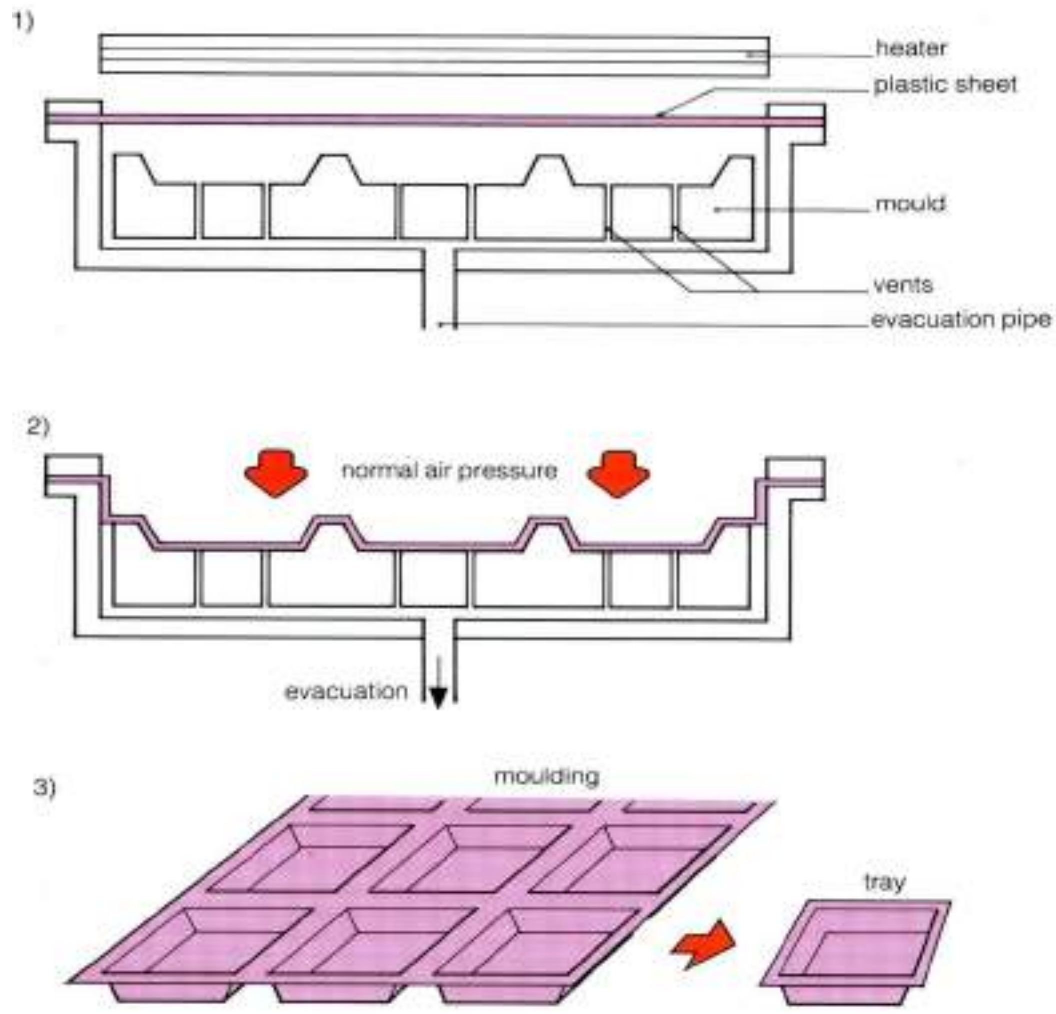
4. Once the plastic sheet has cooled down to below it's freeze point the airflow is reversed to lift the forming off the mould and the mould lowered

Materials used in Vacuum forming

Many types of thermoplastics are suitable for vacuum forming. The most popular is High Impact Polystyrene (HIPS). It is relatively cheap, comes in a wide range of colours and is easy to form. This process is used to manufacture a variety of products in thermoplastic materials. These products range in size from garden pond liners to food trays used in supermarkets.

VacuumForming

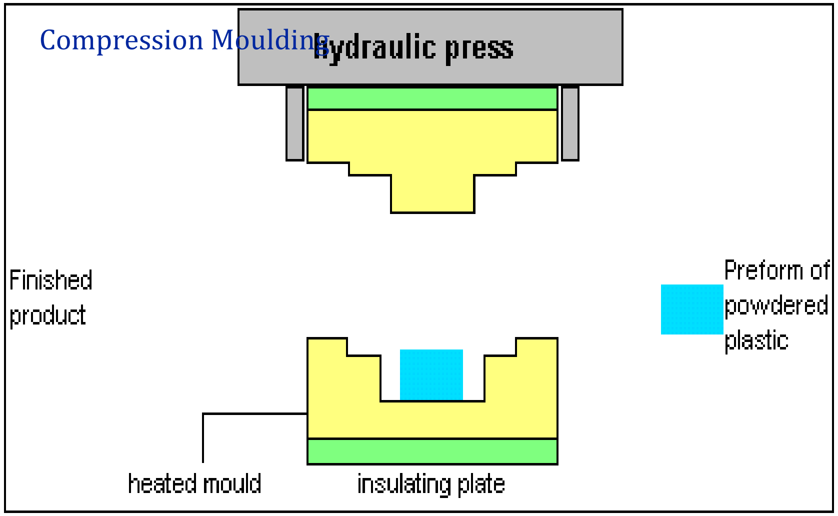
- Plastic sheet is clamped and heated.
- Heat is removed andpattern raised.
- Vacuum forces the sheet onto the pattern.
- The sheet is removedand trimmed.

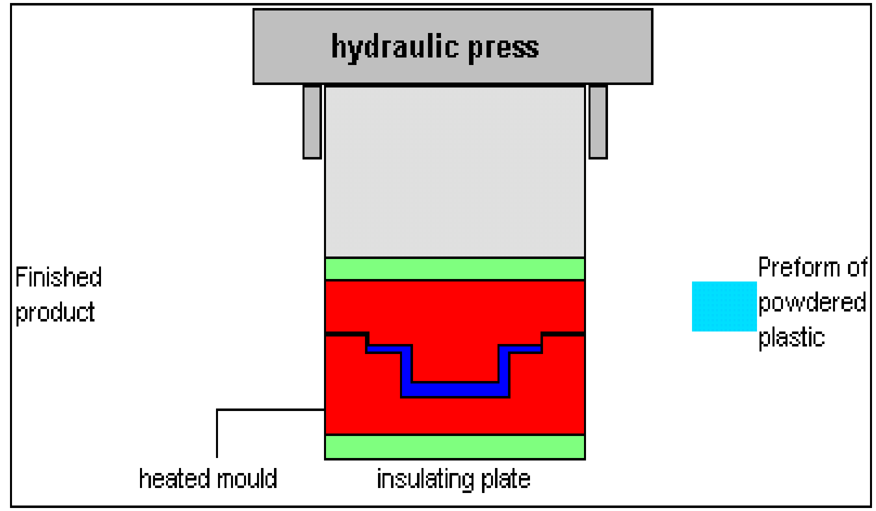


Vacuum Formed Products

- Case tops for limited productionor low-cost item

Compression Moulding

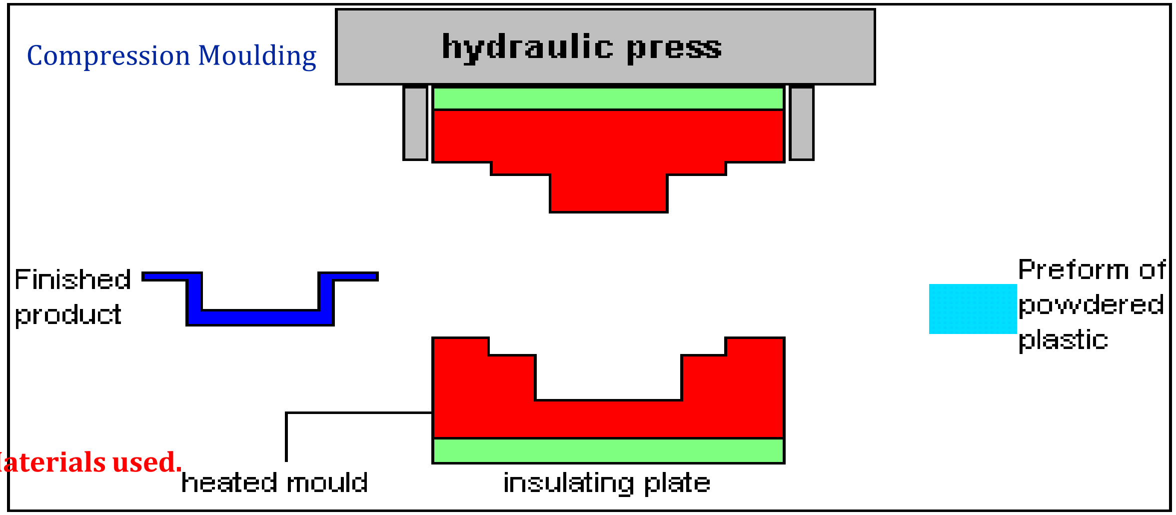




1. The mould is charged with a measured amount of powder or granules ready to be compressed. Sometimes plastic charge is first compacted into a shape called a preform.

2. When the two halves of the mould are brought together the plastic material is forced under compression to flow rapidly around the cavity. heatfrom the platens causes the plastic to cure resulting in a permanent change

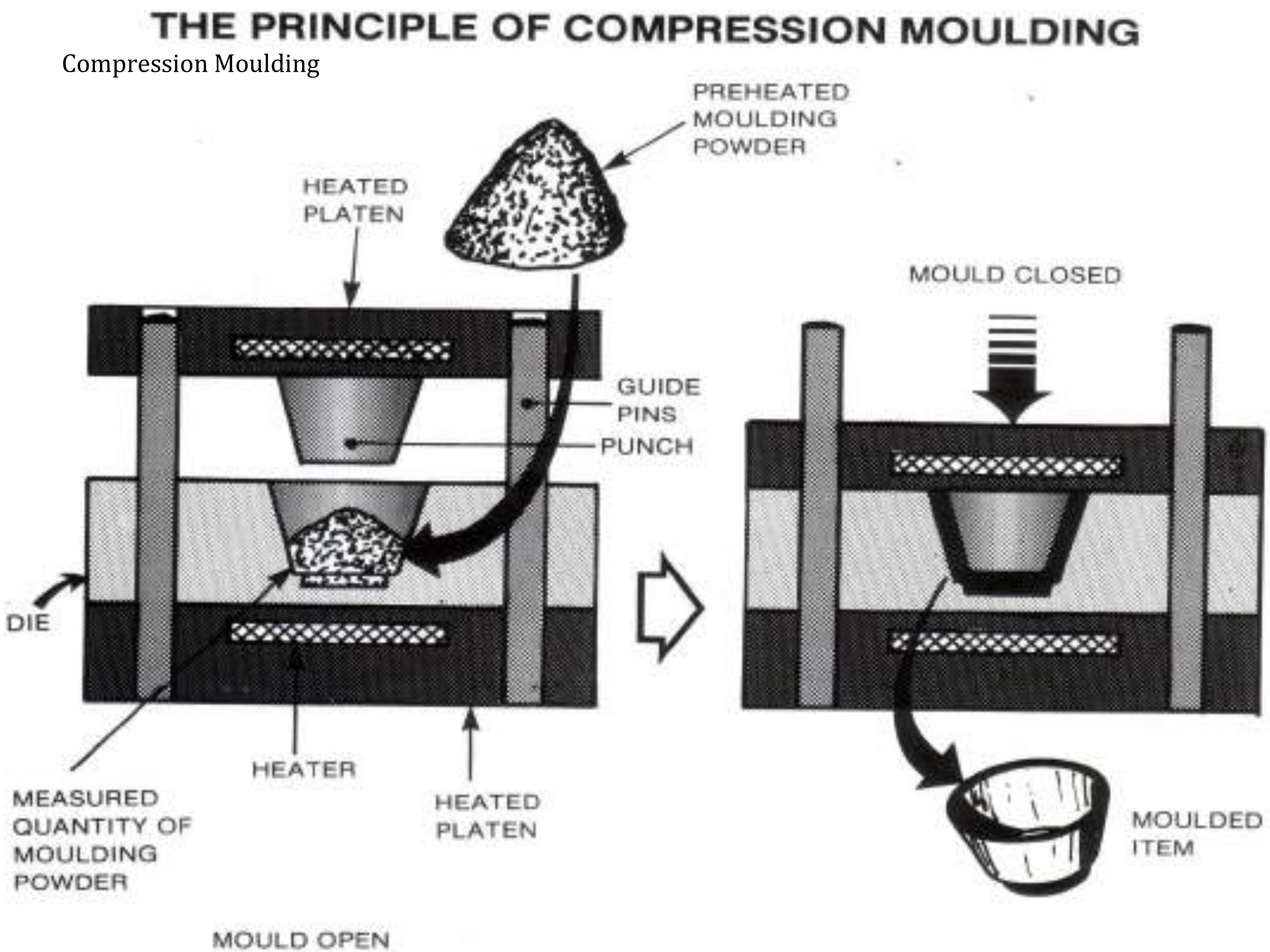
in shape.



The component is ejected from the mould and any excess material formed at edges (flash) is removed.

Materials used.

Typical thermosetting plastics used in compression moulding are urea formaldehydeand phenol formaldehyde.

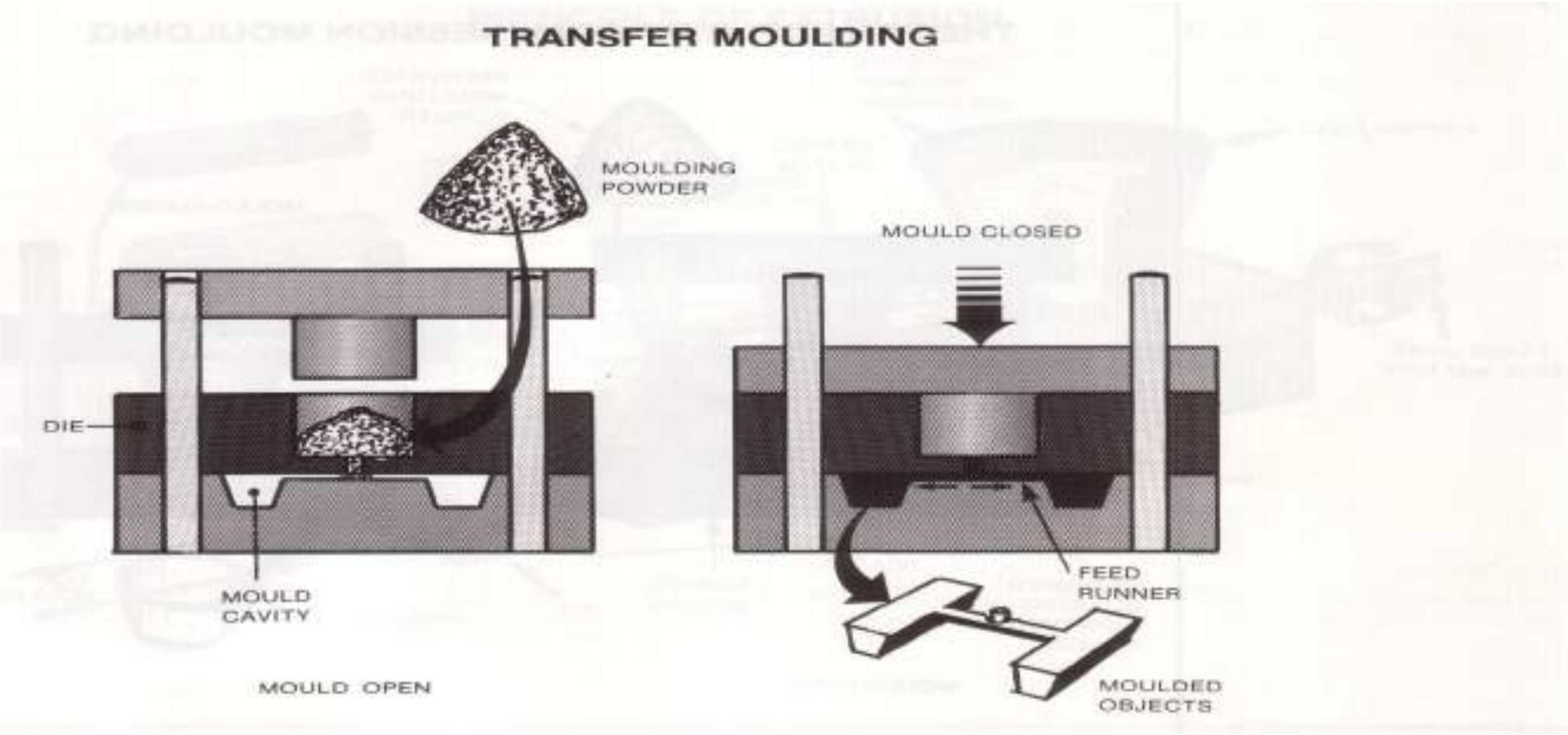


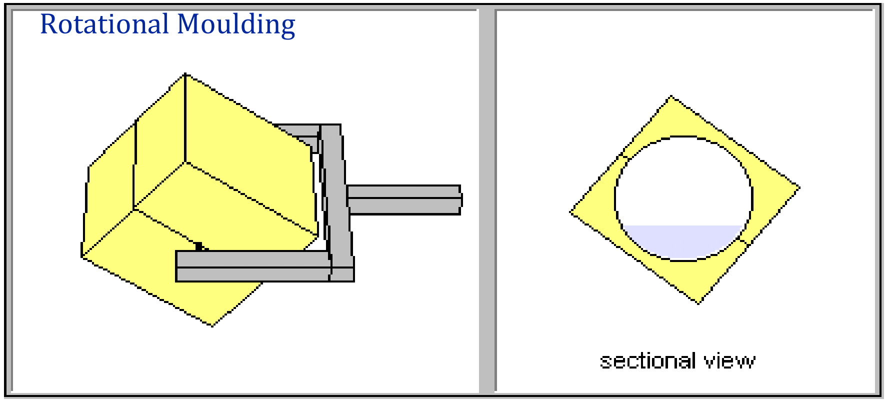
Compression Moulding

- Thermoset plastics are shaped with heat andpressure causing cross-linking.
- The polymer can be in powder or slug (cube)form.
- Products such as electrical fittings, saucepan handles and bottle tops are often formed out of formaldehyde plastics.
- High quality finishes are achieved with only the removal of 'flash' (excess material usually at the mould split) for finished products.

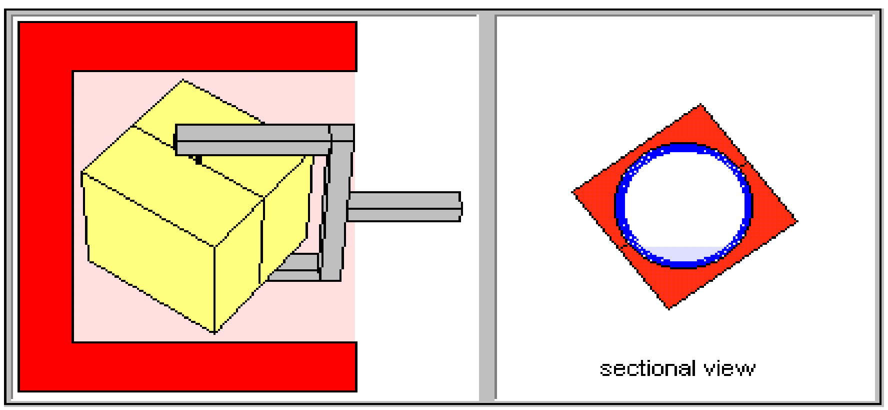
Transfer Moulding

Thermoset polymers can be formed when a preset amount of material is placed in a separate cavity and heated. A plunger moves the material into the shapedmould with high pressure.

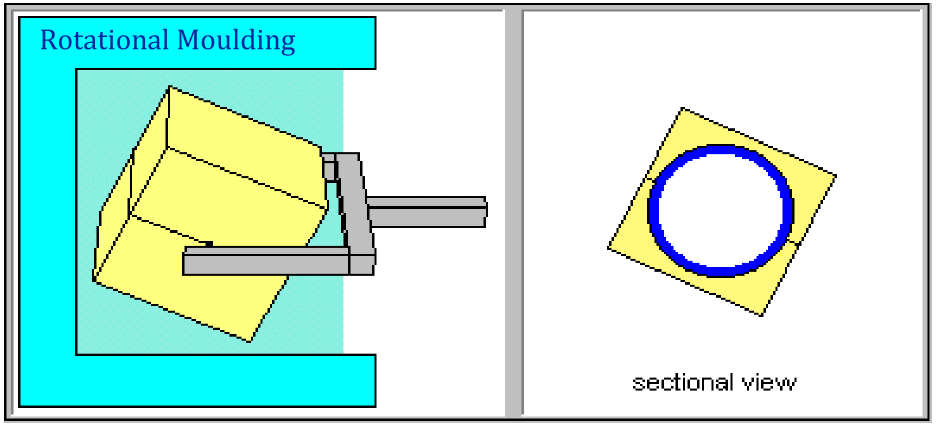


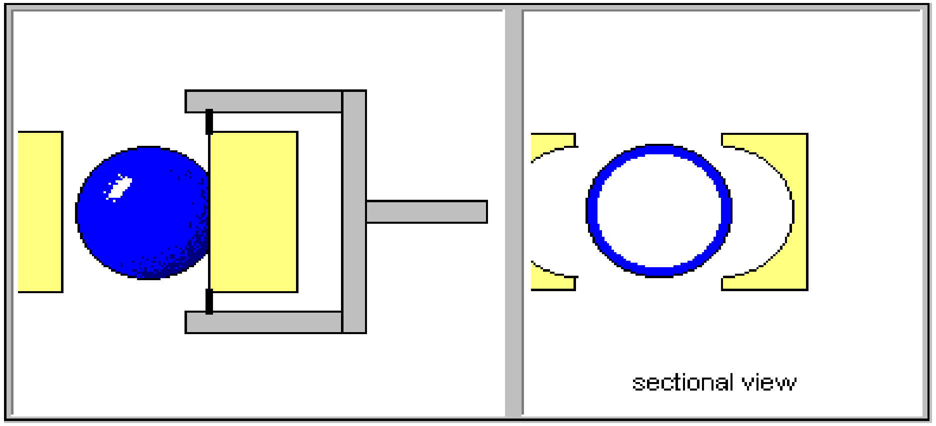


1. A measured weight of thermoplastic is placed inside a cold mould. The mould is then closed and moved into an ovenchamber



2. heated to a temperature of 230- 400 C whilst being rotated around both vertical and horizontal axes. As it rotates the mass of powder at the bottom of the mould fuses andsticks to the mould surface.





3. the mould moves into a cooling area or chamber where it is cooled by air or water jets.

4. The hollow moulding can be removed as soonas it is cool enough to hold its shape.

Materials used

90% of rotational mouldings are made from polyethylene (PE), used mainly to manufacture hollow shaped products such as footballs, road cones and storage tanks up to $3m^3$ capacity.

PROCESSING PLASTICS

- Calendering – produces sheets by rollinginto shape.
- Lamination – layers of materials (eg paper, cloth) are bonded with a resin into a strong solid structure, often with heat and pressure.
- Foaming – expansion into sponge-likematerial by a foaming agent.

MODULE 3

Additive ManufacturingProcess

Module 1

Content

Introduction to Additive Manufacturing: Introduction to AM, AM evolution, Distinction between AM& CNC machining, Advantages of AM.

AM process chain: Conceptualization, CAD, conversion to STL, Transfer to AM, STL file manipulation, Machine setup, build , removal and clean up, post processing.

Classification of AM processes: Liquid polymer system, Discrete particle system, Molten material systems and Solid sheet system.

Post processing of AM parts: Support material removal, surface texture improvement, accuracy improvement, aesthetic improvement, preparation for use as a pattern, property enhancements usingnon-thermal and thermal techniques.

Module 1

Guidelines for process selection: Introduction, selection methods for a part, challenges of selection

AM Applications: Functional models, Pattern for investment and vacuum casting, Medical models,art models, Engineering analysis models, Rapid tooling, new materials development, Bi-metallic parts, Re-manufacturing. Application examples for Aerospace, defence, automobile, Bio-medical and general engineering industries

Introduction

What is Additive Manufacturing?

- The term Rapid Prototyping (or RP) is used to describe a process for rapidly creating a system or part representation before final release or commercialization.

- A recently formed Technical Committee within ASTM International agreed that new terminology should be adopted. Recently adopted ASTM consensus standards now use the term **Additive Manufacturing**.

- The basic principle of this technology is that a model, initially generated using a 3D Computer Aided Design (3D CAD) system, can be fabricated directly without the need for process planning.

Introduction

Prototype fundamentalsDefinition of a Prototype

A prototype is the first or original example of something that has been or will becopied or developed; it is a model or preliminary version;

e.g.: Aprototype supersonic aircraft.

or

An approximation of a product (or system) or its components in some form for adefinite purpose in its implementation.

Introduction

Prototype fundamentals

Types of Prototype

The general definition of the prototype contains three aspects of interests:

(1) Implementation of the prototype; from the entire product itself to its sub-assembliesand components,

(2) Form of the prototype; from a virtual prototype to a physical prototype

(3) Degree of the approximation of the prototype; from a very rough representation toan exact replication of the product.

Introduction

Additive Manufacturing – Layer Manufacturing

Often used terms:

Additive	Additive Manufacturing (AM) Additive Layer Manufacturing (ALM) Additive Digital Manufacturing (DM)
Layer	Layer Based Manufacturing Layer Oriented ManufacturingLayer Manufacturing
Rapid	Rapid Technology, Rapid Prototyping Rapid Tooling, Rapid Manufacturing
Digital	Digital Fabrication, Digital Mock-Up

- 3D Printing, 3D Modeling
- Direct Manufacturing, Direct Tooling

Introduction

Additive Manufacturing – Layer Manufacturing

“Additive Manufacturing” (AM) is a layer-based automated fabrication process for making scaled 3-dimensional physical objects directly from 3D-CAD data without using part-depending tools.

It was originally called “3D Printing”.

Additive manufacturing also refers to technologies that create objects, layer by layer

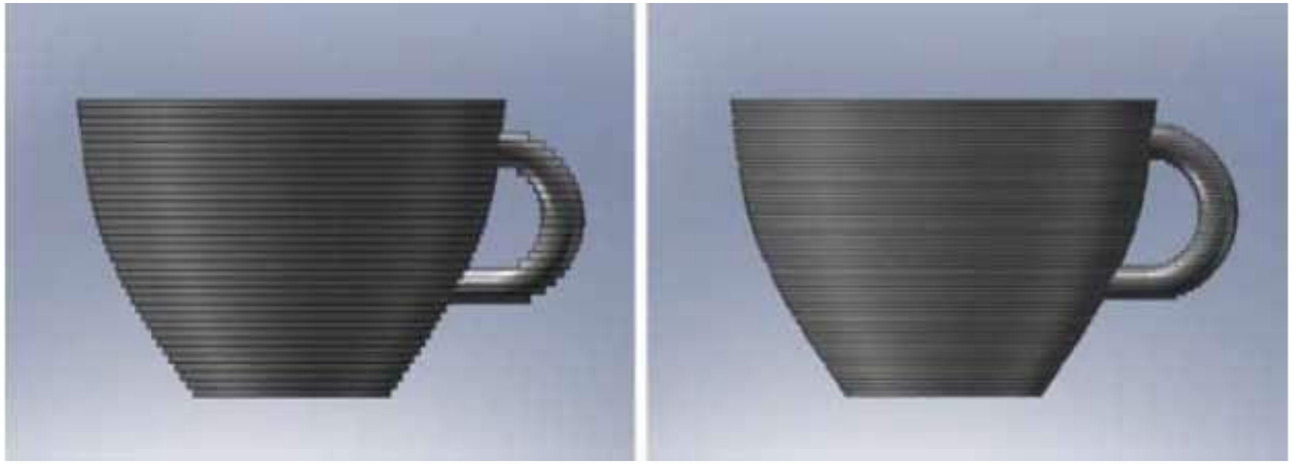
or sequential layering

Introduction

Additive Manufacturing – Layer Manufacturing

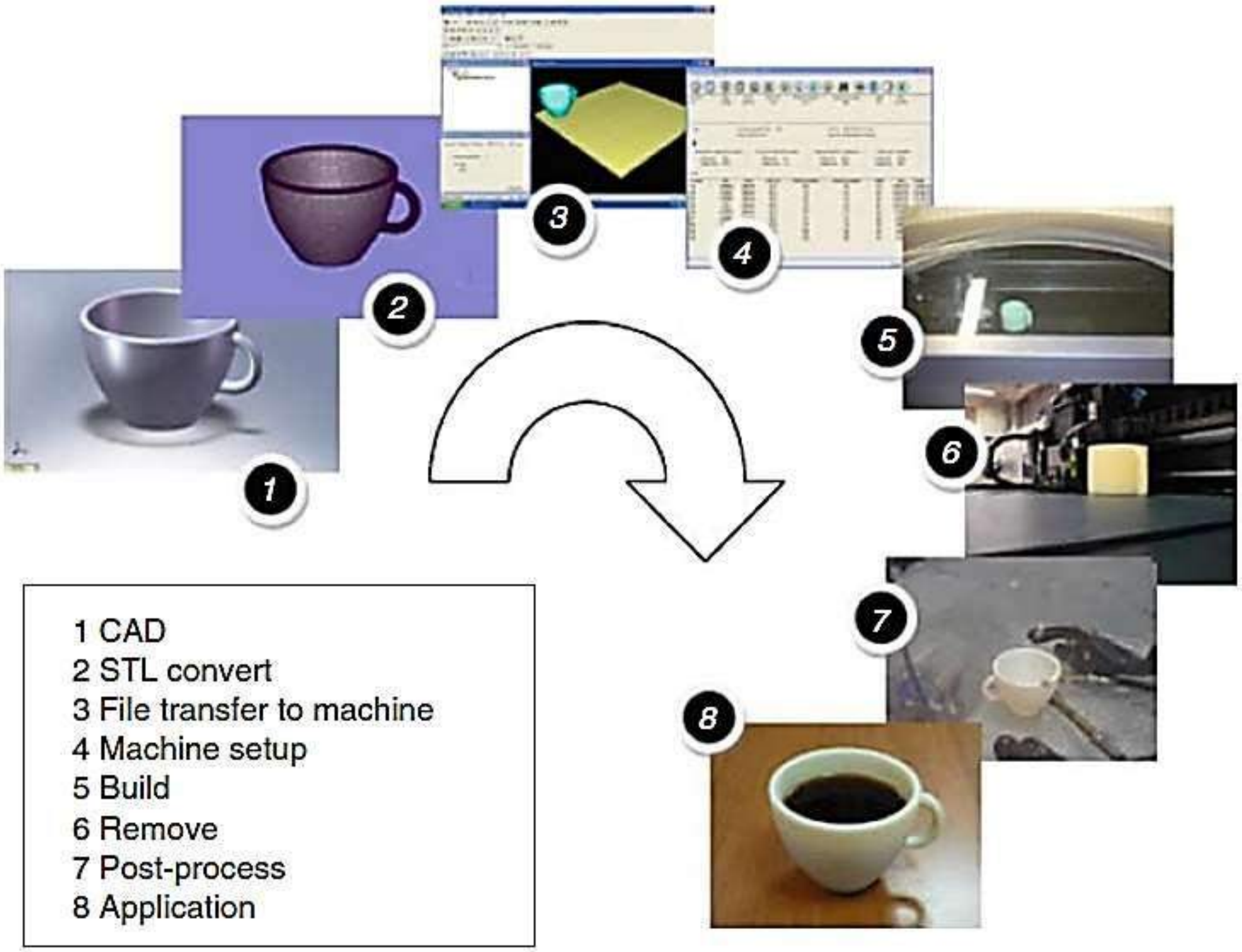
Additive manufacturing, also known as 3D printing, rapid prototyping or freeform fabrication, is 'the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies' such as machining.

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



Introduction

The Generic AM Process



Generic process of CAD to part, showing all 8 stages

Introduction

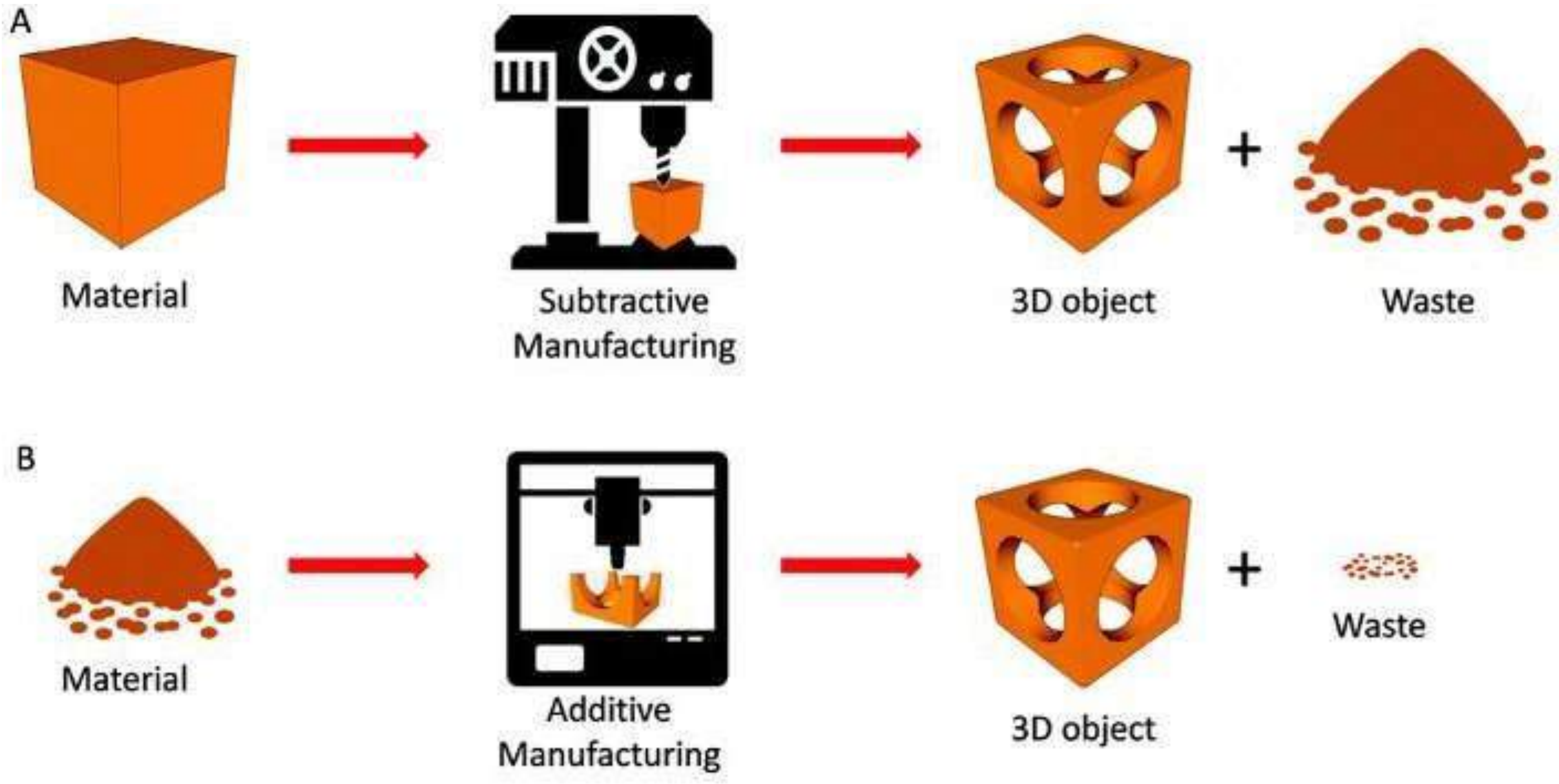
Additive Manufacturing Evolution

Year of Inception	Technology
1770	Mechanization [4]
1946	First Computer
1952	First Numerical Control (NC) Machine Tool
1960	First commercial Laser [5]
1961	First commercial Robot
1963	First Interactive Graphics System (early version of Computer-Aided Design) [6]
1988	First commercial Rapid Prototyping System

Introduction

Distinction between AM & CNC machining

Subtractive vs Additive Manufacturing



Introduction

Distinction between AM & CNC machining

- Materials
- Speed
- Ease of use
- Accuracy, Size limitations & Geometric Complexity
- Programming
- Cost
- Environmentally Friendly

Advantages of AM

- Elimination of design constraints
- Allow parts to be produced with complex geometry with no additional costsrelated to complexity
- Build speed; reduction of lead time
- Flexibility in design
- No expensive tooling requirements
- Dimensional accuracy
- Wide range of materials (polymers, metals, ceramics)
- Well suited to the manufacture of high value replacement and repair parts
- Green manufacturing, clean, minimal waste

Introduction

Limitations of AM

- Part size
- Production series: Generally suitable for unitary or small series and is not relevant for mass production. For small sized parts, series up to 25000 parts/year are already possible.

Introduction

Limitations of AM

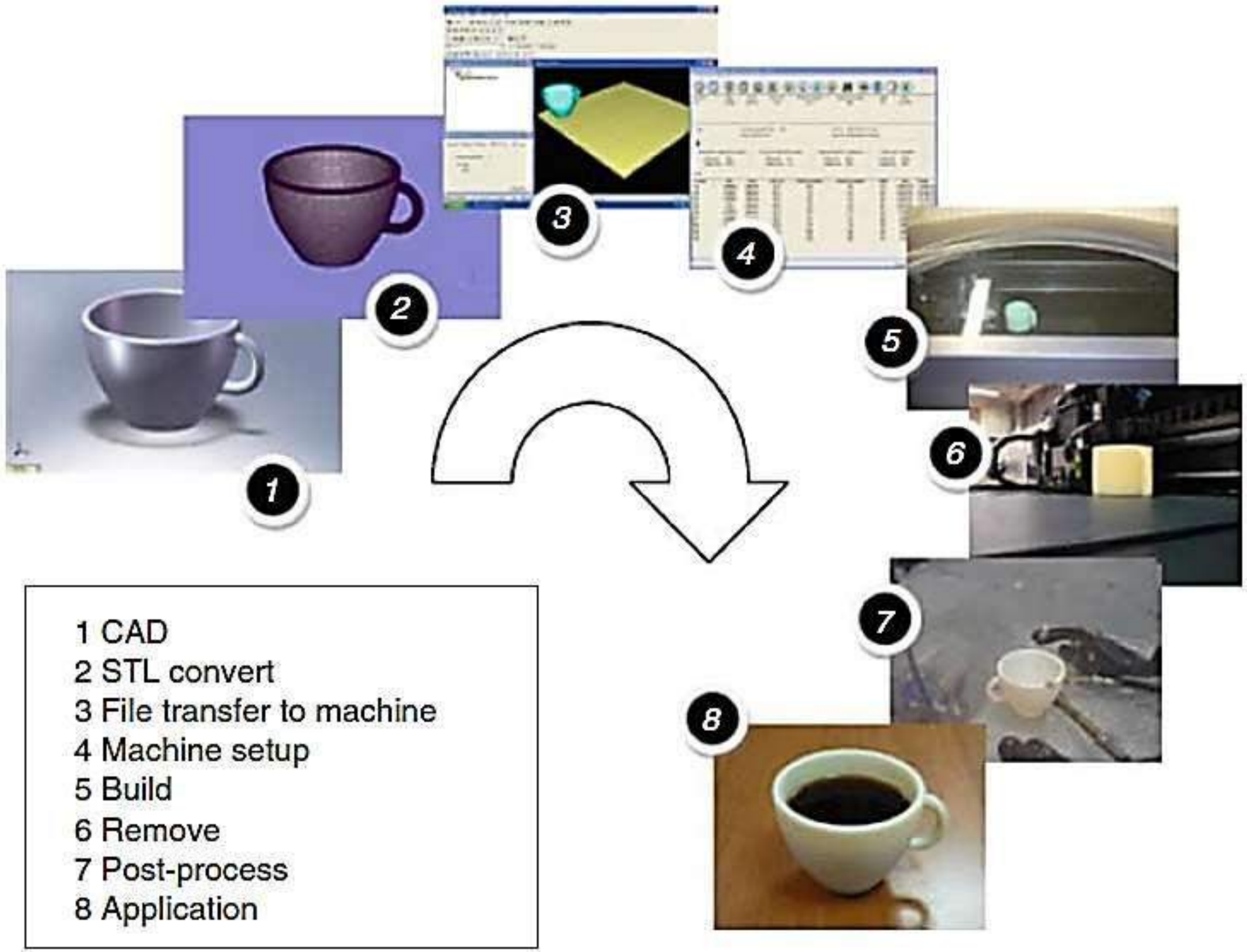
Material choice: Non weldable metals cannot be processed by additive manufacturingand difficult-to-weld alloys require specific approaches.

Material properties: Parts made by additive manufacturing tend to show anisotropy inthe Z axis (construction direction).

- The densities of 99.9% can be reached, there can be some residual internalporosities.
- Mechanical properties are usually superior to cast parts but in general inferior to wrought parts.

Introduction

Additive Manufacturing Process chain



Introduction

Additive Manufacturing Process chain

The Eight Steps in Additive Manufacture

1. Conceptualization and CAD
2. Conversion to STL
3. Transfer and manipulation of STL file on AM machine
4. Machine setup
5. Build
6. Part removal and clean-up
7. Post-processing of part
8. Application

Introduction

Additive Manufacturing Process chain

The Eight Steps in Additive Manufacture

Step 1: Conceptualization and CAD

- The generic AM process start with 3D CAD information.
- There may be a many of ways as to how the 3D source data can be created.
- The model description could be generated by a computer.
- Most 3D CAD systems are solid modeling systems with some surface modelingcomponents.

Introduction

Additive Manufacturing Process chain

The Eight Steps in Additive Manufacture

Step 2: Conversion to STL

- The term STL was derived from STereoLithograhy.
- STL is a simple way of describing a CAD model in terms of its geometry alone.
- It works by removing any construction data, modeling history, etc., and approximating the surfaces of the model with a series of triangular facets.
- 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.

Introduction

Additive Manufacturing Process chain

The Eight Steps in Additive Manufacture

Step 2: Conversion to STL

- The process of converting to STL is automatic within most CAD systems.
- STL file repair software is used when there are problems with the file generated by

  the CAD system that may prevent the part from being built correctly.
- With complex geometries, it may be difficult to detect such problems whileinspecting the CAD or the subsequently generated STL data.
- If the errors are small then they may even go unnoticed until after the part hasbeen built.

Introduction

Additive Manufacturing Process chain

The Eight Steps in Additive Manufacture

Step 2: Conversion to STL

- STL is essentially a surface description, the corresponding triangles in the files must be pointing in the correct direction; (in other words, the surface normal vector associated with the triangle must indicate which side of the triangle is outside vs. inside the part).

- While most errors can be detected and rectified automatically, there may also be a requirement for manual intervention.

Introduction

Additive Manufacturing Process chain

The Eight Steps in Additive Manufacture

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 AMmachine.
- Ideally, it should be possible to press a “print” button and the machine should build
- the part straight away.
- However there may be a number of actions required prior to building the part.
- The first task would be to verify that the part is correct.
- AM system software normally has a visualization tool that allows the user to view

  and manipulate the part.

Introduction

Additive Manufacturing Process chain

The Eight Steps in Additive Manufacture

Step 3: Transfer to AM Machine and STL File Manipulation

- The user may wish to reposition the part or even change the orientation to allow itto 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) orcompletely different STL files.

Introduction

Additive Manufacturing Process chain

The Eight Steps in Additive Manufacture

Step 4: Machine Setup

- 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 perhaps one or two different materials and with no variation in layer thickness or other build parameters.
- In the more complex cases to have default settings or save files from previously defined setups to help speed up the machine setup process and to prevent mistakes.
- Normally, an incorrect setup procedure will still result in a part being built.

Introduction

Additive Manufacturing Process chain

The Eight Steps in Additive Manufacture

Step 5: Build Setup

- The first few stages of the AM process are semi-automated tasks that mayrequire considerable manual control, interaction, and decision making.
- Once these steps are completed, the process switches to the computer-controlled building phase.
- All AM machines will have a similar sequence of layer control, using a height

  adjustable platform, material deposition, and layer cross-section formation.

- All machines will repeat the process until either the build is complete or there isno source material remaining.

Introduction

Additive Manufacturing Process chain

The Eight Steps in Additive Manufacture

Step 6: Removal and Cleanup

- The output from the AM machine should be ready for use.
- More often the parts still require a significant amount of manual finishing before they are ready for use.
- The part must be either separated from a build platform on which the part wasproduced or removed from excess build material surrounding the part.
- Some AM processes use additional material other than that used to make thepart itself (secondary support materials).

Introduction

Additive Manufacturing Process chain

The Eight Steps in Additive Manufacture

Step 7: Post Process

- Post-processing refers to the (usually manual) stages of finishing the parts forapplication purposes.
- This may involve abrasive finishing, like polishing and sandpapering, or application of coatings.

Introduction

Additive Manufacturing Process chain

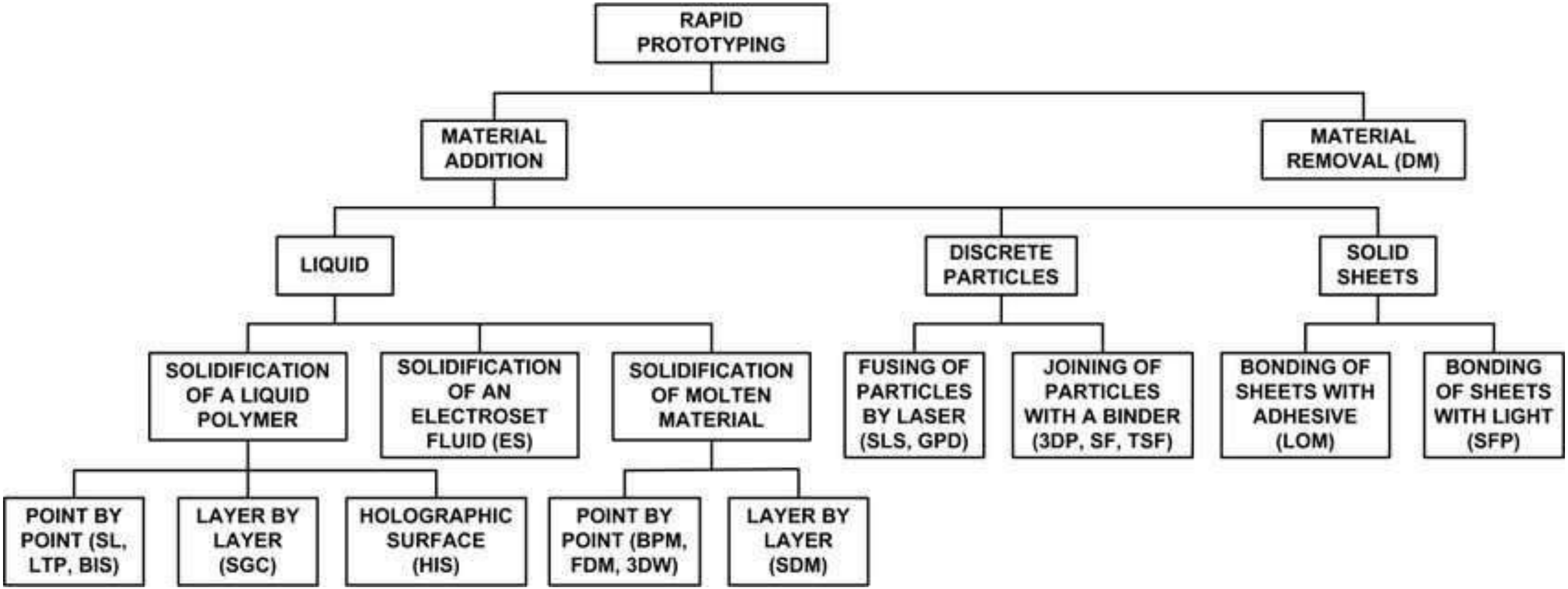
The Eight Steps in Additive Manufacture

Step 8: Application

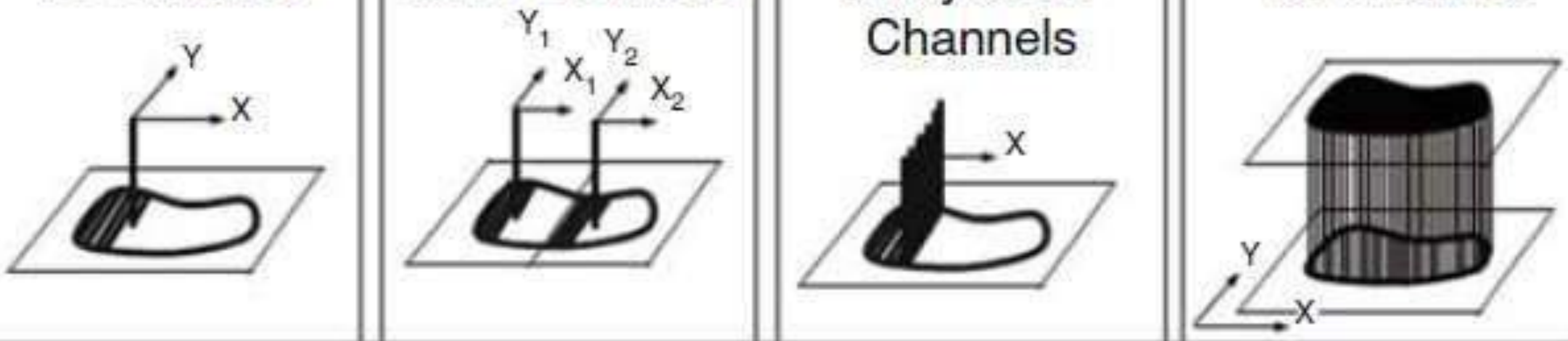
- Following post-processing, parts are ready for use.
- Although parts may be made from similar materials to those available from other manufacturing processes (like molding and casting), parts may not behave according to standard material specifications.
- Some AM processes create parts with small voids or bubbles trapped inside them, which could be the source for part failure under mechanical stress.
- Some processes may cause the material to degrade during build or for materials not to bond, link, or crystallize in an optimum way.

Classification of AM processes

Classification of AM processes



Classification of AM processes



	1D Channel	2x1D Channels	Array of 1D Channels	2D Channel
Liquid Polymer	SLA (3D Sys)	Dual beam SLA (3D Sys)	Objet	Envisiontech MicroTEC
Discrete Particles	SLS (3D Sys), LST (EOS), LENS Phenix, SDM	LST (EOS)	3D Printing	DPS
Molten Mat.	FDM, Solidscape		ThermoJet	
Solid Sheets	Solido PLT (KIRA)			

Layered Manufacturing (LM) processes as classified by Pham

Classification of AM processes

- Liquid polymer system
- Discrete particle system
- Molten material systems
- Solid sheet system

Classification of AM processes

Liquid polymer system

- Liquid-based RP systems have the initial form of its material in liquid state.
- The liquid is converted into the solid state.
- The first commercial system was the 3D Systems Stereolithography processbased on liquid photopolymers.

Classification of AM processes

Liquid polymer system

- The following RP systems fall into this category:
- 3D Systems' Stereolithographic Apparatus (SLA)
- Cubital's Solid Ground Curing (SGC)
- Sony's Solid Creation System (SCS)
- CMET's Solid Object Ultraviolet-Laser Printer (SOUP)
- Autostrade's E-Darts
- Teijin Seiki's Soliform System
- Meiko's Rapid Prototyping System for the Jewelery Industry
- Aaroflex
- Rapid Freeze
- Two Laser Beams
- Microfabrication
- Fockele & Schwarze's LMS
- Light Sculpting
- Denken's SLP
- Mitsui's COLAMM

Classification of AM processes

Discrete Particle Systems

- Discrete particles are normally powders that are graded into a uniform size andshape and narrow distribution.
- The finer the particles the better, but there will be problems if the dimensions get

  too small in terms of controlling the distribution and dispersion.
- The conventional 1D channel approach uses a laser to produce thermal energy ina controlled manner to raise the temperature sufficiently to melt the powder.
- Polymer powders must therefore exhibit thermoplastic behavior so that they canbe melted and re-melted to permit bonding of one layer to another.

Classification of AM processes

Discrete Particle Systems

The two main polymer-based systems commercially available are the;

- Selective Laser Sintering (SLS) technology marketed by 3D Systems.
- The EOSint processes developed by the German company EOS.

Classification of AM processes

Discrete Particle Systems

Powder is by-and-large in the solid state. The following RP systems fall into thisdefinition:

- 3D Systems's Selective Laser Sintering (SLS)
- EOS's EOSINT Systems
- Z Corporation's Three-Dimensional Printing (3DP)
- Optomec's Laser Engineered Net Shaping (LENS)
- Soligen's Direct Shell Production Casting (DSPC)
- Fraunhofer's Multiphase Jet Solidification (MJS)
- Acram's Electron Beam Melting (EBM)
- Aeromet Corporation's Lasform Technology
- Precision Optical Manufacturing's Direct

  Metal Deposition (DMDTM)
- Generis' RP Systems (GS)
- Therics Inc.'s Theriform Technology
- Extrude Hone's PrometalTM 3D PrintingProcess

Classification of AM processes

Molten Material Systems

- Molten material systems are characterized by a pre-heating chamber that raises the material temperature to melting point so that it can flow through a delivery system.
- The most well-known method is the Fused Deposition Modeling system (FDM) developed by the US company Stratasys.
- This approach uses an extrusion technique to deliver the material through a nozzle in a controlled manner.
- Two extrusion heads are often used so that support structures can be fabricated from a different material to facilitate part cleanup and removal.

Classification of AM processes

Molten Material Systems

- The 1D channel approach is very slow in comparison with other methods.
- The Thermojet from 3D Systems also deposits a wax material through dropletbased printing heads.
- The Thermojet approach, however, is not widely used because wax materials aredifficult and fragile when handled.
- Thermojet machines are no longer being made, although existing machines are

  commonly used for investment casting patterns.

Classification of AM processes

Solid Sheet Systems

- One of the earliest AM technologies was the Laminated Object Manufacturing(LOM) system from Helisys, USA.
- This technology used a laser to cut out profiles from sheet paper, supplied from a continuous roll, which formed the layers of the final part.
- Layers were bonded together using a heat-activated resin that was coated on onesurface of the paper.
- Once all the layers were bonded together the result was very like a wooden block.
- A hatch pattern cut into the excess material allowed the user to separate awaywaste material and reveal the part.

Classification of AM processes

Solid Sheet Systems

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:

- Cubic Technologies' Laminated Object Manufacturing (LOM)
- Stratasys' Fused Deposition Modeling (FDM)
- Kira Corporation's Paper Lamination Technology (PLT)
- 3D Systems' Multi-Jet Modeling System (MJM)
- Solidscape's ModelMaker and PatternMaster
- Beijing Yinhua's Slicing Solid Manufacturing (SSM), Melted
- Extrusion Modeling (MEM) and Multi-Functional RPM Systems
- (M-RPM)
- CAM-LEM's CL 100
- Ennex Corporation's Offset Fabbers

Liquid polymer system

Liquid polymer system

Stereolithography Apparatus (SLA) Process

- 3D Systems was founded in 1986 by inventor Charles W. Hull and entrepreneurRaymond S. Freed and its first commercial system marketed in 1988.
- It has been awarded more than 40 United States patents and 20 internationalpatents, with additional patents filed or pending internationally.

Liquid polymer system

Stereolithography Apparatus (SLA) Process

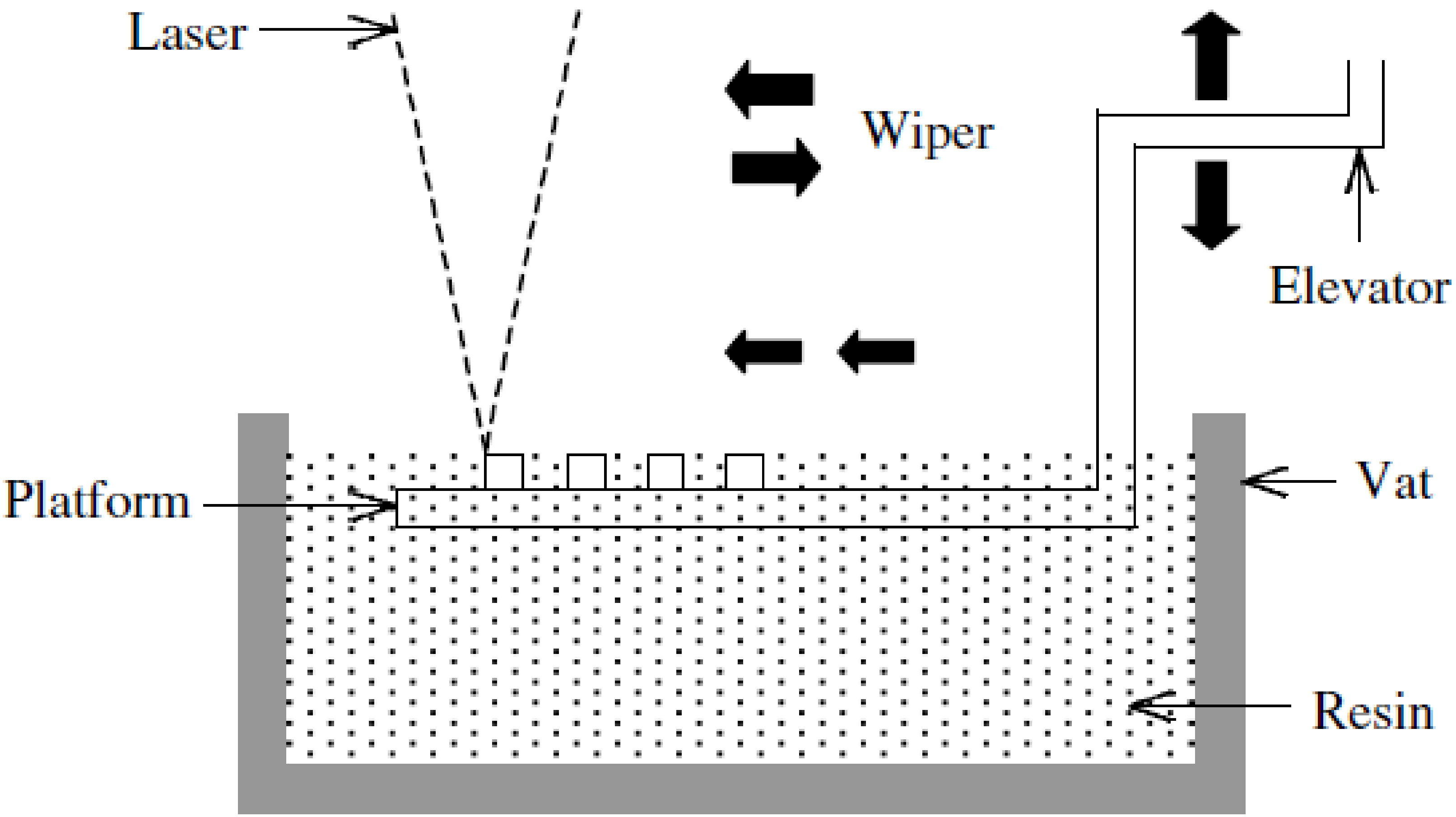
Principle

The SLA process is based on the following principles

- Parts are built from a photo-curable liquid resin that cures when exposed to a laser beam (photopolymerization process) which scans across the surface of the resin.
- The building is done layer by layer, each layer being scanned by the opticalscanning system and controlled by an elevation mechanism which lowers at the completion of each layer.

Liquid polymer system

Stereolithography Apparatus (SLA) Process



Liquid polymer system

Stereolithography Apparatus (SLA) Process

Schematic of SLA process

Liquid polymer system

Stereolithography Apparatus (SLA) Process

- Stereolithography process creates 3D plastic objects directly from CAD data.
- The process begins with the vat filled with the photo-curable liquid resin and the elevatortable set just below the surface of the liquid resin.
- 3D CAD solid model file is loaded into the system by the operator.
- Supports are designed to stabilize the part during building.
- The translator converts the CAD data into a STL file.
- The control unit slices the model and support into a series of cross sections from 0.025to 0.5 mm thick.

Liquid polymer system

Stereolithography Apparatus (SLA) Process

- The optical scanning system directs and focuses the laser beam to solidify a 2D cross-section corresponding to the slice on the surface of the photo-curable liquid resin.
- The elevator table drops enough to cover the solid polymer with another layer of theliquid resin.
- A levelling wiper or vacuum blade moves across the surfaces to recoat the next layer ofresin on the surface.
- The laser then draws the next layer.
- The process continues building the part from bottom up, until the system completes thepart.
- The part is then raised out of the vat and cleaned of excess polymer.

Liquid polymer system

Stereolithography Apparatus (SLA) Process

Applications

- Models for conceptualization, packaging and presentation.
- Prototypes for design, analysis, verification and functional testing.
- Parts for prototype tooling and low volume production tooling.
- Patterns for investment casting, sand casting and molding.
- Tools for fixture and tooling design, and production tooling.

Liquid polymer system

CUBITAL'S SOLID GROUND CURING (SGC)

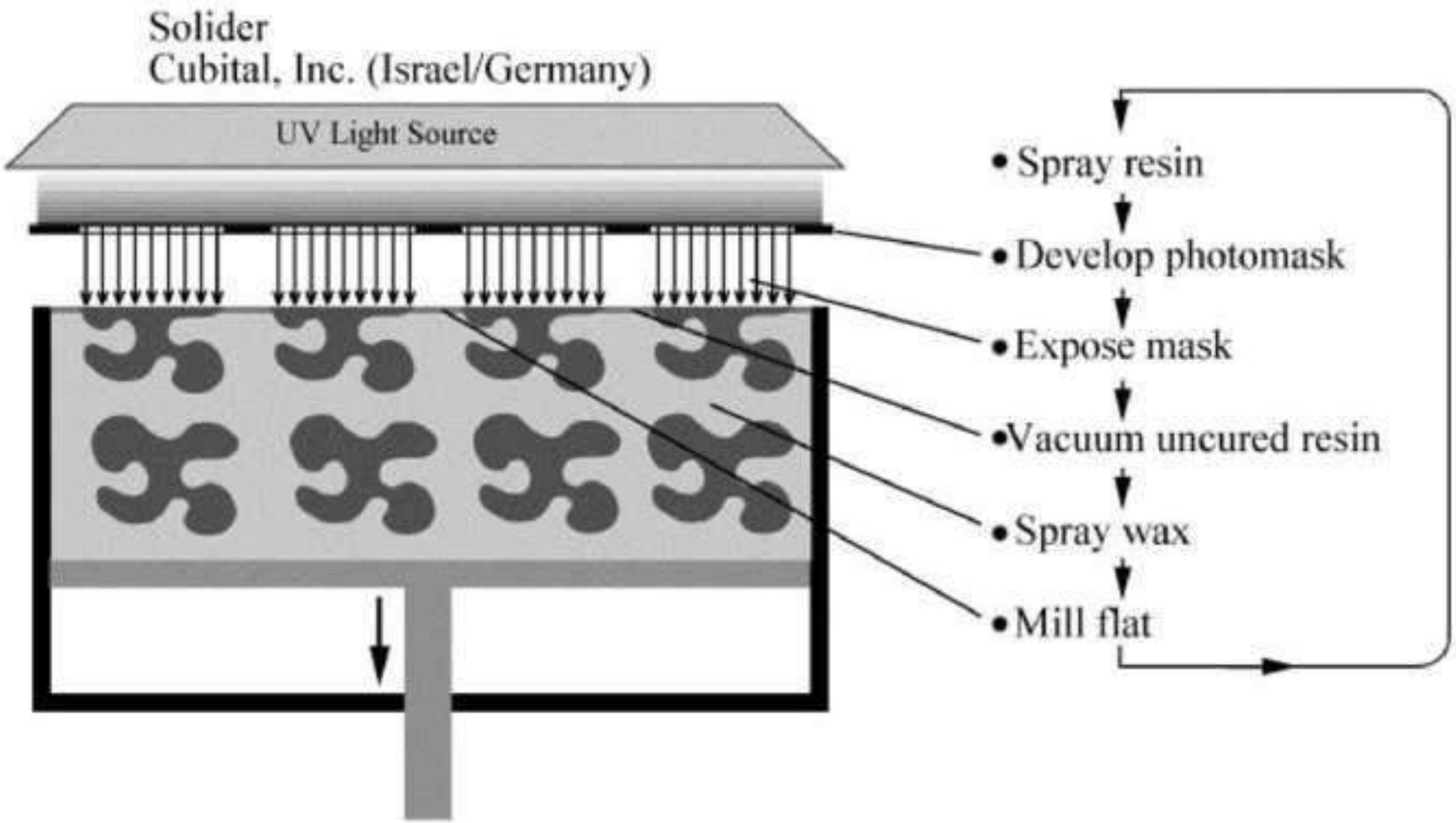
Principle

- Parts are built, layer by layer, from a liquid photopolymer resin that solidifies when exposed to UV light.
- Multiple parts may be processed and built in parallel by grouping them into batches (runs) using Cubital's proprietary software.
- Each layer of a multiple layer run contains cross-sectional slices of one or many parts.
- The process is self-supporting and does not require the addition of externalsupport structures to emerging parts since continuous structural support for the parts is provided by the use of wax, acting as a solid support material.

Liquid polymer system

CUBITAL'S SOLID GROUND CURING (SGC)

Principle



Liquid polymer system

CUBITAL’S SOLID GROUND CURING (SGC)

The Solid Ground Curing (SGC) System is produced by Cubital Ltd.

Process

The Cubital’s Solid Ground Curing process includes three main steps:

- Data preparation
- Mask generation
- Model making

Liquid polymer system

CUBITAL’S SOLID GROUND CURING (SGC)

Data Preparation

- The CAD model of the job to be prototyped is prepared and the cross-sections aregenerated digitally and transferred to the mask generator.

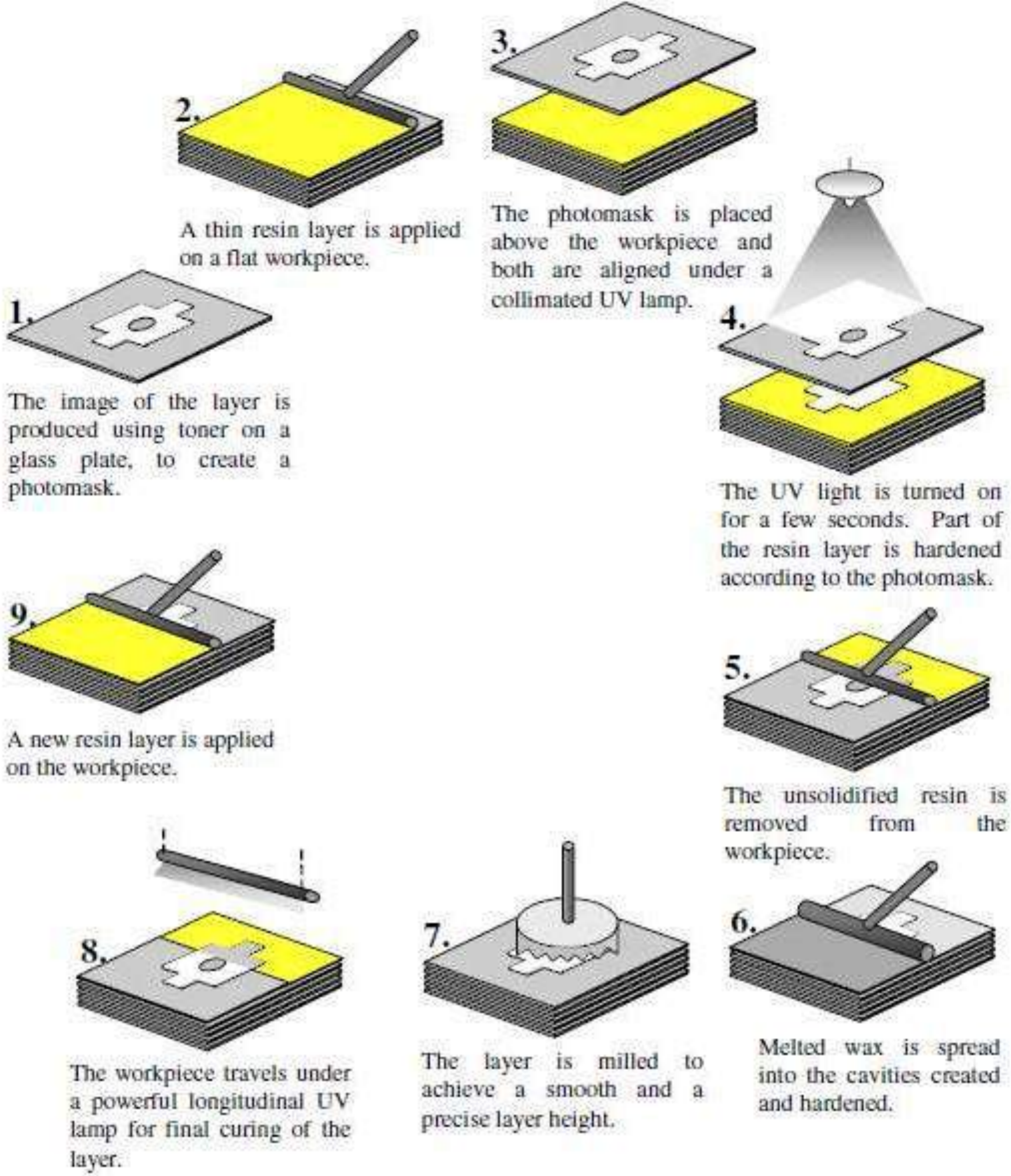
- Cubital’s Solider DFE (Data Front End) software, is a motif-based special-purposeCAD application package that processes solid model.
- DFE can search and correct flaws in the CAD files and render files on-screen forvisualization purposes.

- Solider DFE accepts CAD files in the STL format and other widely used formats.

Liquid polymer system

CUBITAL'S SOLID GROUND CURING (SGC)

Mask Generation



CUBITAL'S SOLID GROUND CURING (SGC)

Model Making

- A thin layer of photopolymer resin is spread on the work surface (2).
- The photo mask from the mask generator is placed in close proximity above the workpiece, andaligned under a collimated UV lamp (3).
- The UV light is turned on for a few seconds (4).
- The part of the resin layer which is exposed to the UV light through the photo mask is hardened, theunsolidified resin is then collected from the workpiece (5).
- The melted wax is spread into the cavities created after collecting the liquid resin (6).
- The wax in the cavities is cooled to produce a solid layer.
- The layer is milled to exact thickness, producing a flat solid surface ready to receive the next layer (7).
- SGC 5600, an additional step (8) is provided for final curing of the layer whereby the workpiece travelsunder a powerful longitudinal UV lamp.
- The cycle repeats itself until the final layer is completed.

Liquid polymer system

CUBITAL'S SOLID GROUND CURING (SGC)

Applications

General applications: Conceptual design presentation, design proofing, engineering testing, functional analysis, exhibitions and pre-production sales, market research.

Tooling and casting applications: Investment casting, sand casting, and rapid, tool-free

manufacturing

Mold and tooling: Silicon rubber tooling, epoxy tooling, spray metal tooling, acrylic tooling,and plaster mold casting.

Medical imaging: Diagnostic, surgical, operation and reconstruction planning and customprosthesis design.

Liquid polymer system

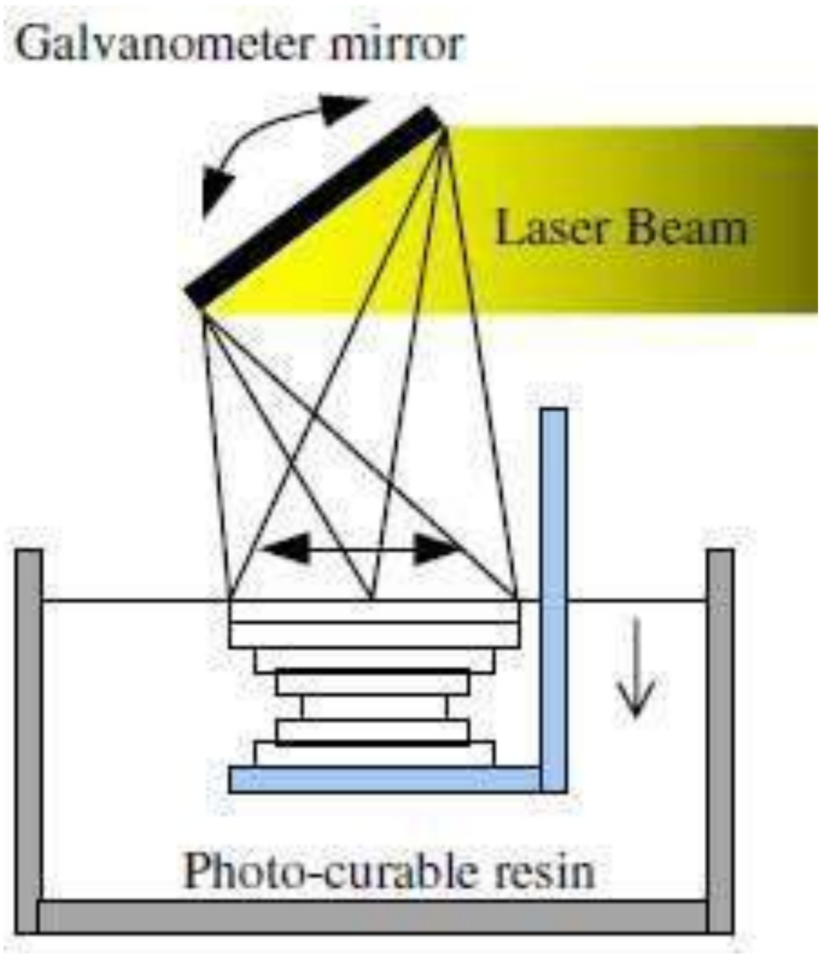
SOLID OBJECT ULTRAVIOLET-LASER PRINTER

Principle

- The SOUP system is based on the laser lithography technology.
- The SOUP system has the option for *XY* plotter, which is easier to control and hasless optic problems than the galvanometer mirror system.
- The main trade-off is in scanning speed and the building speed.
- Parameters which influence performance and functionality are galvanometer mirror precision for the galvanometer mirror machine, laser spot diameter, slicing thickness and resin properties.

Liquid polymer system

SOLID OBJECT ULTRAVIOLET-LASER PRINTER



Schematic of SOUP® system (Adapted from CMET brochure)

Liquid polymer system

SOLID OBJECT ULTRAVIOLET-LASER PRINTER

Process

The SOUP process contains the following three main steps:

1. Creating a 3D model with a CAD system: The 3D model of the part is created with a commercial CAD system.
2. Processing the data with the SOUPware: Using SOUPware, can edit CAD data, repair its defects, like gaps, overlaps, etc., slice the model into cross-sections and finally, SOUPware generates theSOUP machine data.
3. Making the model with the SOUP units: The laser scans the resin, solidifying it according to the cross-sectional data from SOUPware. The elevator lowers and the liquid covers the top layer of the part which is recoated and prepared for the next layer.
4. This is repeated until the whole part is created.

Liquid polymer system

SOLID OBJECT ULTRAVIOLET-LASER PRINTER

Applications

- Concept models
- Working models for form fitting and simple functional tests.
- Master models and patterns for silicon molding, lostwax, investment casting,and sand casting.
- Medical purposes: Creating close to exact physical models of a patient'sanatomy from CT and MRI scans.

Solid Sheet Systems

CUBIC TECHNOLOGIES' LAMINATED OBJECT MANUFACTURING (LOM)

Principle

- Parts are built, layer-by-layer, by laminating each layer of paper or other sheet-formmaterials and the contour of the part on that layer is cut by a CO_2 laser.
- Each layer of the building process contains the cross-sections of one or many parts.
- The next layer is then laminated and built directly on top of the laser-cut layer.
- The *Z*-control is activated by an elevation platform, which lowers when each layer iscompleted, and the next layer is then laminated and ready for cutting.
- No additional support structures are necessary as the **"excess"** material, which arecross-hatched for later removal, act as the support.

Solid Sheet Systems

CUBIC TECHNOLOGIES' LAMINATED OBJECT MANUFACTURING (LOM)

Process

The process consists of three phases:

- Pre-processing
- Building
- Post-processing

Solid Sheet Systems

CUBIC TECHNOLOGIES' LAMINATED OBJECT MANUFACTURING (LOM)

Process

Pre-processing

- Generating an image from a CAD-derived STL file of the part to be manufactured,sorting input data, and creating secondary data structures.
- The LOM system software, calculates and controls the slicing functions.
- Orienting and merging the part on the LOM system are done manually.
- LOMSlice, provides a menu-driven interface to perform transformations (e.g., translation, scaling, and mirroring) as well as merges.

Solid Sheet Systems

CUBIC TECHNOLOGIES' LAMINATED OBJECT MANUFACTURING (LOM)

Process

Building

(1) LOMSlice creates a cross-section of the 3D model measuring the exact height of the model andslices the horizontal plane accordingly.

(2) The software then images crosshatches which define the outer perimeter and convert these excess materials into a support structure.

(3) The computer generates precise calculations, which guide the focused laser beam to cut thecross-sectional outline, the crosshatches, and the model's perimeter.

(4) The laser beam cuts the thickness of one layer of material at a time.

Solid Sheet Systems

CUBIC TECHNOLOGIES' LAMINATED OBJECT MANUFACTURING (LOM)

Process

Building

(5) After the perimeter is burned, the model's boundary is "freed" from the remaining sheet.

(6) The platform with the stack of previously formed layers descends and a new section of material advances.

(7) The platform ascends and the heated roller laminates the material to the stack with a singlereciprocal motion, thereby bonding it to the previous layer.

(8) The vertical encoder measures the height of the stack and relays the new height to LOMSlice.

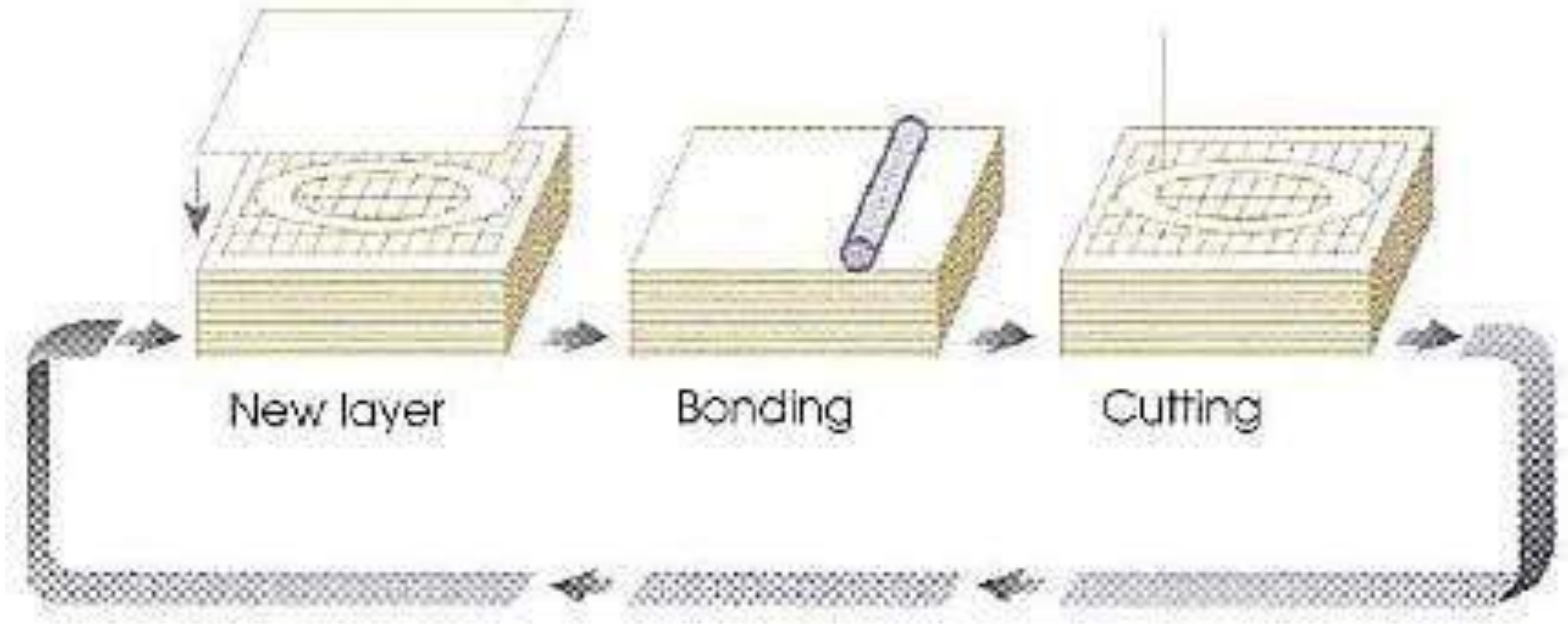
This sequence continues until all the layers are built.

Solid Sheet Systems

CUBIC TECHNOLOGIES' LAMINATED OBJECT MANUFACTURING (LOM)

Process

Building



LOM building process (Courtesy Cubic Technologies Inc.)

Solid Sheet Systems

CUBIC TECHNOLOGIES' LAMINATED OBJECT MANUFACTURING (LOM)

Process

Post-processing

Post-processing, includes separating the part from its support material and finishing it. Theseparation sequence is as follows;

- The metal platform, home to the newly created part, is removed from the LOM machine.
- A hammer and a putty knife are all that is required to separate the LOM block from the platform.
- The surrounding wall frame is lifted off the block to expose the crosshatched pieces of the excessmaterial.
- Crosshatched pieces may then be separated from the part using wood carving tools

Solid Sheet Systems

CUBIC TECHNOLOGIES' LAMINATED OBJECT MANUFACTURING (LOM)

Post-processing


(a)


(b)


(c)


(d)

(a) The laminated stack is removed from the machine's elevator plate.
(b) The surrounding wall is lifted off the object to expose cubes of excess material.
(c) Cubes are easily separated from the object's surface.
(d) The object's surface can then be sanded, polished or painted, as desired.

Solid Sheet Systems

CUBIC TECHNOLOGIES' LAMINATED OBJECT MANUFACTURING (LOM)

Applications

- Visualization
- Form, fit and function: LOM parts lend themselves well for design verification andperformance evaluation
- Manufacturing
- Rapid tooling

Molten Material Systems

STRATASYS' FUSED DEPOSITION MODELING (FDM)

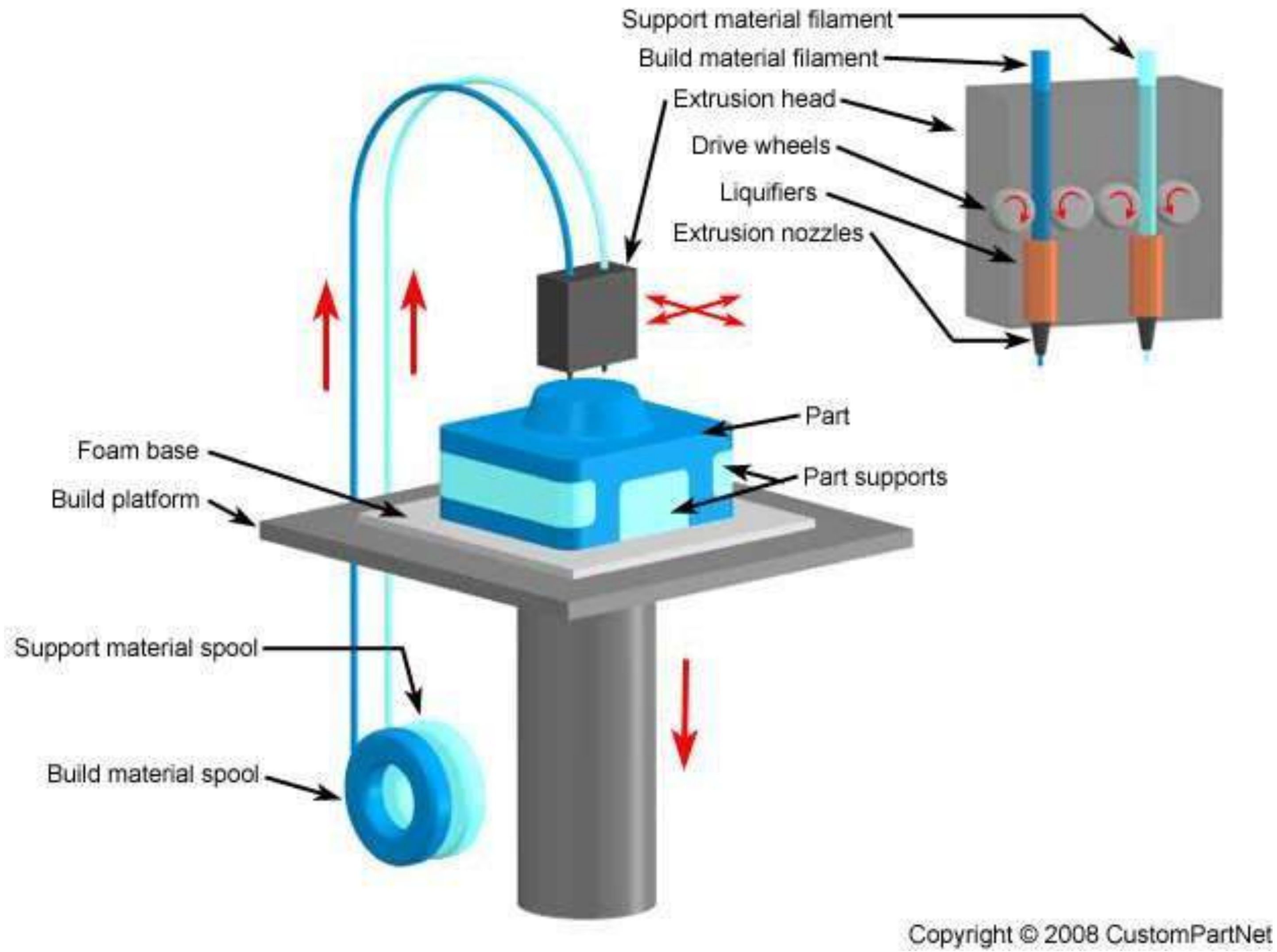
Principle

- The principle of the FDM is based on surface chemistry, thermal energy, and layermanufacturing technology.
- The material in filament (spool) form is melted in a specially designed head, whichextrudes on the model.
- As it is extruded, it is cooled and thus solidifies to form the model.
- The model is built layer by layer, like the other RP systems.

Molten Material Systems

STRATASYS' FUSED DEPOSITION MODELING (FDM)

Process



Molten Material Systems

STRATASYS' FUSED DEPOSITION MODELING (FDM)

Process

- A geometric model of a conceptual design is created on a CAD software which uses IGES or STL formatted files.
- It is then imported into the workstation where it is processed through the QuickSlice and SupportWork propriety software.
- Within this software, the CAD file is sliced into horizontal layers after the part is oriented for the optimum build position, and any necessary support structures are automatically detected and generated.
- The slice thickness can be set manually to anywhere between 0.172 to 0.356 mm depending on the needs of the models. Tool paths of the build process are then generated which are downloaded to the FDM machine.

Molten Material Systems

STRATASYS’ FUSED DEPOSITION MODELING (FDM)

Process

- The modeling material is in spools — very much like a fishing line.
- The filament on the spools is fed into an extrusion head and heated to a semi-liquid state.
- The semi-liquid material is extruded through the head and then deposited in ultra thin layersfrom the FDM head, one layer at a time.
- The air surrounding the head is maintained at a temperature below the materials’ meltingpoint, the exiting material quickly solidifies.
- Moving on the *X*–*Y* plane, the head follows the tool path generated by QuickSlice generatingthe desired layer.

Molten Material Systems

STRATASYS' FUSED DEPOSITION MODELING (FDM)

Process

- When the layer is completed, the head moves on to create the next layer.
- The horizontal width of the extruded material can vary between 0.250 to 0.965 mm dependingon model.
- This feature, called "road width", can vary from slice to slice.
- Two modeler materials are dispensed through a dual tip mechanism in the FDM machine.
- A primary modeler material is used to produce the model geometry and a secondary material,

  or release material, is used to produce the support structures.
- The release material forms a bond with the primary modeler material and can be washedaway upon completion of the 3D models.

Molten Material Systems

STRATASYS' FUSED DEPOSITION MODELING (FDM)

Applications

- Models for conceptualization and presentation
- Prototypes for design, analysis and functional testing
- Patterns and masters for tooling.

Discrete Particle Systems

3D SYSTEMS' SELECTIVE LASER SINTERING (SLS)

Principle

- Parts are built by sintering when a CO_2 laser beam hits a thin layer of powderedmaterial.
- The interaction of the laser beam with the powder raises the temperature to the point of melting, resulting in particle bonding, fusing the particles to themselves and the previous layer to form a solid.
- The building of the part is done layer by layer.
- Each layer of the building process contains the cross-sections of one or many parts.
- The next layer is then built directly on top of the sintered layer after an additional layer of powder is deposited via a roller mechanism on top of the previously formed layer.

Discrete Particle Systems

3D SYSTEMS' SELECTIVE LASER SINTERING (SLS)

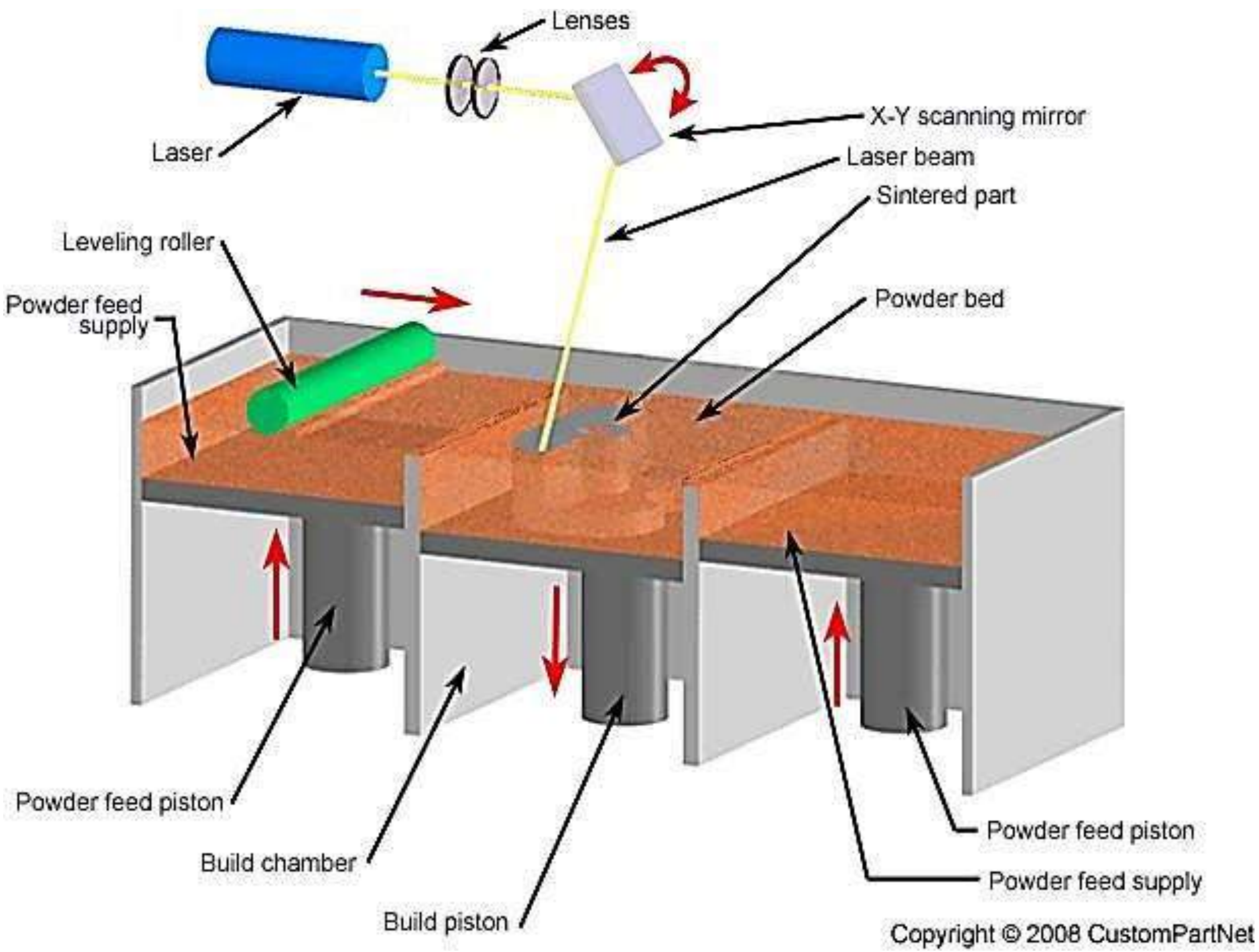
Process

- The SLS process creates three-dimensional objects, layer by layer, from CAD- data generated in a CAD software using powdered materials with heat generated by a CO_2 laser.
- CAD data files in the STL file format are first transferred to the system where they are sliced.
- SLS process starts and operates as follows:

Discrete Particle Systems

3D SYSTEMS' SELECTIVE LASER SINTERING (SLS)

Process



Discrete Particle Systems

3D SYSTEMS’ SELECTIVE LASER SINTERING (SLS)

Process

1. A thin layer of heat-fusible powder is deposited onto the part building chamber.
2. The bottom-most cross-sectional slice of the CAD part under fabrication is selectively "drawn" (or scanned) on the layer of powder by a heat-generating CO_2 laser.
3. The interaction of the laser beam with the powder elevates the temperature to thepoint of melting, fusing the powder particles to form a solid mass.
4. The intensity of the laser beam is modulated to melt the powder only in areas defined by the part’s geometry.
5. Surrounding powder remain loose compact and serve as supports.

Discrete Particle Systems

3D SYSTEMS’ SELECTIVE LASER SINTERING (SLS)

Process

6. When the cross-section is completely drawn, an additional layer of powder isdeposited via a roller mechanism on top of the previously scanned layer.

7. This prepares the next layer for scanning.

8. Steps 2 and 6 are repeated, with each layer fusing to the layer below it.

9. Successive layers of powder are deposited and the process is repeated until the

   part is completed.

AM Applications

AM Applications

- Functional models
- Pattern for investment and vacuum casting
- Medical models
- Art models
- Engineering analysis models
- Rapid tooling
- New materials development
- Bi-metallic parts
- Re-manufacturing.
- Application examples for Aerospace, defence, automobile, Bio-medical andgeneral engineering industries

AM Applications

The Use of AM to Support Medical Applications

A CT (Computerized Tomography) scanner with sliced images and a 3D image created using this technology

AM Applications

The Use of AM to Support Medical Applications

- Surgical and diagnostic aids: Human models
- Prosthetics development
- Manufacturing of medically related products
- Tissue Engineering

3DP used to make a skull with vascular tracks in a darker colour

A bone tumour highlighted using ABS

Objet Connex process showing vascularity inside a human organ

AM Applications

The Use of AM to Support Medical Applications

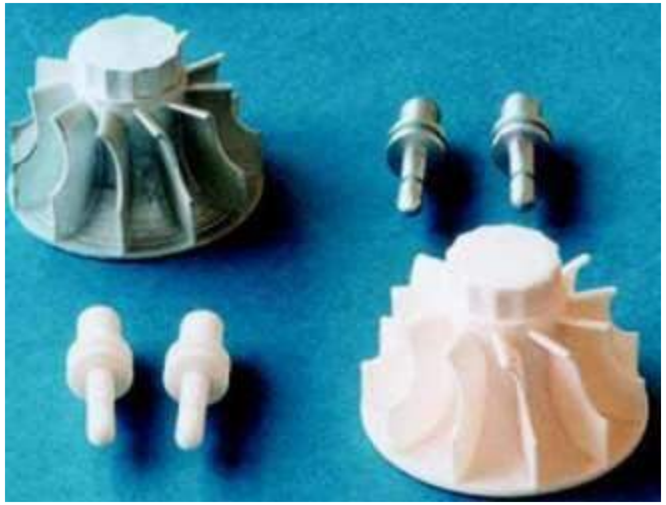
- Surgical and diagnostic aids: Human models
- Prosthetics development
- Manufacturing of medically related products: hearing aids
- Tissue Engineering: The ultimate in fabrication of medical implants would be the directfabrication of replacement body parts

AM Applications

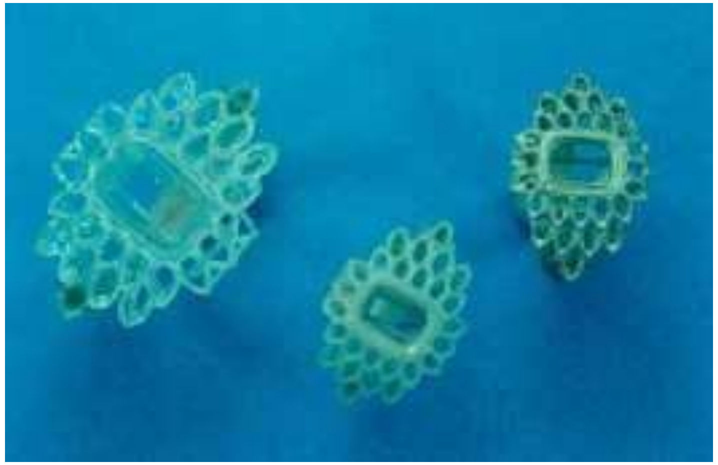
Perfume bottles with different capacity

Cast metal (left) and RP pattern for

sand casting (Courtesy of Helysis Inc.)



Investment casting of fan impeller fromRP pattern



AM Applications

SLA model of a patient's facial details

Polycarbonate investment-casting pattern (right) and the steel air inlethousing (right) for a jet turbine engine (Courtesy DTM Corporation)

End of Module

WHAT IS FMS?

A flexible manufacturing system (FMS) is a highly automated machine cell, consisting of a group of processing workstations (usually CNC machine tools), interconnected by an automated material handling and storage system, and controlled by a distributed computer system. The reason the FMS is called flexible is that it is capable of processing a variety of different part styles simultaneously at the various workstations, and the mix of part styles and quantities of production can be adjusted in response to changing demand patterns. The FMS ismost suited for the mid-variety, mid-volume production range

Need of FMS due to its benefits

A number of benefits can be expected in successful FMS applications. The principal benefits are the following:

Increased machine *utilization.* FMSs achieve a higher average utilization than machines in a conventional batch production machine shop. Reasons for this include:

(1) 24 hr/day operation. (2) Automatic tool changing machine tools. (3) Automatic pallet changing at workstations. (4) Queues of parts at stations, and (5) dynamic scheduling of production that takes into account irregularities from normal operations. It should be possible to approach *80-90%* asset utilization by implementing FMS technology .

Fewer machines required Because of higher machine utilization. Fewer machines are required.

Reduction in factory floor space required*.* Compared with a job shop of equivalent capacity,an fMS generally requires less floor area. Reductions in floor space requirements are estimated to he 40-50%.

Greater responsiveness to change*.* An FMS improves response capability to part design changes. Introduction of new parts, changes in production schedule and product mix. machine breakdowns. and cutting tool failures. Adjustments can be made in the production schedule from one day to the next to respond to rush orders and special customer requests.

Reduced inventory requirements*,* Because different parts are processed together rather than separately in batches. Work-in-process (WIP) is less than in a batch production mode. The inventory of starting and finished parts can be reduced as well. Inventory reductions of 60-80% are estimated.

Lower manufacturing lead times*.* Closely correlated with reduced WIP is the time spent in process by the parts. This means faster customer deliveries

Reduced direct labor *requirements* and *higher labor productivity.* Higher production rates and lower reliance on direct labor translate to greater productivity per labor hour with an FMS than with conventional production methods. Labor savings of 30-.50%, arc estimated

Opportunity for unattended production*.* The high level of automation in an FMS allows it to operate for extended periods of time without human attention. In the most optimistic scenario, parts and tools are loaded into the system at the end of the day shift, and the FMS continues to operate throughout the night so that the finished parts can be unloaded the next morning.

Flexible Manufacturing Systems (FMS) ComponentsFMS COMPONENTS

As indicated in out definition. There are several basic components of an FMS: (1)workstations,

(2) Material handling and storage system,

(3) Computer control system.

In addition, even though an FMS is highly automated, people are required to manage andoperate the system.

1. Workstations

The processing or assembly equipment used in an FMS depends on the type of work accomplished by the system. In a system designed for machining operations, the principle types of processing station are CNC machine tools. Following are the types of workstations typically found in an FMS.

Load/Unload Stations. The load/unload station is the physical interface between the FMS and the rest of the factory. Raw work-parts enter the system at this point, and finished parts exit the system from here. Loading and unloading can be accomplished either manually or by automated handling systems. Manual loading and unloading is prevalent in most FMSs today. The load/unload station should be ergonomically designed to permit convenient and safe movement of work parts. For parts that are too heavy to lift by the operator, mechanized cranes and other handling devices are installed to assist the operator.

The load/unload station should include a data entry unit and monitor for communication between the operator and the computer system. Instructions must be given to the operator regarding which part to load onto the next pallet to adhere to the production schedule. In cases when different pallets are required for different parts, the correct pallet must be supplied to the station. In cases where modular fixturing is used, the correct fixture must be specified. and the required components and tools must be available at the workstation to build it. 'When the part loading procedure has been completed. the handling system must proceed to launch the pallet into the system; however, the handling system must be prevented from moving the pallet while the operator is still working. All of these circumstances require communication between the computer system and the operator at the load/unload station

Machining Stations. The most common applications of FMSs arc machining operations, The workstations used in these systems are therefore predominantly CNC machine tools. Most common is the *CNC machining center* . in particular. the horizontal rnachining center. CNC machining centers possess features that make them compatible with the FMS, including automatic tool changing and tool storage, use of palletized work-parts, CNC, and capacity for distributed numerical control (DNC. Machining centers can be ordered with automatic pallet changers that can be readily interfaced with the FMS part handling system. Machining centers are generally used for non-rotational parts. For rotational parts, *turning centers* are used; and for parts that are mostly rotational hut require multi-tooth rotational cutters (milling and drilling), *mi11·turn centers* can be used.

***Other Processing* Stations**. The FMS concept has been applied to other processing operationsin addition to machining. One such application is sheet metal fabrication processes. The processing workstations consist of press-working operations, such as punching, shearing, and certain bending and forming processes. Also, flexible systems are being developed to automate the forging process. Forging is traditionally a very labor-intensive operation. The workstationsin the system consist principally of a heating furnace, a forging press. and a trimming station.

Assembly. Some FMSs are designed to perform assembly operations. Flexible automated assembly systems are being developed to replace manual labor in the assembly of products typically made in batches. Industrial robots are often used as the automated workstations in these flexible assembly systems. They can be programmed to perform tasks with variations in sequence and motion pattern to accommodate the different product styles assembled in the system. Other examples of flexible assembly workstations are the programmable component placement machines widely used in electronics assembly.

Other Stations and Equipment. Inspection can be incorporated into an FMS, cither by including, an inspection operation at a processing workstation or by including a station specifically designed for inspection. Coordinate measuring machines, special inspection probes that can be used in a machine tool spindle and machine vision are three possible technologiesfor performing inspection on an FMS.

2. Material Handling and Storage System

The second major component of an FMS is its material handling and storage system.

Functions of the Handling System. The material handling and storage system in an FMS performs the fol1owing functions:

Random, independent movement of work-parts between stations. This means that parts must be capable of moving from anyone machine in the system *to* any *other* machine to provide various routing alternatives for the different parts and to make machine substitutions when certain stations are busy.

Handle a variety of work-part configurations. For prismatic parts, this is usually accomplished by using modular pallet fixtures in the handling system. The fixture is located on the top face of the pallet and is designed to accommodate different part configurations by means of common components, quick change features, and other devices that permit a rapid build-up of the fixture for a given part. The base of the pallet is designed for the material handling system. For rotational parts, industrial robots are often used to load and unload the turning machines and to move parts between stations.

Temporary storage. The number of parts in the FMS will typically exceed the number of parts actually being processed at any moment. Thus, each station has a small queue of parts waitingto be processed. which helps to increase machine utilization.

Convenient access for loading and unloading work-parts. The handling system must include locations for load/unload stations.

Compatible with computer control. The handling system must be capable of being controlled directly by the computer system to direct it to the various workstations, load/unload stations, and storage areas

Material Handling Equipment. The types of material handling systems used to transfer parts between stations include a variety of conventional material transport equipment ,inline transfer mechanisms and industrial robots .The material handling function in an FMS is often shared between two systems: (1) a primary handling system and (2) a secondary handling system. The ***prima****ry handling system* establishes the basic layout of the FMS and is responsible for moving work-parts between stations in the system.

The *secondary handling system* consists of transfer devices, automatic pallet changers. and similar mechanisms located at the workstations in the FMS. The function of the secondary handling system is to transfer work from the primary system to the machine tool or other processing station and to position the parts with sufficient accuracy and repeatability to perform the processing or assembly operation. Other purposes served by the secondary handling system include: (1) reorientation of the work-part if necessary to present the surface that is to be processed and (2) buffer storage of parts to minimize work change time and maximize station utilization. In some FMS installations, the positioning and requirements at the individual workstations are satisfied by the primary work handling system. In these cases, the secondary handling system is not included,

FMS Layout Configurations. The material handling system establishes the FMS layout. Most layout configurations found in today's FMSs can he divided into five categories: (1) inline layout, (2) loop lay out, (3) ladder layout. (4) Open field layout, and (5) robot-cantered cell.

In the *inline layout,* the machines and handling system are arranged in a straight line, as illustrated in Figure 1, In its simplest form. The parts progress from one workstation to the nextin a well defined sequence, with work always moving in one direction and no back flow.

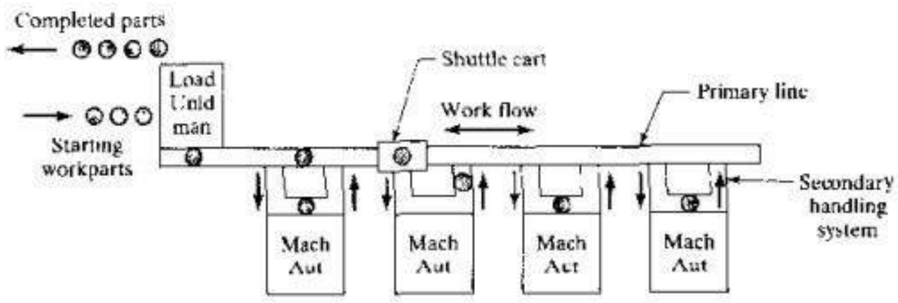


Figure 1

In the *loop layout*, the workstations are organized in a loop that is served by II part handling system in the same shape, as shown in Figure 2. Parts usually flow in one direction around the loop, with the capability to stop and be transferred to any station

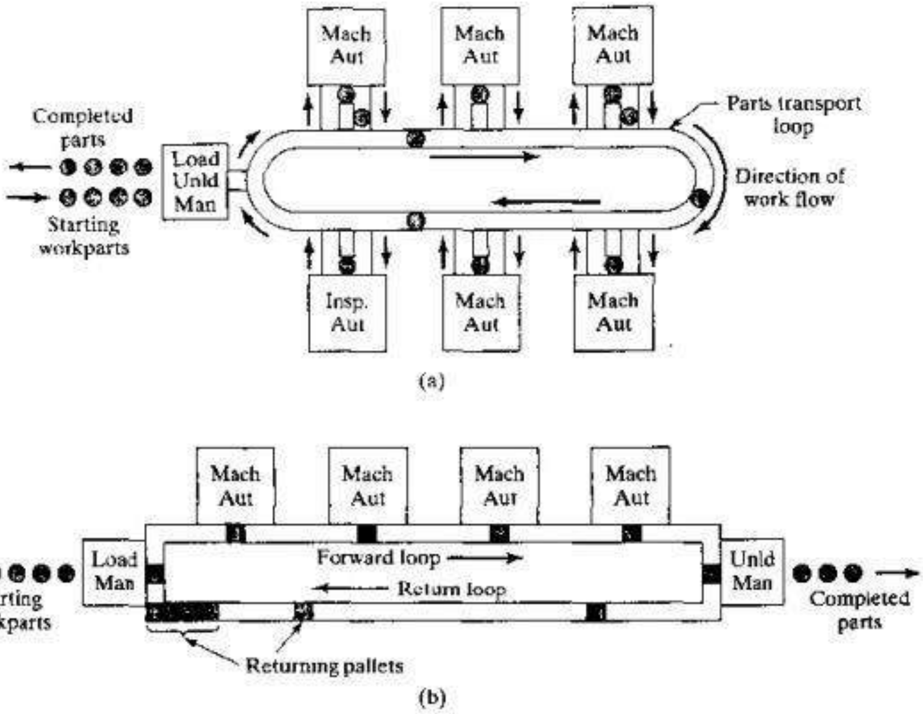
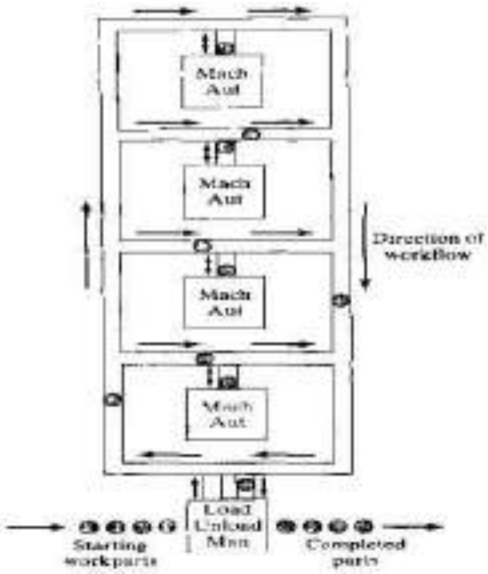


Figure2:Loop Layout



The *ladder layout* consists of a loop with rungs between the straight sections of the loop, on which workstations are located, as shown in Figure.The rungs increase the possible ways of getting from one machine to the next, and obviate the need for a secondary handling system. This reduces average travel distance and minimizes congestion in the handling system, thereby reducing transport time between workstations.

The *open field layout* This layout type is generally appropriate for processing a large family of parts. The number of different machine types may be limited, and parts are routed to different workstations depending on which one becomes available first.

The *robot-centered cell* uses one or more robots as the material handling system. Industrial robots can be equipped with grippers that make them well suited for the handling of rotational parts, and robot centered FMS layouts are often used to process cylindrical or disk shaped parts

3. Computer Control System

The FMS includes a distributed computer system that is interfaced to the workstations, material handling system, and other hardware components. A typical FMS computer system consists ofa central computer and microcomputers controlling the individual machines and other components. The central computer coordinates the activities of the components to achieve smooth overall operation of the system. Functions performed by the FMS computer control system can be grouped into the following categories:

Workstation control. In a fully automated FMS, the individual processing or assembly stations generally operate under some form of computer control. For a machining system, CNC is usedto control the individual machine tools.

Distribution of control instructions to workstations. Some form of central intelligence is also required to coordinate the processing at individual stations. In a machining FMS, part programs must be downloaded to machines, and DNC is used for this purpose, The DNC system stores the programs, allows submission of new programs and editing of existing programs as needed,and performs other DNC functions

Production control. The part mix and rate at which the various parts are launched into the system must be managed. Input data required for production control includes desired daily production rates per part. Numbers of raw work-parts available, and number of applicable pallets.' The production control function is accomplished by routing an applicable pallet 10 the load/unload area and providing instructions to the operator for loading the desired work-part.

Traffic control. This refers to the management of the primary material handling system that moves work parts between stations. Traffic control is accomplished by actuating switches at branches and merging points. Stopping parts at machine tool transfer locations, and moving pallets to load/unload stations.

Shuttle control. This control function is concerned with the operation and control of the secondary handling system at each workstation. Each shuttle must be coordinated with the primary handling system and synchronized with the operation of the machine tool it serves

Work-piece monitoring. The computer must monitor the status of each cart and/or pallet in the primary and secondary handling systems as well as the status of each of the various workpiece types.

Tool control. In a machining system, cutting tools are required. Tool control is concerned with managing two aspects of the cutting tools:

Tool location. This involves keeping track of the cutting tools at each workstation, If one or mere tools required to process a particular workpiece is not present at the station that is specified in the part's routing, the tool control subsystem takes one or both of the following actions: (a) determines whether an alternative workstation that has the required tool is available and/or (b) notifies the opera tor responsible for tooling in the system that the tool storage unit at the station must be loaded with the required cutter(s).

Tool life monitoring. 1.nthis aspect of tool control, a tool life isspecif.ied to the computer for each cutting tool in the FMS. A record of the machining time usage maintained for each of the tools, and when the cumulative machining time reaches the specified life of the tool, the operator is notified that a tool replacement is needed.

Performance monitoring and reporting. The computer control system is programmed to collect data on the operation and performance of the FMS. This data is periodically summarized, and reports are prepared for management on system performance.

Diagnostics. This function is available to a greater or lesser degree on many manufacturing systems to indicate the probable source of the problem when a malfunction occurs. It can alsobe used to plan preventive maintenance in the system and to identify Impending failures. The purpose of the diagnostics function is to reduce breakdowns and downtime and increase availability of the system.

The modular structure of the FMS application software for system control is illustrated in Figure 4. It should be noted that an FMS possesses the characteristic architecture or a DNC system. As in other DNC systems. Two-way communication is used. Data and commands an:sent from the central computer to the individual machines and other hardware components, anddata on execution and performance are transmitted from the components hack up to the central computer. In addition, an uplink from the FMS to the corporate host computer is provide

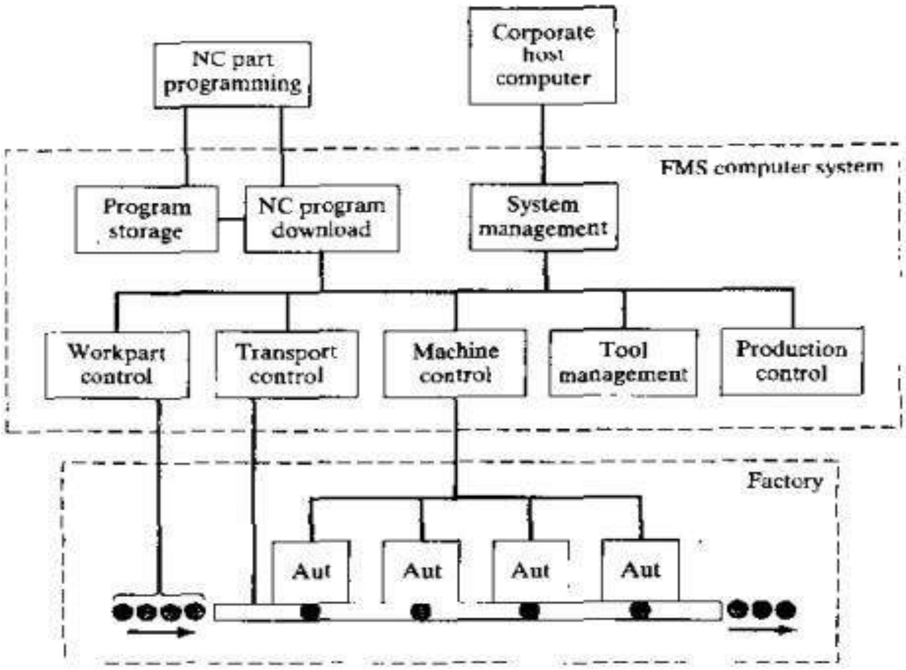


Figure 4 **Structure of FMS application software system. Key:**
NC = numerical control, Aut = automated workstation.

4. Human Resources

One additional component in the FMS is human labor. Humans are needed to manage the operations of the FMS. Functions typically performed by humans include: (1) loading raw workparts into the system, (2) unloading finished parts (or assemblies) from the system. (3) changing and setting tools. (4) equipment maintenance and repair, (5) NC part programming in a machining system, (6) programming and operating the computer system, and (7) overall management of the system

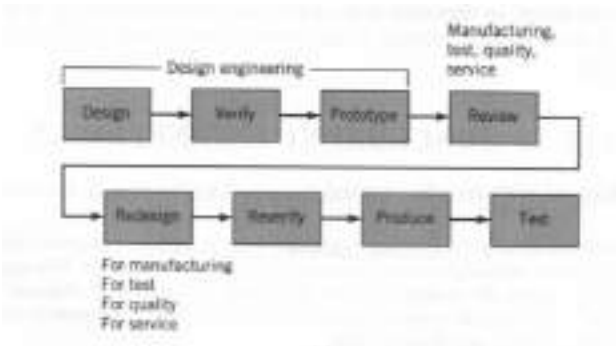
Concurrent Engineering

- Market share and profitability are the major determinants of the success of any organization.
- The factors that influence and improve the competitive edge of a company are unit cost of products, quality, and lead time.
- Concurrent engineering (CE) has emerged as discipline to help achieve the objectives of reduced cost, better quality, and improved delivery performance. CE is perceived as a vehicle for change in the way the products and processes are designed, manufactured, and distributed.
- Concurrent engineering is a management and engineering philosophy for improving quality and reducing costs and lead time from product conception to product development for new products and product modifications.
- CE means that the design and development of the product, the associated manufacturing equipment and processes, and the repair tools and processes are handled concurrently.
- The concurrent engineering idea contrasts sharply with current industry sequential practices, where the product is first designed and developed, the manufacturing approach is then established. And finally the approach to repair is determined.

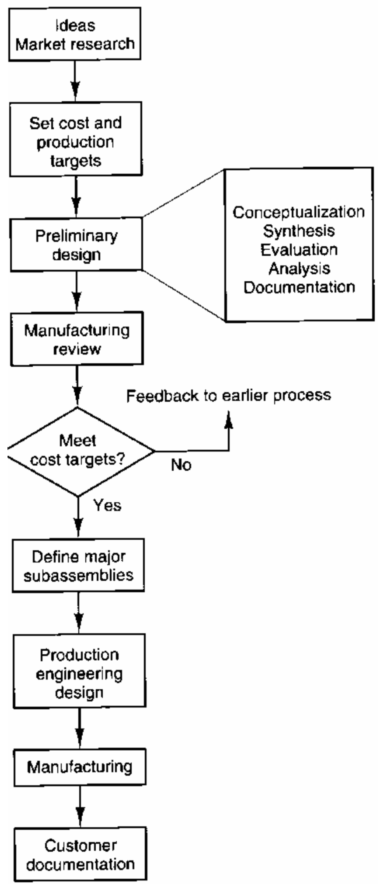
What is concurrent engineering?

Concurrent engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers from the outset, to consider all elements of the product life cycle from conception to disposal, including quality, cost, schedule, and user requirements.

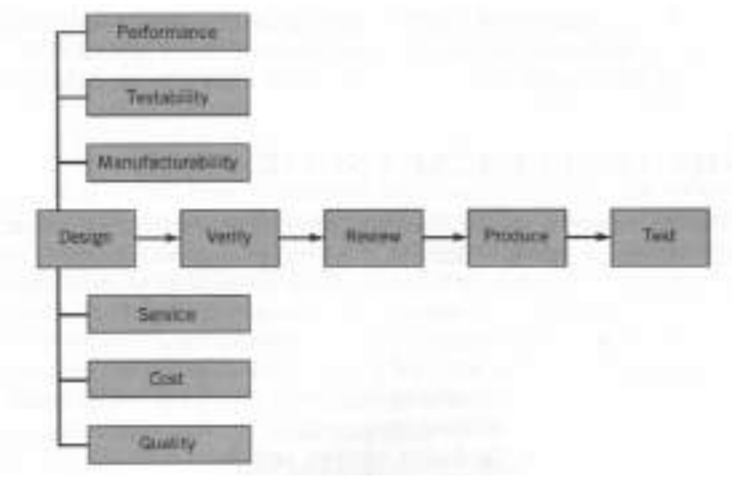
Serial or Sequential Engineering

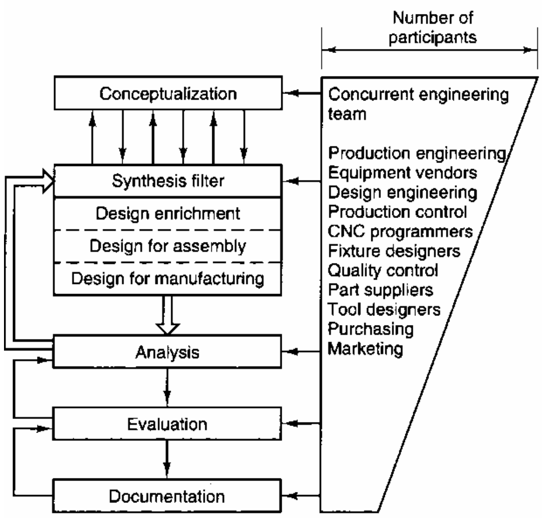


Traditional product development process



Concurrent Engineering **New model for product design**

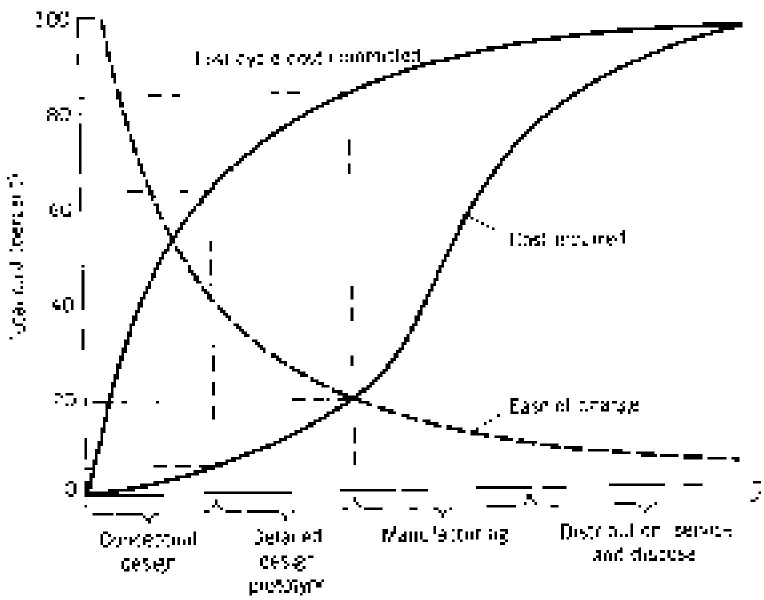




Why concurrent engineering?

- Increasing product variety and technical complexity that prolong the product development process and make it more difficult to predict the impact of design decisions on the functionality and performance of the final product.
- Increasing global competitive pressure that results from the emerging concept of reengineering.
- The need for rapid response to fast-changing consumer demand.
- The need for shorter product life cycle.
- Large organizations with several departments working on developing numerous products at the same time.
- New and innovative technologies emerging at a very high rate, thus causing the new product to be technological obsolete within a short period.

A characteristic curve representing cost incurred and committed during the product life cycle



- Summarized the results of a survey that include the following improvements to specific product lines by the applications of concurrent engineering.
  1. Development and production lead times
  2. Measurable quality improvements

3. Engineering process improvements
4. Cost reduction

1. Development and production lead times

- Product development time reduced up to 60%.
- Production spans reduced 10%.
- AT&T reduced the total process time for the ESS programmed digital switch by 46% in 3 years.
- Deere reduced product development time for construction equipment by60%.
- ITT reduced the design cycle for an electronic countermeasures system by33% and its transition-to-production time by 22%.

2. Measurable quality improvements

- Yield improvements of up to four times.
- Field failure rates reduced up to 83%.
- AT&T achieved a fourfold reduction in variability in a polysilicon deposition process for very large scale integrated circuits and achieved nearly two orders of magnitude reduction in surface defects.
- AT&T reduced defects in the ESS programmed digital switch up to 87% through a coordinated quality improvement program that included product and process design.
- Deere reduced the number of inspectors by two-thirds through emphasis on process control and linking the design and manufacturing processes.

3. Engineering process improvements

- Engineering changes per drawing reduced up to 15 times
- Early production engineering changes reduced by 15%.
- Inventory items stocked reduced up to 60%.
- Engineering prototype builds reduced up to three times.
- Scrap and rework reduced up to 87%.

4. Cost reduction

- McDonnell Douglas had a 60% reduction in life-cycle cost and 40% reduction in production cost on a short-range missile proposal.
- Boeing reduced a bid on a mobile missile launcher and realized costs 30 to 40% below the bid.
- IBM reduced direct costs in system assembly by 50%.
- ITT saved 25% in ferrite core bonding production costs

Summary

- The customer is consulted during the early product development process; therefore, the product can meet the expectations of the customer.
- Improved design quality. The lower the number of design changes, the more robust the design of the product is.
- Reduced product development and design times by listing the voice of the customer and the information between various departments involved.
- Reduced product cost - reduction in the number of design changes and reduce cost.
- Elimination of delays

- Reduced design time and effort
- Increasing reliability and customer satisfaction.

Schemes for CE

- CE is the application of a mixture of all following techniques to evaluate the total life-cycle costand quality.
  1. Axiomatic design
  2. Design for manufacturing guidelines
  3. Design science
  4. Design for assembly
  5. The Taguchi method for robust design
  6. Manufacturing process design rules
  7. Computer-aided DFM
  8. Group technology
  9. Failure-mode and effects analysis
  10. Value engineering
  11. Quality function deployment

Examples of design axioms for optimization

- Axioms have the fundamental properties that (1) they cannot proven and (2) they are general truths

1. Minimize the number of functional requirements and constraints
2. Satisfy the functional requirements from most important first to least important last
3. Minimize information content
4. Everything being equal, conserve materials
5. Integrate functional requirements in a single part if they can be independently satisfied in the proposed solution
6. There may be several optimum solution

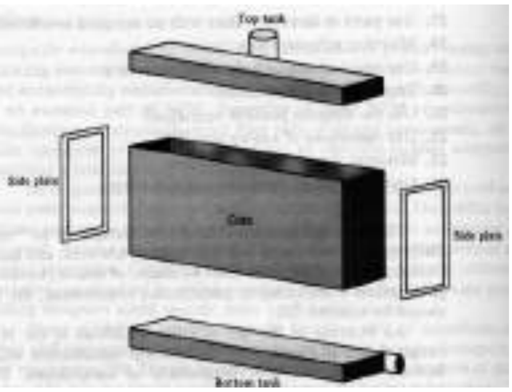
DFM Guidelines

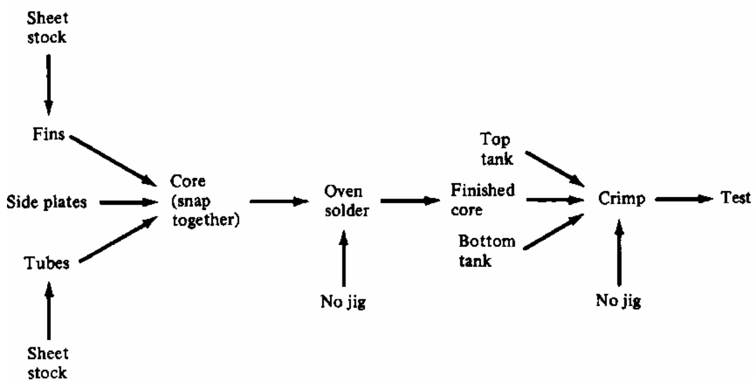
1. Design for a minimum number of parts
2. Develop a modular design
3. Minimize part variations
4. Design parts to be multifunctional
5. Design parts for multiuse
6. Design parts for ease of fabrication
7. Avoid separate fasteners
8. Minimize assembly directions; design for top-down assembly
9. Maximize compliance; design for ease of assembly
10. Minimize handling; design for handling presentation
11. Evaluate assembly methods

12. Eliminate adjustments
13. Avoid flexible components; they are difficult to handle
14. Use parts of known capability
15. Allow for maximum intolerance of parts
16. Use known and proven vendors and suppliers
17. Use parts at de-rated values with no marginal overstress
18. Minimize subassemblies
19. Use new technology only when necessary
20. Emphasize standardization
21. Use the simplest possible operations
22. Use operations of known capability
23. Minimize setups and interventions
24. Undertake engineering changes in batches

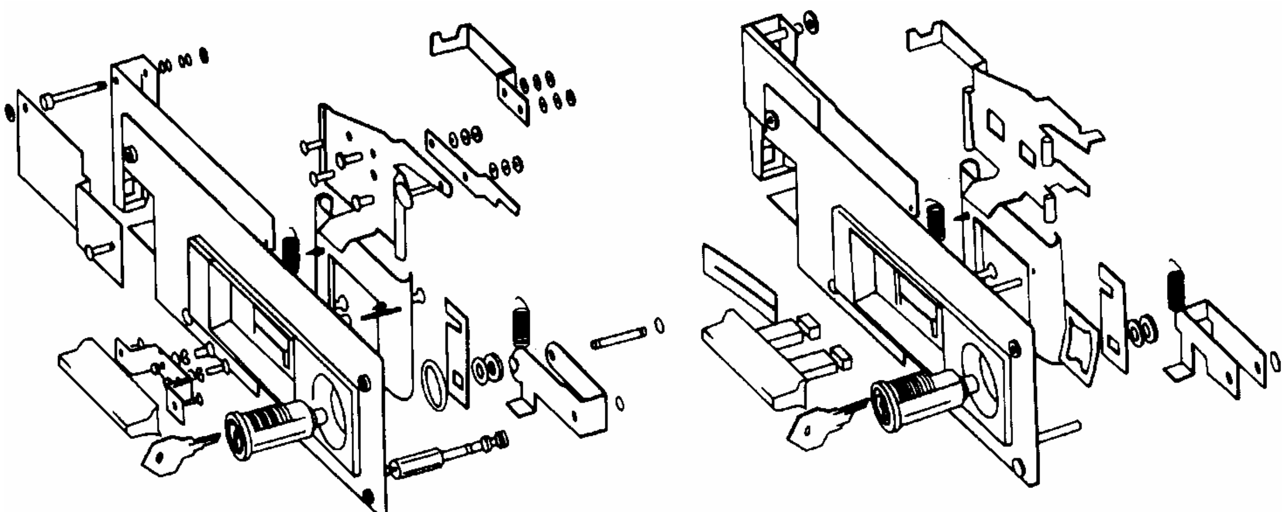
The use of DFM guidelines in Nippondenso radiator design

- Develop a modular design
- Minimize part variations
- Design parts for multiuse
- Use the simplest possible operations





Design for Assembly (Xerox latch mechanism design)



(a) (b)

Capstan and Turret Lathe: Working,Advantages, Bar Feeding Mechanism

Page Contents

Capstan and Turret Lathe:

A **capstan and turret lathe is a production lathe**. It is used to manufacture any number of identical pieces in the minimum time.

These lathes were first developed in the **United States of America** by **Pratt and Whitney** in 1960.

Capstan lathe is one of the types of **semi-automatic lathe**.

In semi-automatic lathes machining operations are done automatically.

Functions other than machining like loading and unloading of a job, the positioning of tools coolant operations are done manually.

The turret head is mounted on the ram fitted with turret slides longitudinally on the saddle.

Turret head has a **hexagonal block having six faces** with a bore for mounting six or more than six tools at a time.

The threaded hole on these faces is used to hold the tools.

In the case of a **Capstan Lathe**, **the hexagonal turret is mounted on a short slide or ram** which again fitted with a saddle.

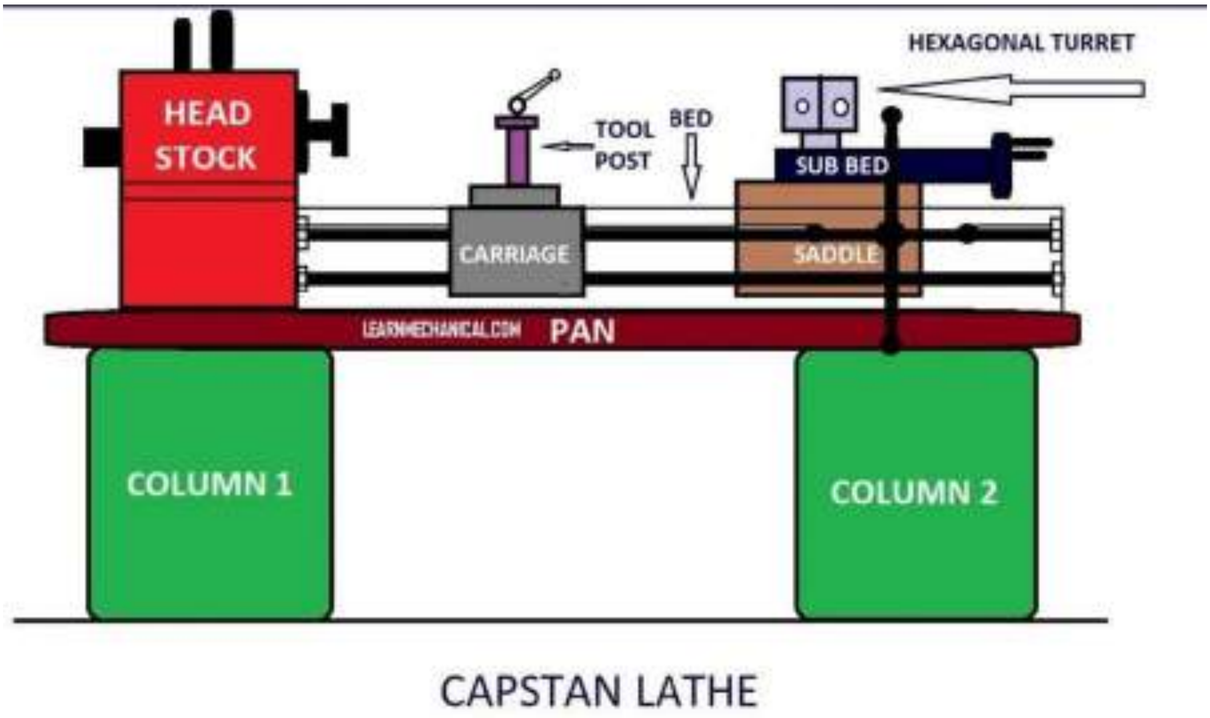
The saddle can be move accordingly throughout the bed ways and can be fixed to the bed if necessary.

It is specially used for bar type jobs.

But in the case of **Turret Lathe**, the **hexagonal turret directly mounted on the saddle.** The saddle can be move through the bed ways.

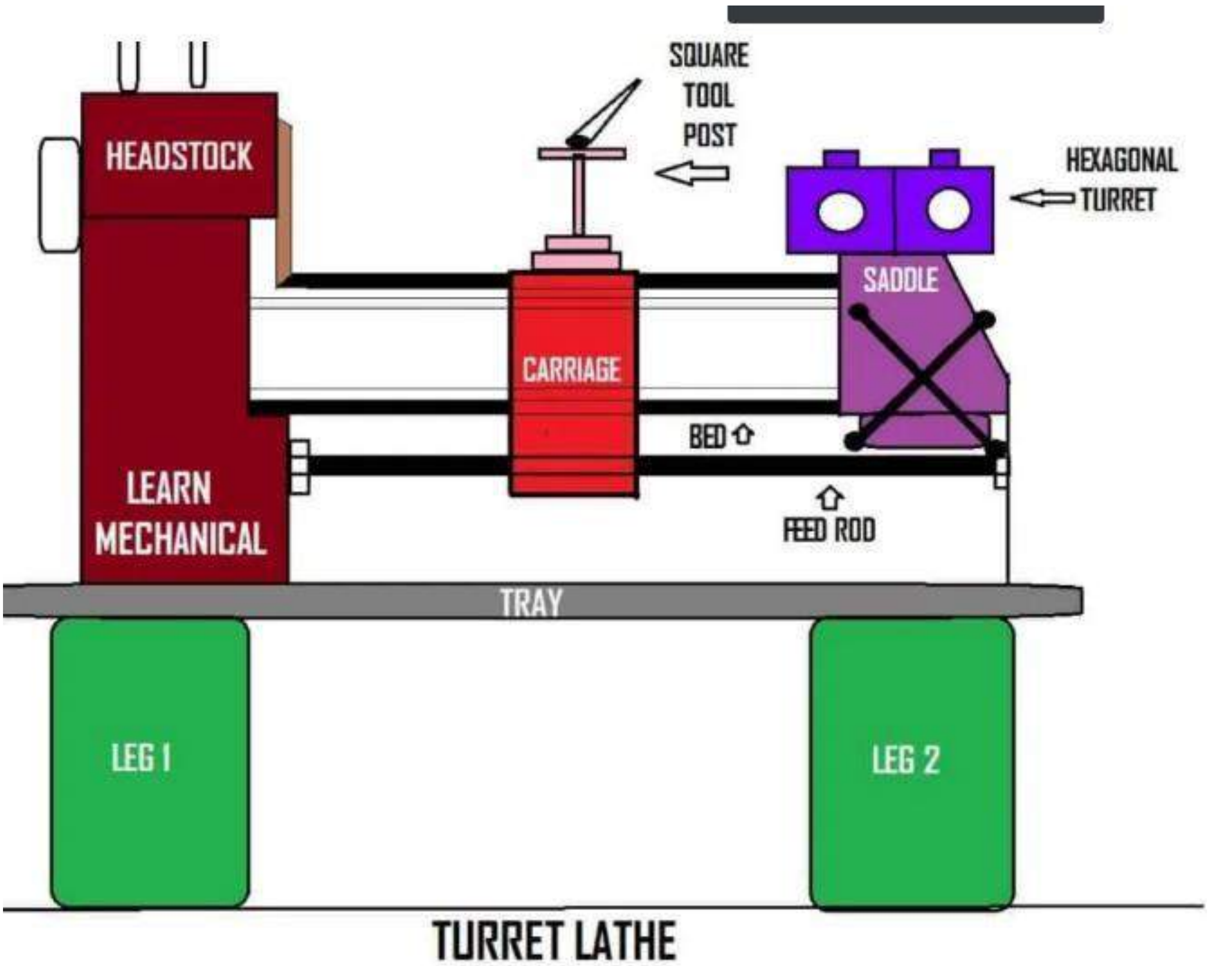
Turret lathe is generally used for chucking type work.

Schematic Diagram of a Capstan Lathe:



SCHEMATIC DIAGRAM OF CAPSTAN LATHE

Schematic Diagram of a Turret Lathe:



Capstan and Turret Lathe Working:

The work piece is held in collet or chucks which are actuated **hydraulically orpneumatically.**

All the needed tools are held in the respective holes on the turret head.

According to the sequence of operation, the tool is moved with the help of a turret head.

Drilling, boring, turning, reaming, threading tools are mounted on the turret head.

Forming, chamfering, knurling tools are mounted on the front end of the turret.

The Parting tool is mounted in an inverted position on the rear end of the turret.

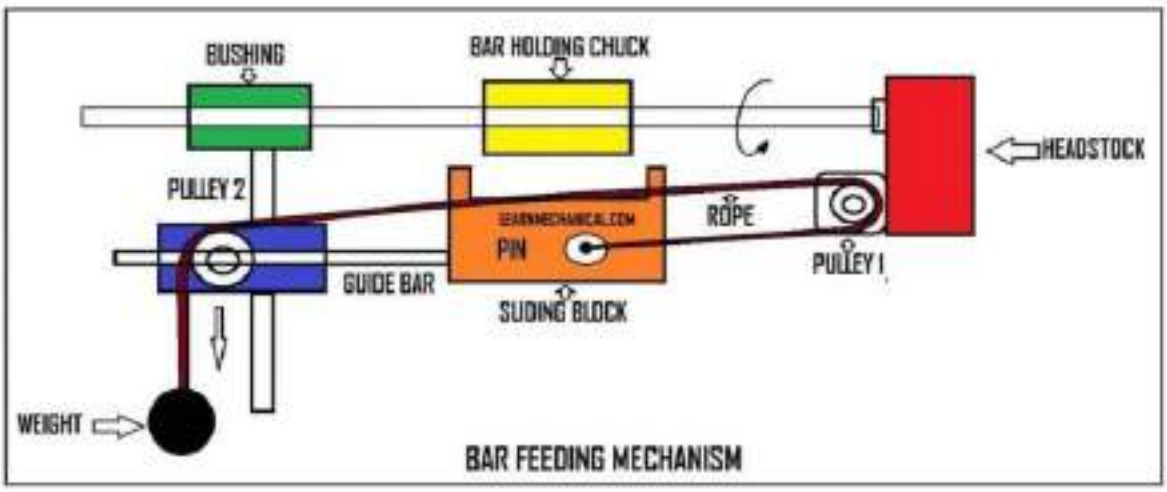
After completing each operation the turret head is moved back to its initial position which indexes the tools automatically.

Capstan and Turret Lathe Advantages:

The advantages of Capstan and Turret Lathe is the following:

- *The rate of production is higher*
- *Different ranges of speeds are obtained.*
- *A number of tools can be accommodated.*
- *Chucking of larger workpieces can be done.*
- *Operators of less skill are required hence lowers the labor cost.*
- *Higher rigidity so can withstand heavy loads.*

Bar Feeding Mechanism in Capstan and Turret Lathe:



BAR FEEDING MECHANISM IN CAPSTAN LATHE

In the **bar feeding mechanism**, the bar is pushed after the chuck is released without stopping the [Lathe Machine](#).

We use this mechanism for minimizing the setting time.

The bar is passed through the pedestal bushing, bar holding chuck, headstock spindle, and the collet chuck.

The **collet chuck** is screwed on the headstock spindle and holding the feed bar and also helps the bar to rotates as per spindle speed.

Bar holding chuck rotates within the sliding block with the rotation of the feeding bar.

Also, you can see a rope and a deadweight in this mechanism.

One side of the rope is attached with the sliding block with the help of pin and another side of rope passes through 2 different pulleys and then connecting with a deadweight at its end.

So now when the collet chuck released by the lever the dead weight tends to move in the downward direction, due to this it exerts thrust on the bar holding chuck and feed the bar untilit touches the workshop.

As we already have seen that Capstan Lathe is best for bar types jobs that's why we are generally seeing Bar Feeding Mechanism on Capstan Lathe.

Tools used in Capstan and Turret Lathe:

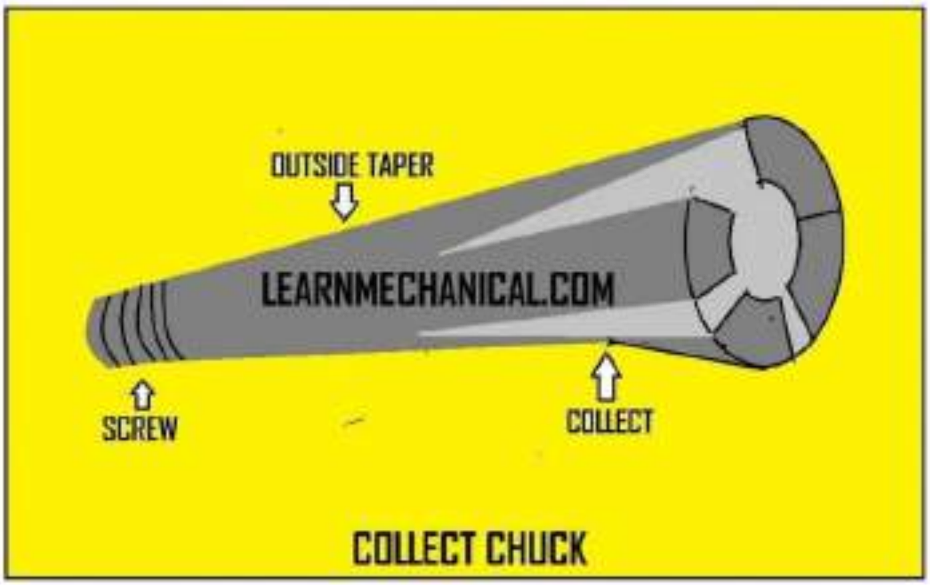
Collect Chuck:

This is **used for griping or you can holding any small bars in Capstan and Turret Lathe** (Mainly when we do Mass production).

The size of collet chucks is different corresponding to the bar sizes.

The jaws of the collet chuck are gripped the workpiece by its springing nature.

t is a thin steel brass bushing having slots on the outer side throughout its length.



Roller Box Steady Turning Tool:

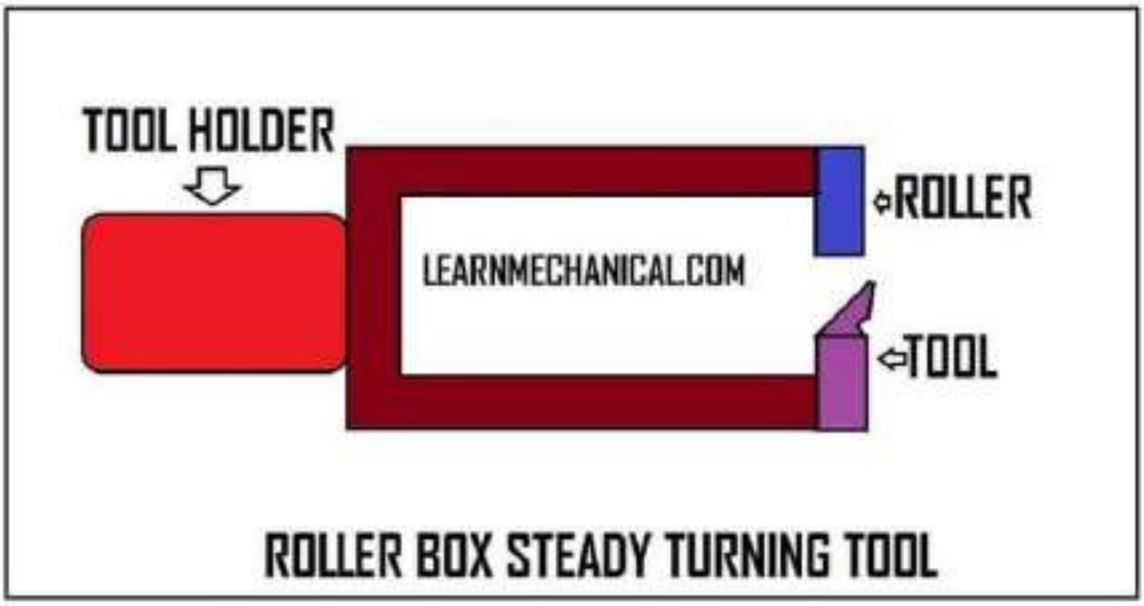
This type of tool is **used on bar work and when a considerable amount of stock is to be removed from the job.**

Roller box consists of the backrest or traveling two roller steadies that can be adjusted as per requirement.

A single point cutting tool is present in front of two rollers and gives rigidity to the workpiece.

Due to this rigid support, depth of cut, turning, etc. can be performed very smoothly.

This is a costly tool only used in mass production.



ROLLER BOX STEADY TURNING TOOL USED IN CAPSTAN AND TURRET LATHE

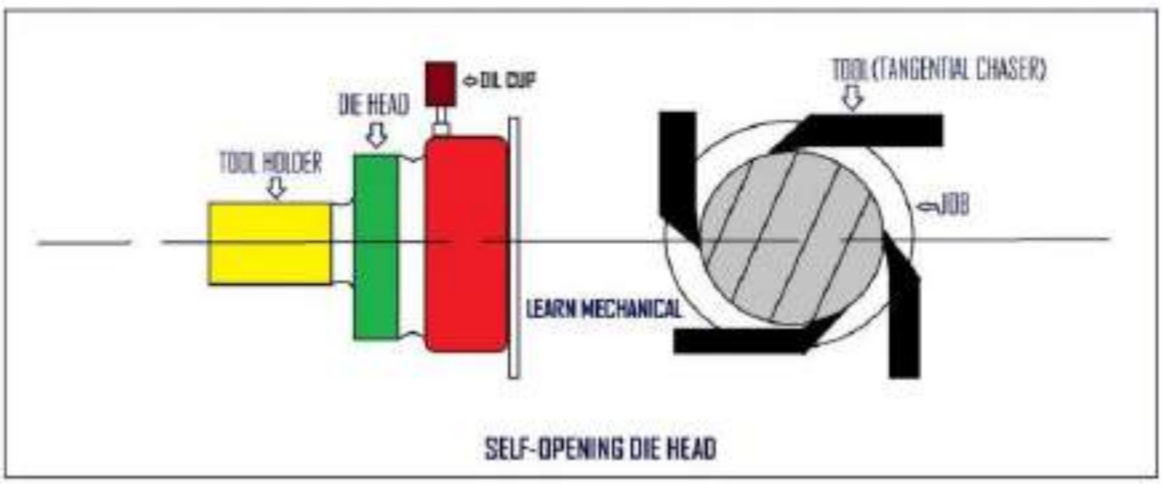
Self-opening Die Head:

This tool is **used especially for cutting external threads.**

The pitch of the cutting edges is determined according to the required thread pitch to be cut.

Chasers may be triangular, tangential, and circular types.

The function of the self-opening die is it opened automatically when the tool travel is stopped after the screw cutting operation.



SELF-OPENING DIE HEAD

Difference Between Capstan and Turret Lathe Machine:

Capstan Lathe	Turret Lathe
In capstan lathe, the turret tool head is mounted over the ram and that is mounted over the saddle.	In turret lathe, the turret tool head is mounted over the saddle like a single unit.
For providing feed to the tool, ram is moved.	For providing feed to the tool,a saddle is moved.
Capstan lathe is a Lightweight machine.	Turret Lathe is a Lightweight machine.
The turret head cannot be moved in the lateraldirection of the bed.	The turret head can be moved crosswise i.e. in the lateral direction of bed in some turret lathe.
In capstan lathe, the collet is used to gripping the Job.	In turret lathe, power Jaw chuck is used to gripping the Job.
Capstan lathe is usually horizontal lathes.	Turret lathes are available in horizontal and vertical lathes.
Because of no saddle displacement, Movement of turret tool head over the longitudinal direction of bed is small along with the ram.	Turret tool head moves along with the saddle over the entire bed in the longitudinal direction.
For indexing turret tool head, the handwheel of the ram is reversed and turret tool index automatically.	For indexing turret tool head, a turret is rotated manually after releasing clamping lever.
Capstan lathe working operations are faster because of lighter in construction.	Turret lathe working operations are slower because of heavier in constructions.

Capstan lathe used for shorter workpiece because of limited ram movement.	Turret lathe used for longer workpiece because of saddle movement along the bed.
In Capstan lathe used for machining workpiece up to 60 mm diameter.	In Turret lathe used for machining workpiece up to 120 mm in diameter.
Heavy cuts on the workpiece cannot be given because of non-rigid construction.	Heavy cuts on the workpiece can be given because of the rigid construction of the machine.

Difference between Capstan and Turret Lathe from the Engine Lathe:

ENGINE LATHE	CAPSTAN AND TURRET LATHE
The direction of rotation is mostly anti-clockwise	It can rotate in both directions.
Required less power as these machines are design for doing a single operation at a time.	Requied 4-5 times more power because of handaling 2-3 operations at a time.
Less number of spindle speed available in these types of lathe	The vast amount of spindle speeds are available
Setting and machining time is higher.	Setting and machining time for mass production is very less, as its handle sevaral operation at a time.
The skilled operator needed.	Semi-skilled operators can be run the machine
The lead screw present in these types of lathe is long	Lead screw is not present but short threads can be easily cut by chaser.
Any type of taper turning can be done by this machine	Only short length taper can be done with the help of the form tool.

Summary:

What is capstan and turret lathe?

A capstan and turret lathe is a production lathe. It is used to manufacture any number of identical pieces in the minimum time.
These lathes were first developed in the United States of America by Pratt and Whitney in 1960.

What is the working principle of Capstan and Turret lathe?

In these types of a lathe, the workpiece is held in collet or chucks which are actuated hydraulically or pneumatically. All the needed tools are held in the respective holes on the turret head. According to the sequence of operation, the tool is moved with the help of a turret head.

What are the advantages of Capstan and Turret Lathe?

The advantages of Capstan and Turret Lathe is the following:

The rate of production is higher
Different ranges of speeds are obtained. A number of tools can be accommodated.
Chucking of larger workpieces can be done.
Operators of less skill are required hence lowers the labor cost.
Higher rigidity so can withstand heavy loads.

What is Rapid Prototyping?

Rapid prototyping is the fast fabrication of a physical part, model or assembly using 3D computer aided design (CAD). The creation of the part, model or assembly is usually completed using additive manufacturing, or more commonly known as 3D printing.

Rapid prototyping using selective laser meltingWhere the design closely matches the proposed finished product it is said to be a high fidelity prototype, as opposed to a low fidelity prototype, where there is a marked difference between the prototype and the final product.

How Does Rapid Prototyping Work?

Rapid prototyping (RP) includes a variety of manufacturing technologies, although most utilise layered additive manufacturing. However, other technologies used for RP include high-speed machining, casting, moulding and extruding.

While additive manufacturing is the most common rapid prototyping process, other more conventional processes can also be used to create prototypes.

These processes include:

- **Subtractive** - whereby a block of material is carved to produce the desired shape using milling, grinding or turning.
- **Compressive** - whereby a semi-solid or liquid material is forced into the desired shape before being solidified, such as with casting, compressive sintering or moulding

What are the Different Types of Rapid Prototyping?

Stereolithography (SLA) or Vat Photopolymerization

This fast and affordable technique was the first successful method of commercial 3D printing.It uses a bath of photosensitive liquid which is solidified layer-by-layer using a computer-controlled ultra violet (UV) light.

Selective Laser Sintering (SLS)

Used for both metal and plastic prototyping, SLS uses a powder bed to build a prototype one layer at a time using a laser to heat and sinter the powdered material. However, the strength of the parts is not as good as with SLA, while the surface of the finished product is usually roughand may require secondary work to finish it.

Fused Deposition Modelling (FDM) or Material Jetting

This inexpensive, easy-to-use process can be found in most non-industrial desktop 3D printers.It uses a spool of thermoplastic filament which is melted inside a printing nozzle barrel beforethe resulting liquid plastic is laid down layer-by-layer according to a computer deposition program. While the early results generally had poor resolution and were weak, this process is improving rapidly and is fast and cheap, making it ideal for product development.

Selective Laser Melting (SLM) or Powder Bed Fusion

Often known as powder bed fusion, this process is favoured for making high-strength, complex parts. Selective Laser Melting is frequently used by the aerospace, automotive, defence and medical industries. This powder bed based fusion process uses a fine metal powder which is melted in a layer by layer manner to build either prototype or production parts using a high-powered laser or electron beam. Common SLM materials used in RP include titanium, aluminium, stainless steel and cobalt chrome alloys.

Laminated Object Manufacturing (LOM) or Sheet Lamination

This inexpensive process is less sophisticated than SLM or SLS, but it does not require specially controlled conditions. LOM builds up a series of thin laminates that have been accurately cut with laser beams or another cutting device to create the CAD pattern design. Each layer is delivered and bonded on top of the previous one until the part is complete.

Digital Light Processing (DLP)

Similar to SLA, this technique also uses the polymerisation of resins which are cured using a more conventional light source than with SLA. While faster and cheaper than SLA, DLP often requires the use of support structures and post-build curing.

An alternative version of this is Continuous Liquid Interface Production (CLIP), whereby the part is continuously pulled from a vat, without the use of layers. As the part is pulled from thevat it crosses a light barrier that alters its configuration to create the desired cross-sectional pattern on the plastic.

Binder Jetting

This technique allows for one or many parts to be printed at one time, although the parts produced are not as strong as those created using SLS. Binder Jetting uses a powder bed onto which nozzles spray micro-fine droplets of a liquid to bond the powder particles together to form a layer of the part.

Each layer may then compacted by a roller before the next layer of powder is laid down and the process begins again. When complete the part may be cured in an oven to burn off the binding agent and fuse the powder into a coherent part.

Applications

Product designers use this process for rapid manufacturing of representative prototype parts. This can aid visualisation, design and development of the manufacturing process ahead of mass production.

Originally, rapid prototyping was used to create parts and scale models for the automotive industry although it has since been taken up by a wide range of applications, across multiple industries such as medical and aerospace.

Rapid tooling is another application of RP, whereby a part, such as an injection mould plug or ultrasound sensor wedge, is made and used as a tool in another process.

MODULE 4

Special Purpose Machines(SPM)

SPECIAL PURPOSE MACHINE TOOL (SPM)

What are SPMs:

- Special purpose machine tools are designed and manufactured for specific jobs and as such never produced in bulk
- Special Purpose Machine (SPM) are those machine which are not available off the shelf.
- These are not Covered in standard manufacturing programs. Therefore those have to be designed & tailor made as Per the customers specific requirements.

Need of SPMs:

- Always in the production process there is a long felt need to improve the quality of product, minimize rejection and increase the productivity per person, to cater to the pressing circumstances in the globalised world economy.
- For that purpose SPMs are used

SPMs are considered to be a new series of machine tools that produce high rates of produced parts.

SPMs have superior efficiency in increasing the quality and quantity of production lines. Engineers' knowledge and experience are important in the SPM design process and inapplying this technology.

Moreover, the modularity gives SPMs an advantage in the production processes of various types of parts, and SPMs can therefore be applied in different configurations .

There are specific advantages achieved by applying SPM technology, such as mass production in a short time, high accuracy of products, reduced labour requirements, and the ability to undertake simultaneous machining.

To compare SPMs with other machining tools, production volumes and the variety of products should be considered. **Figure1** shows the comparison of three types of machine tools: CNC, universal machine tools, and SPMs.

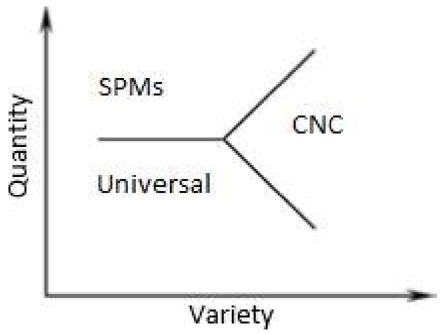


Figure 1 The comparison of three types of machine tools

This figure shows that universal machine tools are used for low production mass with low variety. CNC is suitable in the production of various parts, while SPMs are the best solution for high production quantities with low variety.

SPMs are used to perform drilling and related operations such as tapping, reaming, counterboring and countersinking . The machining forces in these operations are relatively low; therefore, the machine-tool vibrations can be eliminated. On the other hand, SPMs canbe used to perform milling and some other machining operations, and in these cases, high cutting forces are generated.. **Figure 2** shows an example of an SPM.

Figure 2 An example of an SPM

The basic units of SPMs

SPMs consist of two basic units: machining units and sliding units. The former are responsible for performing the machining operations and come in five types:
MONO master, MULTI master, POWER master, TAP master, and CNC master units.

MONO and MULTI units are used for light drilling operations while POWER units are used for large capacity drilling and milling operations.

CNC units can also be used for drilling, milling, and tapping while TAP master units are used for tapping operations .

CNC units can be programmed, and they can produce parts with high controlled accuracy during machining operations.

Sliding units are used to carry the machining units, and they also supply the required feed motion during machining operations. These units provide a flexible mounting of the machining units whether they are mounted perpendicular or parallel to the sliding direction depending on the requirements of the machining operations .

The Concept of SPMs

In SPMs, different machining operations such as drilling, tapping, reaming, milling, and cutting can be performed at the same time by using multiple machining units from different directions, while in the machining centre (which uses CNC), only one operation can be performed in the same cycle time.

For example, a part whose production involves twenty machining operations including drilling, countersinking, reaming, and tapping can be machined in 1.6 minutes by SPMs. However, it takes about 20 minutes to perform the same operations for the same part in the traditional machining centre. This proves the efficiency of SPMs in reducing production time and costs.

Another example providing a comparison between SPMs and traditional machining tools involved three different types of machining systems – the traditional lathe, CNC, and SPMs - to perform machining operations for the same part . From this example, the total time required to produce the part in SPMs was lower than the times for the other machining systems, as represented in **Table 1**. SPMs offer a range of machining units that can perform different machining operations by considering factors such as materials, quantities, geometric specifications of the workpiece, and the type of machining operations

Table 1 The time required for machining a part in three different machining systems

	Machining time in seconds (Lathe)	Machining time in seconds (CNC)	Machining time in seconds (SPMs)
Counterboring	5.0	3.0	3.0
Drilling	8.0	4.0	4.0
Tapping	10.0	5.0	5.0
Cutting	23.0	12.0	5.6
Tool changing per part	6.0	0.12	
Free tool traveling per part	6.0	0.6	
Indexing time per part			1.2
Loading/unloading	15.0	2.40	5.0
Non-cutting time	27.0	3.12	1.2
Total time per part	50.0	15.12	6.8
Number of parts per hour	72	238.10	529.41

Drilling units

There are two types of drilling units: direct drive drilling units and multiple drive units. The first is driven by a direct electric drive and the second is driven by flexible drive shafts. A combination of these two units can be used to achieve efficient solutions.

Flexible drive shafts transmit the power from the motor to the drilling spindle. They provide many advantages to the drilling system such as a very long life span, smooth running, flexible settings for the drilling spindles at any required position, and easy connection and disconnection. Multiple drive drilling units are more economical than direct drive units.

Tapping units

SPMs offer a complete program of tapping units suitable for any supplier. There are six types of units for applying tapping technology from very small pitches - up to 5 mm - to an M48 thread size. Tapping units can be used together with drilling units (MONO master or MULTI master), and these units form perfect threads in a fast and reliable way.

CNC units

There are three types of CNC units in SPMs: CNC with one-axis spindle, with two-axes spindles, and with three-axes spindles. These units are controlled numerically, and they are driven by AC-servomotors. In addition, there are three basic slides for CNC units, and these slides come with an integrated preloaded ball screw and a digital AC-servomotor drive.

Multiple spindle heads

SPMs have the most economical multiple spindle heads for drilling and tapping technology with five angle heads. There are two-, three-, and four spindle heads which are adjustable. These include special heads with fixed hole spacing and up to 30 spindles.

Tool holders

There is a comprehensive program of tool holders in SPMs that provides the ideal combination for the machining units. This is very important in obtaining suitable machining results and helping to extend the tool's life.

Assembly components

Machining and sliding units need to be assembled in order to achieve SPM layouts and perform the machining operations. Therefore, assembly components are used in SPMs with both machining and sliding units.

Base plates are one of these components, and they are used to mount the machining units. These plates are available in standard specifications and they can be designed and made on special request .

There are other assembly components used in SPMs. For instance, horizontal supports are used to adjust the height of the machining units depending on the workpiece specifications and the type of machining unit. They are available in different dimensions and they can be designed and made for special requirements

In addition, vertical supports are used, and they are designed with multiple tapped locations to achieve different height positions for the machining units.

Slide blocks are used with SPMs units in one axis, two axes, and three axes. Universal supports are designed to adjust the vertical and angular positions of the machining units in the Z- axis. They can adjust the position in three axes and they can be used to install the machining units in four axes.

Machine components

Besides the assembly components, there are other elements called machine components. One of these components is the indexing table, which is important in SPMs because it is used to position and move the workpiece between different machining stations. Technical considerations and production volume are considered to determine the number of stations required to complete all operations .

Self-centring chucks are other machine components with two jaw system functions. These chucks generate and transfer the clamping forces, and they have a compact design for internal and external clamping. They are operated pneumatically with pressure up to 12 bar. Swing clamps are provided in SPMs in four standard sizes, and each size is available with five types of clamping arms. The clamping arms can be mounted at any angle and these clamps are provided with no rotation (fixed) or with clockwise and counter clockwise rotations

. There are also other parts which contribute to the layout of SPMs. Examples of these parts are the angle support, the header, the support for vertical units, the base module (four and six stations), the long and short columns, the coolant system, the hydraulic system, and the safety door.

Integration methods

A number of methodologies have been considered for the automation of design and assembly, and different approaches have been implemented in these methodologies. In order to build an integrated system for automating design and assembly processes, it is important to include the following components:

A Computer programming platform.

A 3D modelling environment

A database or a library of features.

The computer programming platform

A computer programming platform is needed to integrate different software, and it facilitates the automation of design and assembly. Computer programming languages can be classified into three types: imperative, functional and logic, and object-oriented programming [94]. For design and assembly automation, an object-oriented programming language is preferredbecause it has advantages such as simple software design and effective use of real world objects for modelling, because it reduces development risks for complex designs, and because it is easy to maintain and upgrade . Moreover, object-oriented languages have many characteristics such as abstraction of data, modularity, and inheritance. These characteristics help engineers to define specific values and organise assembly automation into classes. Some of the common programming languages are listed below.

- **Visual Basic programming language**
- **C++ programming language**
- **Delphi programming language**
- **Flex programming language**
- **Matlab software**

The 3D modelling environment

The 3D modelling of products has become an important factor in many engineering activities. This model provides the essential features and specifications of designed products and helps to avoid many errors by applying engineering analysis such as finite element analysis (FEA) . In addition, 3D modelling provides a reliable environment for product assembly processes, and can help to avoid problems during manufacturing. A 3D modelling environment

is provided by CAD software such as AutoCAD and SolidWorks. SolidWorks has a powerful 3D modelling environment for the assembly process which is very important for mechanical mechanisms. SolidWorks is a particularly effective tool for 3D modelling activities due to its specific functions, 3D features, 3D views, assembly features, and mates.

The Database

The database can be defined as an integrated computer structure used to store the necessary information that can be shared and used by a system. The database is an important factor in any integrated system when selection and assembly processes are performed for certain parts. The database can be constructed in Solid Works by using the design library features. The design library is flexible in storing, managing, and selecting the elements, and it can

Simplify the design and assembly process . Moreover, the database can be Created in Microsoft Access, which is implemented in VB and SolidWorks.

The SPM elements

In order to build a database for SPM elements, it is important to consider the
Following factors

- The category of each element.
- The supporting and supported faces of each element.
- The assembly features on the supporting and supported faces of each element.
- The geometric parameters of each element.
- The classification of each element with regard to its role in the SPM design.

With regards to the first factor, SPM elements are divided into four main categories: function, motion, supporting, and accessory elements. **Figure 3** shows the main categories and classifications of SPM elements.

- Function elements are used to perform machining processes such as drilling, milling, tapping, and reaming.
- Motion elements provide rotational and linear movements. A linear movement is needed when function elements are required to move during machining processes, andit can be in one to four directions. A rotational movement is required to transfer the workpiece from one station to another in order to perform multiple machining processes.

- Supporting elements are needed to provide the positioning support for the function elements.

- Accessory elements such as clamps, chucks, and multi-spindle heads are used to complete the design of SPM layouts.

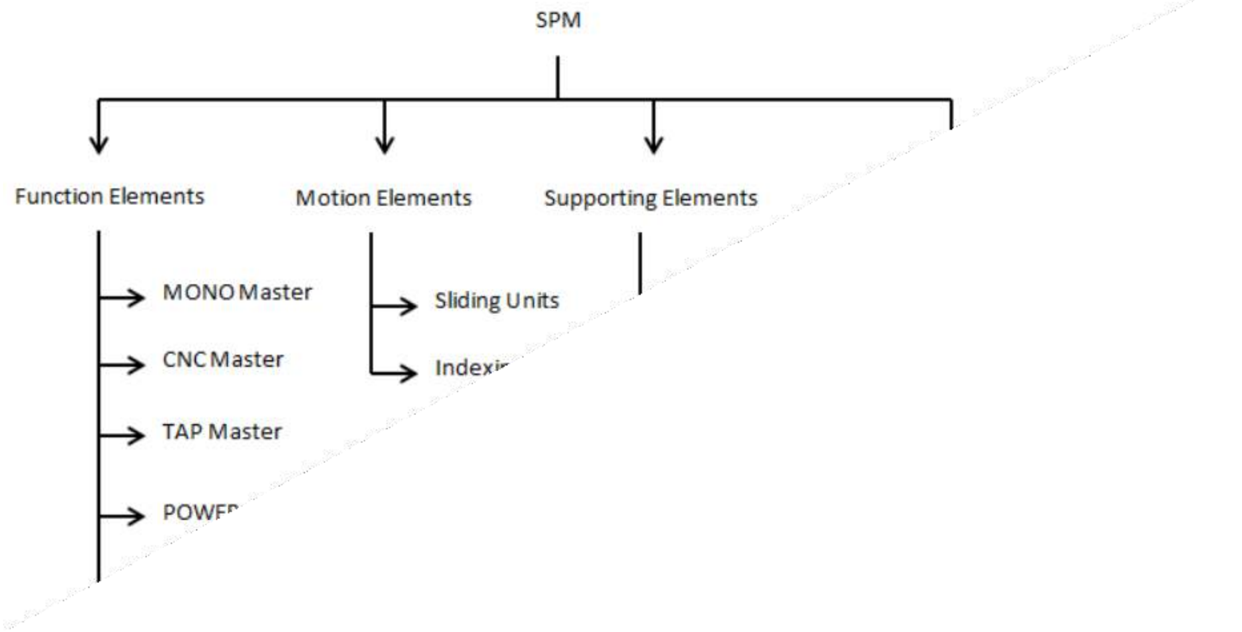


Figure 3. The categories and classifications of SPM elements.

Regarding factors 2, 3, and 4, the assembly features and geometric information need to be defined and used to represent SPM elements in order to define the assembly relationships between these elements. In this work, eight assembly features were identified: supporting faces, supported faces, locating holes, counterbore holes, screw holes, fixing slots, pins, and screw bolts, as shown in **Figure 4**

A supporting face is the surface on an element that supports other SPM elements or the work piece, while a supported face is the surface on an element that is supported by other SPM elements. A locating hole can be used as a locating point with a locating pin, while a counter bore hole and a fixing slot are used to join two SPM elements with screw bolts. In SPM elements, the assembly features are designed with standard dimensions and are perpendicular to the supporting or supported faces. These features are identified as associated assembly features with supporting and supported faces of the elements, and because the features have standard designs and dimensions, their positions and orientations are known.

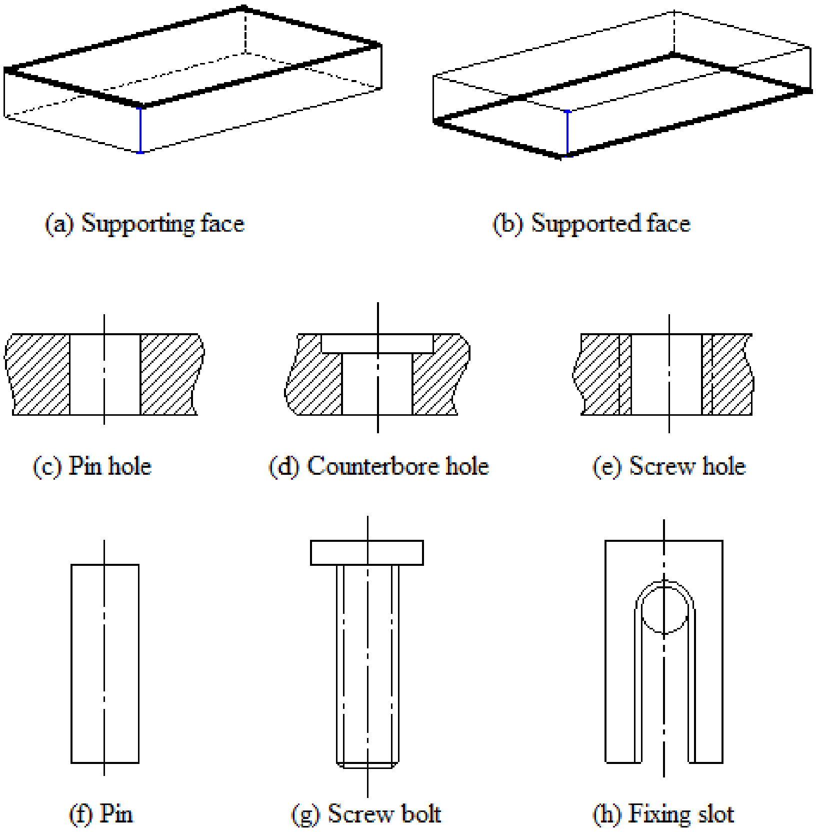


Figure 4. The eight assembly features.

Some SPM elements have supporting and supported faces and they can be used to support an element, while they are already supported by other elements, as shown in **Figure 5**.

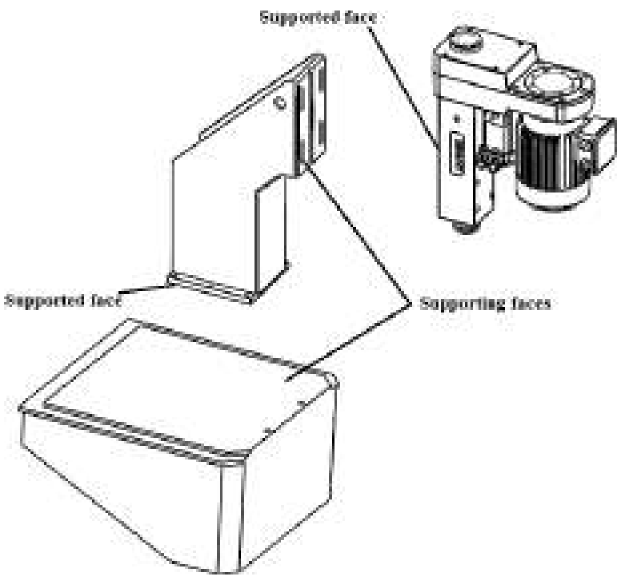


Figure 5 Supporting and supported faces for SPM elements.

Productivity development by Special purposemachine

A Special Purpose Machine can be defined as a "mother machine", custom designed to do a specific operation or a combination of some operations on a specific job or on a small variety of similar jobs, in a mass scale, at short cycle times.

The special purpose machine are designed and manufactured to improve productivity.

Productivity is generally defined as the ratio of aggregate output and aggregate input

In any firm or industry, productivity is a concept that measures the efficiency with which inputs are transformed into valuable output in a production process. Similarly, it can be defined as the combination of efficiency and effectiveness of a production process that aims to maximize output while minimizing the use of inputs.

Productivity measures the relationship between outputs such as goods and services produced, and inputs that include labor, capital, material and other resources[

Some major considerations in developing a special purpose machine

- **Specific operations on the job and produce components at shortest possible time**
- Work automatically, to the extent possible.
- Involve only the barest minimum of operator's involvement.
- Should set up and run machine in the shortest time

Special purpose machine are aimed at reducing the cycle times and control unnecessary costs thus increasing the profits.

Special purpose machine should work automatically, to the extend possible. This sentence reveals the study that productivity improvement can be accomplished via. People and technology.

Special purpose machine are designed and manufactured keeping in focus that it must have barest minimum of operator's involvement. This sentence supports the sentence that "people will agree that significant increase in productivity in long run cannot be achieved by increasing work effort alone, when the trend in industrialized societies of world is towards ever increasing labor costs; the real growth can come about through capital investment in newer and better machines, equipments and facilities.

In addition to technology, there are also other means for improving productivity like,

- re – organisation of resources,
- Effective management of human resources.
- Improving the quality work,
- reducing the amount of maintenance needed,

- Making sure that delays do not occur etc. are only some examples.
- management effects have a strong influence on productivity

Problems Involved in traditional approach

As far as considering CNC machines to perform these operations, it improves productivity and accuracy as well as it overcomes all shortfalls of traditional approach, **but Machine hour rate of a CNC is higher. While performing these operations on CNC turning machine, we face the same problem as on a lathe.**

Also while processing the component on CNC milling machine, only one of the face can be machined. Considering the above limitations of the lathe, CNC Turning machine and CNC Milling machine, the component cannot be processed in a single setup and it doesn't provide with optimized cycle time.

Hence, the best alternative solution is to design a special purpose machine which will provide processing of the component in a single setup and in much lesser cycle time. This will enhance the rate of production. The accuracy of positioning of the cutting tool can be obtained with the incorporation of various electronic sensors so as to achieve the required dimensions within the given tolerances.

Hence the quality and accuracy at which the component is produced can be achieved compared to that of a CNC Machine.

Another advantage of a special purpose machine is that the scope of operator is only limited to clamping and declamping of the component i.e. no skilled operator is required.

DFMA Approach

This concept reveals the fact that design department should work in co-ordination with production department resulting in economic production processes with saving in time and labour enhancing product quality.

It can also be simply stated as design for a product with manufacturing and assembly in mind.

- -**The design should be done in least time with minimum cost of development.**
- **-Smoothen the phases of transition from design to manufacturing and assembly.**
- **-This helps to meet customer demand and achieve competitive position in market.**

The design was done with minimum or literally no modifications during design and manufacturing. The design was optimised using CAD software and its compatibility was also confirmed.

DFA

Significant cost of manufacturing is decided at the design stage of assembly. The parts in the assembly were actually questioned and challenged for its being in the assembly. The level of accuracy, the shape and size of the components were in question

Since being a Special Purpose Machine its design norms contradicted with the DFA procedure. Components like base weighed almost half ton, which were questioned by DFA. The justification for the part being so heavy was that, the machines are supposed to work and machine similar component over a long duration with consistent results

DFM

It is having a manufacturing approach while designing. The designers tried to minimise total number of parts for simplification and cost reduction. Again some contradictions can be seen in DFM. Parts design to be multi functional, modularity in design, minimising part variation. Since being a SPM one could not enforce modularity or variations in parts design, because these machines are specially meant for a purpose. They are designed for a particular method or process of manufacturing

Concept and Design

This is based on following factors

- **Power required for centre drills**
- **Power required for milling cutter**
- **Torque and axial thrust on centre drills**
- **Torque and tangential cutting force on milling spindle**
- **-Number of belts for drills -Number of belts for Milling**
- **-Design of spindle shafts -Selection of bearings**
- **-Selection of Hydraulic power pack**

DFMA (Design for Manufacture and Assembly)

Design for Manufacture and Assembly (DfMA) is a design approach that focuses on ease of manufacture and efficiency of assembly. By simplifying the design of a product it is possible to manufacture and assemble it more efficiently, in the minimum time and at a lower cost.

Traditionally, DfMA has been applied to sectors such as the design of automotive and consumer products, both of which need to efficiently produce high quality products in large numbers. More recently, construction contractors have begun to adopt DfMA for the off-site prefabrication of construction components such as concrete floor slabs, structural columns and beams, and so on.

DfMA combines two methodologies – Design for Manufacture (DFM)and Design for Assembly (DFA):

Design for Manufacture (DFM)

DFM involves designing for the ease of manufacture of a product's constituent parts. It is concerned with selecting the most cost-effective materials and processes to be used in production, and minimising the complexity of the manufacturing operations.

Design for Assembly (DFA)

DFA involves design for a product's ease of assembly. It is concerned with reducing the product assembly cost and minimising the number of assembly operations.

Both DFM and DFA seek to reduce material, overhead, and labour costs.

DfMA principles

In a similar approach to lean construction, applying DfMA enables the identification, quantification and elimination of waste or inefficiency

in product manufacture and assembly. It can also be used as a benchmarking tool to study the products of competitors.

The main principles of DfMA are:

- **Minimise the number of components: Thereby reducing assembly and ordering costs, reducing work-in-process, and simplifying automation.**

- **Design for ease of part-fabrication: The geometry of parts is simplified and unnecessary features are avoided.**

- **Tolerances of parts: Part should be designed to be within process capability.**

- **Clarity: Components should be designed so they can only be assembled one way.**

- **Minimise the use of flexible components: Parts made of rubber, gaskets, cables and so on, should be limited as handling and assembly is generally more difficult.**

- **Design for ease of assembly: For example, the use of snap-fits and adhesive bonding rather than threaded fasteners such as nuts and bolts. Where possible a product should be designed with a base component for locating other components quickly and accurately.**

- **Eliminate or reduce required adjustments: Designing adjustments into a product means there are more opportunities for out-of-adjustment conditions to arise.**

Advantages of DfMA

Some of the main advantages of DfMA include:

Speed

One of the primary advantages of DfMA in construction is the significantly reduced programme on-site through the use of prefabricated elements.

Lower assembly cost

By using fewer parts, decreasing the amount of labour required, and reducing the number of unique parts, DfMA can significantly lower the cost of assembly.

Higher quality and sustainability

A highly automated approach can enhance quality and efficiency at each stage.

There may be less waste generation in the construction phase, greater efficiency in site logistics, and a reduction in vehicle movements transporting materials to site.

Shorter assembly time

DFMA shortens assembly time by utilising standard assembly practices such as vertical assembly and self-aligning parts. DFMA also ensures that the transition from the design phase to the production phase is as smooth and rapid as possible.

Increased reliability

DfMA increases reliability by lowering the number of parts, thereby decreasing the chance of failure.

Safety

By removing construction activities from the site and placing them in a controlled factory environment there is the possibility of a significant positive impact on safety.

MODULE 5

Maintenance of Machine Tools

What is machine maintenance?

Machine maintenance is the work that keeps mechanical assets running with minimaldowntime.

Machine maintenance can include regularly scheduled service, routine checks, and both scheduled and emergency repairs. It also includes replacement or realignment of parts that are worn, damaged, or misaligned. Machine maintenance can be done either in advance of failureor after failure occurs.

Machine maintenance is critical at any plant or facility that uses mechanical assets. It helps organizations meet production schedules, **minimize costly downtime**, and lower the risk of workplace accidents and injuries.

Types of machine maintenance

There are nine types of machine maintenance. Each one has its pros and cons (except reactive maintenance, which is all cons), and can be mixed and matched with assets to create a **balanced maintenance program**.

Reactive maintenance

Reactive maintenance refers to repairs done when a machine has already reached failure. Since it's unexpected, unplanned, and usually leads to rushed, emergency repairs, It's often called "fighting fires."

Run to fail maintenance

Run to fail maintenance is very similar to reactive maintenance. It involves letting a piece of equipment run until it breaks down. However, run to fail is a deliberate choice, whereas reactive maintenance is not. A plan is in place to ensure parts and labour are available to get the asset up and running, or replaced, as soon as possible.

Routine maintenance

Routine maintenance consists of basic maintenance tasks, such as checking, testing,lubricating, and replacing worn or damaged parts on a planned and ongoing basis.

Corrective maintenance

Corrective maintenance is any work that gets assets back into proper working order, although it's most commonly associated with smaller, non-invasive tasks that fix a problem before a complete failure occurs. For example, realigning a part during a routine inspection.

Preventive maintenance

Preventive maintenance refers to any regularly scheduled machine maintenance intended to identify problems and repair them before failure occurs. Preventive maintenance can be split up into two predominant types: Time-based preventive maintenance and usage-based preventive maintenance.

Time-based preventive maintenance are tasks scheduled at a certain time interval, such as the last day of every month or every 10 days. Usage-based preventive maintenance is when work is scheduled based on the operation of equipment, such as after 500 miles or 15 production cycles.

Condition-based maintenance

Condition-based maintenance depends on monitoring the actual condition of assets in order to perform maintenance when there is evidence of decreased performance or upcoming failure. This evidence can be obtained through inspection, performance data, or scheduled tests, and it can be gathered either on a regular basis or continuously, through the use of internal sensors.

Predictive maintenance

Predictive maintenance builds on condition-based maintenance, using tools and sensors to track machinery performance in real-time. This enables the identification of potential problems so they can be corrected before failure occurs.

Prescriptive maintenance

Prescriptive maintenance automates the maintenance process even further through the use of machine learning and artificial intelligence (AI). With a prescriptive maintenance strategy in place, sensors track machinery

performance in real-time and uses AI to let you know what maintenance work needs to bedone and when.

Maintenance Manual

INTRODUCTION

- Introduction

In the past, during the facility design/build phases, it was uncommon to devote substantial resources to life-cycle Operation and Maintenance (O&M) concerns. However, it is now widely recognized that O&M represents the greatest expense in owning and operating a facility over its life cycle. The accuracy, relevancy, and timeliness of well-developed, user- friendly O&M manuals are becoming increasingly important. Hence, it is becoming more common for detailed, facility-specific O&M manuals to be prepared prior to commissioning. The goal is to effectively and efficiently support the life cycle of the facility by eliminating unplanned shutdowns and realizing life-cycle cost savings.

This page presents a typical O&M manual development process (see Figure 1). Based on as-built information, comprehensive facility O&M manuals should include:

- System-level O&M information:
    - Physical Descriptions
    - Functional Descriptions
    - Troubleshooting
    - Preventive Maintenance (Procedures and Schedules)
    - Corrective Maintenance (Repair Requirements)
    - Parts Lists
    - Operation-/Maintenance-Significant Drawings
- Equipment-specific O&M information, organized into a vendor/manufacturer data library

DESCRIPTION

Sustainable design being an integral part of any facility management philosophy, the O&M manual provides a means to reduce operating costs as part of a comprehensive Maintenance Program, which includes the Maintenance Plan (MP).

O&M manual content and format requirements are conveyed through a detailed Statement of Work (SOW), sufficiently tailored to satisfy the Owner's Facility Management (FM) needs. This effort should be considered in the planning and design phases, and is typically carried out in the construction phase. Building Information Modeling (BIM) and, in particular, COBie, introduced at the front end of the project helps facilitate the entire process.

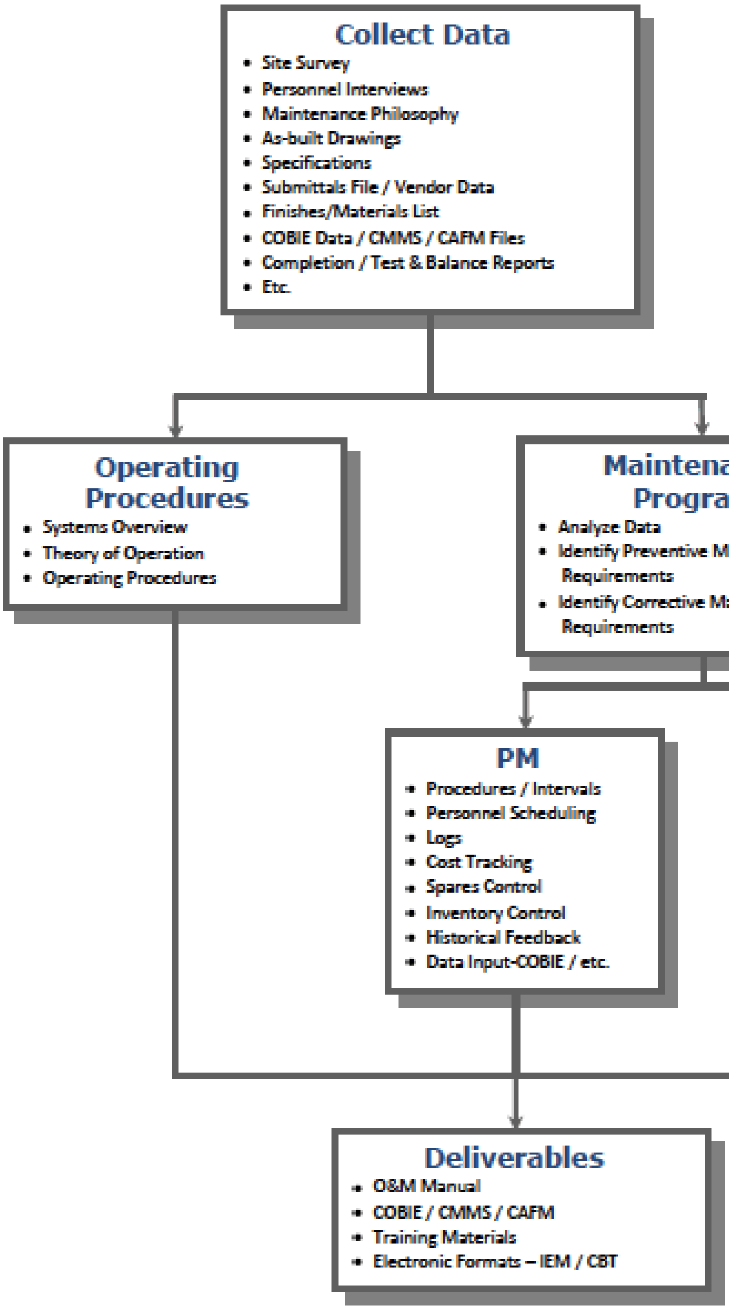


Figure 1. Operation & Maintenance Manual Development Process

O&M manuals should be developed in a modular, building block style, to simplify the incorporation of new/additional data, such as design/configuration changes, and to reflect as-built conditions. The manual should be available no later than facility start- up/commissioning. However, fast track programs can be 'front-end loaded' to meet immediate goals; i.e. only that information necessary to train personnel in preparation for systems start-up/commissioning can be developed first. It can then be integrated with the overall O&M manual for completion and turnover to the Owner within a specified timeframe. Using the manual at start-up/commissioning affords an additional opportunity for its contents to be verified against installed systems.

The efforts of experienced technical writers, editors, engineering technicians, trainers, 3D modelers, illustrators, and software specialists can ensure that an Owner receives comprehensive, site-specific (as-built), user-oriented documentation of the highest quality. Those selected to perform the work should have the following capabilities:

- Collect pertinent data through interviews with staff, engineers, equipment manufacturers / installers / integrators, etc., submittals, and on-site verification of as-installed systems/equipment and related physical data collection.
- Review, analyze, and evaluate the facility at the system level using engineering/technical data collected.
- Identify/develop procedures required to attain the most efficient systems integration.
- Develop the O&M manual contents using terms that maintenance personnel with general technical expertise understand.
- Provide a high level of confidence to the Owner's staff, e.g., through accurate contentand user-friendly format.

O&M procedures at the system level do not replace manufacturers' documentation for specific pieces of equipment, but rather supplement those publications and guide their use. For example, system-level troubleshooting will fault-analyze to the component level, such as a pump, valve, or motor, then reference specific manufacturer requirements to remove/clean/inspect/repair/test or replace the component.

Training for new personnel is considered a vital element of operation & maintenance,especially when new equipment is installed or emerging technology is being employed. It's important to the overall facility management program that facilities personnel be properly instructed and motivated. Training courses will familiarize personnel with the procedures necessary to operate and maintain complex systems and equipment, often using the system-level O&M manual as a basis of information. Courses can be developed for presentation by subject-matter experts/trainers, or if specified, through computer-based training (CBT) and multimedia technologies, ideal for individual/self training in either a classroom setting or through the company intranet or over the internet.

O&M manuals, likewise conducive for use in training, can be provided in both paper and as an 'on-line' interactive electronic manuals (IEM) developed using web-based and other accepted applications (html, xml, PDF, etc.). Training should be ongoing to keep pace with technology and equipment changes in the facility.

A. Maintenance Program

Preventive Maintenance (PM) consists of a series of maintenance requirements that provide a basis for planning, scheduling, and executing scheduled maintenance, planned versus corrective for the purpose of improving equipment life and to avoid any unplanned maintenance activity/minimize equipment breakdowns. These can be defined through a Maintenance Plan (MP). PM includes adjusting, lubricating, cleaning, painting, and replacing minor components. Time intensive PM, such as bearing/seal replacement (as identified by predictive maintenance), would typically be scheduled/planned for regular plant or 'line' shutdown periods.
The O&M manual itself, and particularly the CMMS or CAFM data, should be maintained on an as-needed basis, typically whenever systems/equipment are "changed out."

MAINTENANCE PLAN (MP)

The purpose of a Maintenance Plan (MP) is to describe the best means to maximize equipment operational availability, while minimizing equipment downtime. Once developed, the MP will typically identify PM task descriptions and schedules, troubleshooting, corrective maintenance (repair) task descriptions, and spare parts identification, stockage (quantity), and any unique storage requirements. This information will be incorporated in the manual, both as tabular data and text.

PREVENTIVE MAINTENANCE DATA

Preventive maintenance (PM) data includes equipment tag information, procedures, replacement parts, special tools, lubrication requirements, service providers, warranty information, etc. It is often presented in tabular format in the O&M manual. Construction-Operations Building information exchange (COBie)—If specified (based on the draft guide specification, COBie facilitates the capture of real-time as-built asset information by using the collection of contractor submittals. COBie may also be applied through Building Information Modeling (BIM) technology, although BIM is not necessary to implement COBie. Any project can take advantage of/utilize COBie to increase the accuracy and timeliness of data that can be incorporated into system- level operation and maintenance manuals as well as CMMS.

The collection of data can start early in the process as it has been determined thatup to 48% of the data is available at the 100% design phase. Stretching out the process avoids the tsunami of information at handover. The BIM should be used for commissioning, and then the information can be provided immediately for O&M use the day the facility opens. Using the National BIM Standard-United States™ open information standards will help ensure that the project is not locked into any one vendor and can use any product that supports the open standard for BIM.

CMMS/CAFM applications typically support facility management needs associated with personnel, leasing, furniture, construction, equipment (including fleet vehicles), labor, spare parts inventory (with bar coding), PM scheduling, work order generation, and associated costs tracking. The CMMS/CAFM products should have the ability to be tailored to Owner-specific requirements.

B. O&M Manual Layout And Contents

O&M Manuals provide procedures to operate and maintain a facility's various systems and equipment. It is important to analyze and evaluate a facility from the system level, then develop procedures to attain the most efficient systems integration, based on as-built information and the Maintenance Program philosophy. The following paragraphs provide an example of system-level O&M Manual layout and technical content/description that can be successfully applied to many facility types.

SYSTEM-LEVEL O&M MANUAL LAYOUT

- ***Introduction***: Introduces the reader to the facility. Outlines the structure, content, how to use the manual, and includes a brief outline of the various systems covered. In addition, this chapter contains a list of emergency contacts and a list of supplementary material available on the facility such as:
  - Design/Construction Specifications

- Submittals File
    - Completion Report
    - As-built Drawings
    - Materials List
    - Certified Tests and Reports
        - Civil/Sanitary
        - Mechanical/HVAC
        - Electrical
- ***Safety Data***: Safety hazards commonly associated with the operation of system/equipment applicable to the facility are identified and their prevention is discussed.
- ***Utility Systems***: Discusses the various site utility systems that interface with the facility. These include water supply systems, sanitary waste, electrical, natural gas, communications, security, and storm water, etc.
- ***Building Interior & Exterior***: Includes housekeeping and general maintenance of the facility. The importance of conducting an annual inspection is discussed together with record keeping forms for conducting the inspections.
- ***Plumbing***: O&M of the domestic water and sanitary waste systems.
- ***Fire Protection***: O&M of the fire protection wet/dry pipe sprinkler systems.
- ***Heating, Ventilating & Air Conditioning (HVAC)***: O&M of the building's HVAC systems, including automated controls and exhaust, space heating, and central air systems.
- ***Fire Detection & Intrusion Alarms***: O&M of fire detection, intrusion detection, and alarm systems (wet/dry pipe sprinkler).
- ***Electrical***: O&M of power distribution equipment and backup/emergency electrical systems (uninterruptible power supply, generator).
- ***Conveying Systems***: General information and preventive maintenance for elevators, escalators, wheel chair lifts, conveyors, etc.
- ***Other Systems Based on Facility Requirements***: General information and preventive maintenance requirements for other systems and equipment not already identified.
- ***Operating Logs***: General information and instructions for using maintenance log forms. A listing of maintenance tasks with their recommended frequencies of performance is included.
- ***Maintenance Charts***: Maintenance charts include maintenance frequency checklists, maintenance summary, lamp replacement data sheet, equipment data sheets, recommended maintenance and service contacts, and a recommended work order form.
- ***Manufacturers' Literature***: Identifies manuals, cut sheets, etc., from equipment manufacturers that amplify information provided within the system-level O&M manual. Manufacturers' literature generally provides procedures to operate, maintain, troubleshoot, and repair specific items at the equipment level. This information is contained in a separate volume of binders, identified by facility/system, for easy reference. Specific material or complete documents can also be electronically scanned for its 'on-line' use, such as linking from the system-level manual.

SYSTEM-LEVEL O&M MANUAL TECHNICAL CONTENT/DESCRIPTION

- ***Description - System-Level***: Description of the system and its purpose, how it operates, and any interfaces it may have. A table can provide overall system design criteria, i.e. flow, pressure, temperature, capacity, power requirements, etc.
- ***Operating Procedures - Controls/Start-up/Shutdown/Emergency Over-Ride/Seasonal Changeover***: Operating instructions include equipment configurations for each mode of operation, e.g. valve positions, control settings, intended operating strategies, and break-in procedures.
- ***Problems and Solutions - Troubleshooting***: System-level troubleshooting tables guide maintenance personnel, via fault tree analysis, in a sequential, step-by-step isolation of a system problem to identify faulty equipment. Typical malfunctions, tests, or inspections, and corrective actions or recommendations to correct malfunctions are included.
- ***Preventive (Planned) Maintenance (PM) - Procedures/Intervals***: Maintenance tasks are developed for equipment that comprises the system. Preventive and corrective maintenance are discussed. Scheduled intervals (e.g., daily, weekly, monthly, etc.) are determined and assigned to PM tasks to maximize systems' run time, thereby reducing corrective maintenance tasks.

FIGURES/ILLUSTRATIONS

Operation-/ maintenance-significant figures/illustrations should be included in the manual and referenced from the narrative text. Illustrations can provide the layout of the overall site-campus/facility/floor down to systems/equipment and area/room locations. They can be generated for O&M Manual use from BIM/3D models and engineering drawings that are modified for ease of readability in the manual. They typically include the following:

- Area floor plans with system/ equipment tags and physical (room) locations identified.
- Safety warnings and cautions regarding potential hazards, both to personnel and to equipment.
- Photographs of systems/equipment with identifying callouts.
- Electrical schematics, piping diagrams, and air flow schematics provide equipment interconnections and are important for troubleshooting.
- Valve schedules indicating valve number, location, type, size, normal position, and description.

C. Electronic Formats

The elements of narrative text (pdf, html, xml, etc.), graphics including BIM, sound, photographs, and videos can all be organized into a user-friendly, interactive, stand-alone PC or web-based (e.g., Intranet) application or platform.
For O&M manuals, it is often referred to as the Interactive Electronic Manual (IEM), for training materials, Computer-Based Training (CBT). Similar to this document, text and graphical information is typically linked to related data within the O&M manual, or to external sources such as an Owner's intranet or the internet, accessed by a click of the mouse. One caution relative to linking to internet sources is that of security. The Owner's information technology (IT) department should be consulted in these instances.
Screens can be printed on demand. All information, including text, BIM / 3D models / animations, CAD drawings , illustrations, and digital photographs can be viewed and manipulated (read only) by on-line viewers and can only be modified off-line.
Updates/modifications are typically through a configuration management process and formal authorization.

D. Typical Task Performance

Based on the owner's SOW/scope requirements and maintenance philosophy:

- Perform a review and extract as-built information from engineering data such as the basis of design, specifications, as-built drawings, and submittals, vendor/manufacturer documentation, site visit(s), etc., to prepare a comprehensive facility maintenance plan.
- Organize and develop information into a clear and concise system-level O&M manual.
    - Physical Descriptions
    - Functional Descriptions
    - Troubleshooting
    - Preventive Maintenance (procedures and schedules)
    - Corrective Maintenance (repair requirements)
    - Parts Lists
- Organize and tailor scanned / electronic versions of graphical information (e.g., CAD drawings, BIM/3D models, illustrations, digital photographs, etc.) to support text.
- Compile warranty information.
- Compile spare parts lists.
- Enter pertinent data via COBie for its transfer into the owner's CMMS or CAFM application for use by the operation and maintenance staff.
- Create equipment-specific O&M information (vendor/manufacture data) library.
- Develop training plan, student/instructor guides, presentation materials, etc.
- Develop IEM/CBT.

E. Caution

Avoid having independent redundant information, such as data in the CAFM/CMMS application and data in a hardcopy facility O&M manual, that are not integrated. If the information is not linked, then any equipment changes will require updates to both the CAFM/CMMS database and the facility O&M manual.

APPLICATION

This information is applicable to governmental; military; industrial; and commercial facilities such as offices, laboratories, institutions, historical buildings, manufacturing, water/wastewater treatment, hangars, test facilities, etc. The philosophy behind the development of supporting O&M documentation is often predicated on the Owner's O&M organizational capabilities. This in itself may require the performance of a task and skills *analysis to ensure that any given facility is staffed appropriately.*

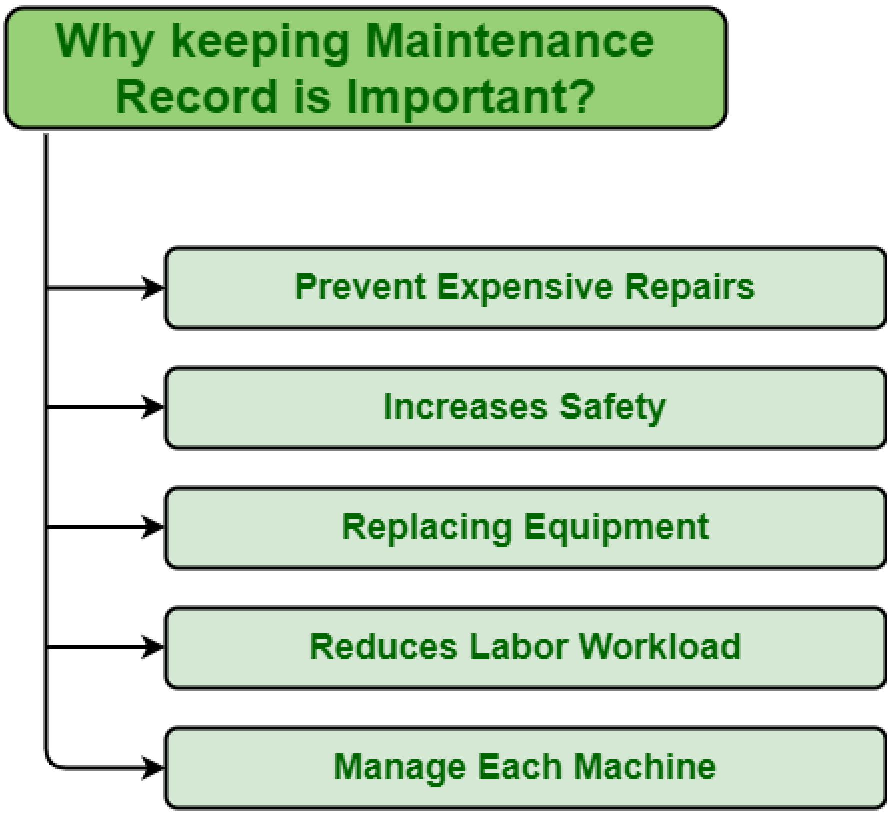
Maintenance record

Maintenance record, as name suggests, is a document that includes information regarding each repair and maintenance work that is done on asset or equipment. In simple words, it keeps tracks of assets failures and repairs. It is one of best way to maintain health and safety management. It also improves asset management as such record includes information such as :

- Time and date when maintenance is required to be done.
- Type of maintenance required to be done.
- Asset details such as number, parts required, working condition, etc.
- Risk associated with it.
- Environment condition and its affect.

Advantages of keeping Maintenance Record:

There are several benefits of keeping maintenance record. Some of them are given below:



1. **Prevent Expensive Repairs:**

Asset Maintenance is something that leads to increase in overall cost of organizations. Some assets maintenance is less costly and some of them arevery high. Repair cost is simply amount required to bring back asset back to its normal working condition. Maintenance record keeps information regarding reach maintenance and repair done on equipment. With help of maintenance record, one can easily determine when and which maintenance strategy is required to be performed on particular asset. These helps to prevent assetsfrom failure and reduces cost required to repair.

2. **IncreasesSafety:**

Maintenance record also includes information regarding affect of each assets failure on system, employees, environment. It also includes information regarding how workers or operators are performing their tasks. With help of maintenance record, one can easily determine how severe asset is, when its going to fail, how it can be prevented from failure so that one can take measure steps to prevent it from occurrence. This is turn reduces risk regarding safety and environmental health. It also helps one to ensure that which equipment'sare safe to work with. Even operators or workers also perform their task in well manner.

3. **Replacing Equipment :**

Maintenance record includes information regarding asset failure about number of times particular asset is getting failed, asset condition. One can easily determine about working condition of asset, when asset is required to repair, cost associated with each repair of particular asset. One of main advantage is that, one can easily determine when asset is required to be replaced. If repaircost of asset is more than cost required to replace with new one, then its much better to replace asset with new one as it can reduce cost, reduces failureoccurrences, includes warranty, minimizes effort required to repair, etc.

4. Reduce Labor Workload :

As we know that with help of maintenance record, one can prevent failure from occurrence. It helps to reduces unnecessary maintenance work required, schedule maintenance work that is required, help management to ensure employees, workers or labors that are performing well, labors that are required to perform tasks. This simply reduces efforts required to repair assets. In turn, it reduces number of labors required to perform task and as well as reduce labor workload.

5. Manage Each Machine :

Maintenance record keeps each information about assets. It includes working details, maintenance details, repair details, working environment, its processing, risk associated with it, etc. With help of all this information, one can perform maintenance task whenever required so that assets condition is maintained well, prevent it from failures, and increases its life span.

An Introduction to Total ProductiveMaintenance (TPM)

By Venkatesh J

http://www.plant-maintenance.com/articles/tpm_intro.shtml

What is Total Productive Maintenance (TPM) ?

It can be considered as the medical science of machines. Total Productive Maintenance (TPM) is a maintenance program which involves a newly defined concept for maintaining plants and equipment. The goal of the TPM program is to markedly increase production while, at the same time, increasing employee morale and job satisfaction.

TPM brings maintenance into focus as a necessary and vitally important part of the business. It isno longer regarded as a non-profit activity. Down time for maintenance is scheduled as a part of the manufacturing day and, in some cases, as an integral part of the manufacturing process. The goal is to hold emergency and unscheduled maintenance to a minimum.

Why TPM ?

TPM was introduced to achieve the following objectives. The important ones are listed below.

- Avoid wastage in a quickly changing economic environment.
- Producing goods without reducing product quality.
- Reduce cost.
- Produce a low batch quantity at the earliest possible time.
- Goods send to the customers must be non defective.

Similarities and differences between TQM andTPM :

The TPM program closely resembles the popular Total Quality Management (TQM) program. Many of the tools such as employee empowerment, benchmarking, documentation, etc. used inTQM are used to implement and optimize TPM.Following are the similarities between the two.

1. Total commitment to the program by upper level management is required in bothprogrammes
2. Employees must be empowered to initiate corrective action, and
3. A long range outlook must be accepted as TPM may take a year or more to implementand is an on-going process. Changes in employee mind-set toward their job responsibilities must take place as well.

The *differences* between TQM and TPM is summarized below.

Category	TQM	TPM
Object	Quality (Output and effects)	Equipment (Input and cause)
Mains of attaining goal	Systematize the management. It issoftware oriented	Employees participation and it ishardware oriented
Target	Quality for PPM	Elimination of losses and wastes.

Types of maintenance :

1. Breakdown maintenance :

It means that people waits until equipment fails and repair it. Such a thing could be used when the equipment failure does not significantly affect the operation or production or generate any significant loss other than repair cost.

2. Preventive maintenance (1951):

It is a daily maintenance (cleaning, inspection, oiling and re-tightening), design to retain the healthy condition of equipment and prevent failure through the prevention of deterioration, periodic inspection or equipment condition diagnosis, to measure deterioration. It is further divided into periodic maintenance and predictive maintenance. Just like human life is extended by preventive medicine, the equipment service life can be prolonged by doing preventive maintenance.

2a. Periodic maintenance (Time based maintenance - TBM) :

Time based maintenance consists of periodically inspecting, servicing and cleaning equipmentand replacing parts to prevent sudden failure and process problems.

2b. Predictive maintenance :

This is a method in which the service life of important part is predicted based on inspection or diagnosis, in order to use the parts to the limit of their service life. Compared to periodic maintenance, predictive maintenance is condition based maintenance. It manages trend values, by measuring and analyzing data about deterioration and employs a surveillance system, designed to monitor conditions through an on-line system.

3. Corrective maintenance (1957) :

It improves equipment and its components so that preventive maintenance can be carried out reliably. Equipment with design weakness must be redesigned to improve reliability or improvingmaintainability

4. Maintenance prevention (1960):

It indicates the design of a new equipment. Weakness of current machines are sufficiently studied (on site information leading to failure prevention, easier maintenance and prevents of defects, safety and ease of manufacturing) and are incorporated before commissioning a new equipment.

TPM - History:

TPM is a innovative Japanese concept. The origin of TPM can be traced back to 1951 when preventive maintenance was introduced in Japan. However the concept of preventive maintenance was taken from USA. Nippondenso was the first company to introduce plant wide preventive maintenance in 1960. Preventive maintenance is the concept wherein, operators produced goods using machines and the maintenance group was dedicated with work of maintaining those machines, however with the automation of Nippondenso, maintenance became a problem as more maintenance personnel were required. So the management decided that the routine maintenance of equipment would be carried out by the operators. (This is Autonomous maintenance, one of the features of TPM). Maintenance group took up only essential maintenance works.

Thus Nippondenso which already followed preventive maintenance also added Autonomous maintenance done by production operators. The maintenance crew went in the equipment modification for improving reliability. The modifications were made or incorporated in new equipment. This lead to maintenance prevention. Thus *preventive maintenance* along with *Maintenance prevention* and *Maintainability Improvement* gave birth to ***Productive maintenance***. The aim of productive maintenance was to maximize plant and equipment effectiveness to achieve optimum life cycle cost of production equipment.

By then Nippon Denso had made quality circles, involving the employees participation. Thus allemployees took part in implementing Productive maintenance. Based on these developments Nippondenso was awarded the distinguished plant prize for developing and implementing TPM, by the *Japanese Institute of Plant Engineers* (JIPE). Thus Nippondenso of the Toyota group became the first company to obtain the TPM certification.

TPM Targets:

P
Obtain Minimum 80% OPE.
Obtain Minimum 90% OEE (Overall Equipment Effectiveness)
Run the machines even during lunch. (Lunch is for operators and not for machines !)

Q
Operate in a manner, so that there are no customer complaints.

C
Reduce the manufacturing cost by
30%.D

Achieve 100% success in delivering the goods as required by the customer.

S
Maintain a accident free environment.

M
Increase the suggestions by 3 times. Develop Multi-skilled and flexible workers.

Motives of TPM	1. Adoption of life cycle approach for improving the overall performance ofproduction equipment. 2. Improving productivity by highly motivated workers which is achieved byjob enlargement. 3. The use of voluntary small group activities for identifying the cause offailure, possible plant and equipment modifications.
Uniqueness of TPM	The major difference between TPM and other concepts is that the operators are also made to involve in the maintenance process. The concept of *"I (Production operators) Operate, You (Maintenance department) fix"* is not followed.
TPM Objectives	1. Achieve Zero Defects, Zero Breakdown and Zero accidents in allfunctional areas of the organization. 2. Involve people in all levels of organization. 3. Form different teams to reduce defects and Self Maintenance.
Direct benefits of TPM	1. Increase productivity and OPE (Overall Plant Efficiency) by 1.5 or 2times. 2. Rectify customer complaints. 3. Reducethe manufacturing cost by 30%. 4. Satisfy the customers needs by 100 % (Delivering the right quantity atthe right time, in the required quality.) 5. Reduce accidents. 6. Follow pollution control measures.
Indirect benefits of TPM	1. Higher confidence level among the employees. 2. Keep the work place clean, neat and attractive. 3. Favorablechange in the attitude of the operators. 4. Achieve goals by working as team. 5. Horizontaldeployment of a new concept in all areas of the organization. 6. Share knowledge and experience. 7. The workers get a feeling of owning the machine.

OEE (Overall Equipment Efficiency) :

OEE = A x PE x Q

A - Availability of the machine. Availability is proportion of time machine is actually available out oftime it should be available.

A = (MTBF - MTTR) / MTBF.

MTBF - Mean Time Between Failures = (Total Running Time) / Number of Failures.MTTR - Mean Time To Repair.

PE - Performance Efficiency. It is given by RE X SE.

Rate efficiency (RE) : Actual average cycle time is slower than design cycle time because ofjams, etc. Output is reduced because of jams
Speed efficiency (SE) : Actual cycle time is slower than design cycle time machine output isreduced because it is running at reduced speed.

Q - Refers to quality rate. Which is percentage of good parts out of total produced sometimes called "yield".

Steps in introduction of TPM in a organization :

Step A - PREPARATORY STAGE :

STEP 1 - Announcement by Management to all about TPM introduction in the organization :

Proper understanding, commitment and active involvement of the top management in needed for this step. Senior management should have awareness programmes, after which announcement is made to all. Publish it in the house magazine and put it in the notice board. Send a letter to all concerned individuals if required.

STEP 2 - Initial education and propaganda for TPM :

Training is to be done based on the need. Some need intensive training and some just an awareness. Take people who matters to places where TPM already successfully implemented.

STEP 3 - Setting up TPM and departmental committees :

TPM includes improvement, autonomous maintenance, quality maintenance etc., as part of it.When committees are set up it should take care of all those needs.

STEP 4 - Establishing the TPM working system and target :

Now each area is benchmarked and fix up a target for achievement.

STEP 5 - A master plan for institutionalizing :

Next step is implementation leading to institutionalizing wherein TPM becomes an organizational culture. Achieving PM award is the proof of reaching a satisfactory level.

STEP B - INTRODUCTION STAGE

This is a ceremony and we should invite all. Suppliers as they should know that we want qualitysupply from them. Related companies and affiliated companies who can be our customers, sisters concerns etc. Some may learn from us and some can help us and customers will get thecommunication from us that we care for quality output.

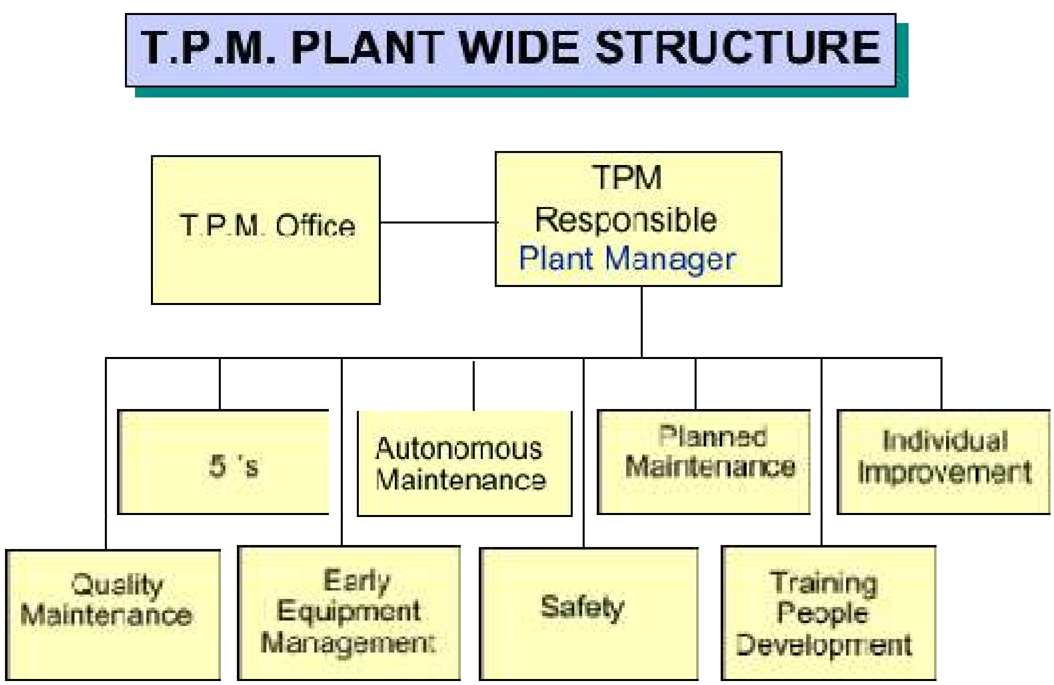
STAGE C - IMPLEMENTATION

In this stage eight activities are carried which are called eight pillars in the development of TPMactivity.
Of these four activities are for establishing the system for production efficiency, one for initial control system of new products and equipment, one for improving the efficiency of administrationand are for control of safety, sanitation as working environment.

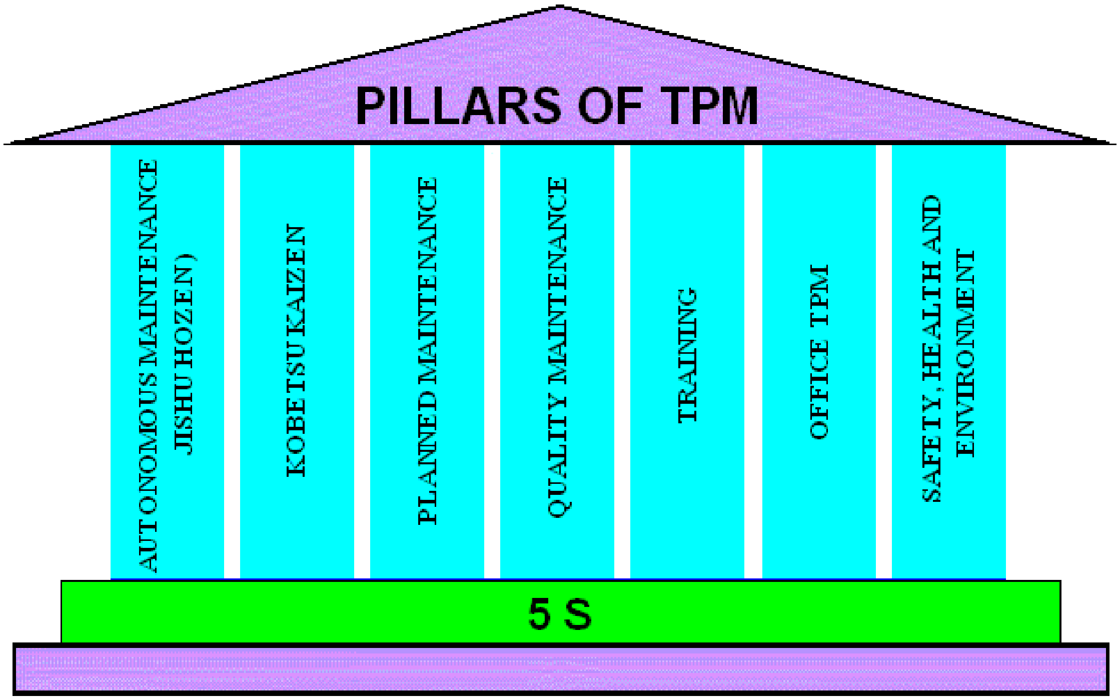
STAGE D - INSTITUTIONALISING STAGE

By all there activities one would has reached maturity stage. Now is the time for applying for PM award. Also think of challenging level to which you can take this movement.

Organization Structure for TPMImplementation:



Pillars of TPM



PILLAR 1 - 5S :

TPM starts with 5S. Problems cannot be clearly seen when the work place is unorganized. Cleaning and organizing the workplace helps the team to uncover problems. Making problemsvisible is the first step of improvement.

Japanese Term	**English Translation**	**Equivalent 'S' term**
Seiri	Organisation	Sort
Seiton	Tidiness	Systematise
Seiso	Cleaning	Sweep
Seiketsu	Standardisation	Standardise
Shitsuke	Discipline	Self - Discipline

SEIRI - Sort out :

This means sorting and organizing the items as critical, important, frequently used items, useless, or items that are not need as of now. Unwanted items can be salvaged. Critical items should be kept for use nearby and items that are not be used in near future, should be stored in some place. *For this step, the worth of the item should be decided based on utility and not cost*. As a result of this step, the search time is reduced.

Priority	**Frequency of Use**	**How to use**
Low	Less than once per year, Once per year<	Throw away, Store away from the workplace
Average	At least 2/6 months, Once per month,Once per week	Store together but offline
High	Once Per Day	Locate at the workplace

SEITON - Organise :

The concept here is that "*Each items has a place, and only one place*". The items should be placed back after usage at the same place. To identify items easily, name plates and colored tagshas to be used. Vertical racks can be used for this purpose, and heavy items occupy the bottom position in the racks.

SEISO - Shine the workplace :

This involves cleaning the work place free of burrs, grease, oil, waste, scrap etc. No looselyhanging wires or oil leakage from machines.

SEIKETSU - Standardization :

Employees has to discuss together and decide on standards for keeping the work place / Machines / pathways neat and clean. This standards are implemented for whole organization andare tested / Inspected randomly.

SHITSUKE - Self discipline :

Considering 5S as a way of life and bring about self-discipline among the employees of the organization. This includes wearing badges, following work procedures, punctuality, dedication tothe organization etc.

PILLAR 2 - JISHU HOZEN (Autonomous maintenance) :

This pillar is geared towards developing operators to be able to take care of small maintenance tasks, thus freeing up the skilled maintenance people to spend time on more value added activity and technical repairs. The operators are responsible for upkeep of their equipment to prevent it from deteriorating.

Policy :

1. Uninterrupted operation of equipments.
2. Flexible operators to operate and maintain other equipments.
3. Eliminating the defects at source through active employee participation.
4. Stepwise implementation of JH activities.

JISHU HOZEN Targets:

1. Prevent the occurrence of 1A / 1B because of JH.
2. Reduce oil consumption by 50%
3. Reduce process time by 50%
4. Increase use of JH by 50%

Steps in JISHU HOZEN :

1. Preparation of employees.
2. Initial cleanup of machines.
3. Take counter measures
4. Fix tentative JH standards
5. General inspection
6. Autonomous inspection
7. Standardization and
8. Autonomous management.

Each of the above mentioned steps is discussed in detail below.

1. Train the Employees : Educate the employees about TPM, Its advantages, JH advantages and Steps in JH. Educate the employees about abnormalities in equipments.
2. Initial cleanup of machines :
    - Supervisor and technician should discuss and set a date for implementing step1
    - Arrange all items needed for cleaning
    - On the arranged date, employees should clean the equipment completely withthe help of maintenance department.
    - Dust, stains, oils and grease has to be removed.
    - Following are the things that has to be taken care while cleaning. They are Oilleakage, loose wires, unfastened nits and bolts and worn

out parts.

- After clean up problems are categorized and suitably tagged. White tags is place where problems can be solved by operators. Pink tag is placed where the aid of maintenance department is needed.
- Contents of tag is transferred to a register.
- Make note of area which were inaccessible.
- Finally close the open parts of the machine and run the machine.

3. Counter Measures :
    - Inaccessible regions had to be reached easily. E.g. If there are many screw to open a fly wheel door, hinge door can be used. Instead of opening a door for inspecting the machine, acrylic sheets can be used.
    - To prevent work out of machine parts necessary action must be taken.
    - Machine parts should be modified to prevent accumulation of dirt and dust.
4. Tentative Standard :
    - JH schedule has to be made and followed strictly.
    - Schedule should be made regarding cleaning, inspection and lubrication and italso should include details like when, what and how.
5. General Inspection :
    - The employees are trained in disciplines like Pneumatics, electrical, hydraulics,lubricant and coolant, drives, bolts, nuts and Safety.
    - This is necessary to improve the technical skills of employees and to useinspection manuals correctly.
    - After acquiring this new knowledge the employees should share this with others.
    - By acquiring this new technical knowledge, the operators are now well aware ofmachine parts.
6. Autonomous Inspection :
    - New methods of cleaning and lubricating are used.
    - Each employee prepares his own autonomous chart / schedule in consultationwith supervisor.
    - Parts which have never given any problem or part which don't need any inspection are removed from list permanently based on experience.
    - Including good quality machine parts. This avoid defects due to poor JH.
    - Inspection that is made in preventive maintenance is included in JH.
    - The frequency of cleanup and inspection is reduced based on experience.
7. Standardization :
    - Upto the previous stem only the machinery / equipment was the concentration. However in this step the surroundings of machinery are organized. Necessary items should be organized, such that there is no searching and searching time isreduced.
    - Work environment is modified such that there is no difficulty in getting any item.
    - Everybody should follow the work instructions strictly.
    - Necessary spares for equipments is planned and procured.

8. Autonomous Management :
    - OEE and OPE and other TPM targets must be achieved by continuous improvethrough Kaizen.
    - PDCA (Plan, Do, Check and Act) cycle must be implemented for Kaizen.

PILLAR 3 - KAIZEN :

"Kai" means change, and "Zen" means good (for the better). Basically kaizen is for small improvements, but carried out on a continual basis and involve all people in the organization. Kaizen is opposite to big spectacular innovations. Kaizen requires no or little investment. The principle behind is that "a very large number of small improvements are move effective in an organizational environment than a few improvements of large value. This pillar is aimed at reducing losses in the workplace that affect our efficiencies. By using a detailed and thorough procedure we eliminate losses in a systematic method using various Kaizen tools. These activities are not limited to production areas and can be implemented in administrative areas aswell.

Kaizen Policy :

1. Practice concepts of zero losses in every sphere of activity.
2. relentless pursuit to achieve cost reduction targets in all resources
3. Relentless pursuit to improve over all plant equipment effectiveness.
4. Extensive use of PM analysis as a tool for eliminating losses.
5. Focus of easy handling of operators.

Kaizen Target :

Achieve and sustain zero loses with respect to minor stops, measurement and adjustments, defects and unavoidable downtimes. It also aims to achieve 30% manufacturing cost reduction.

Tools used in Kaizen :

1. PM analysis
2. Why - Why analysis
3. Summary of losses
4. Kaizen register
5. Kaizen summary sheet.

The objective of TPM is maximization of equipment effectiveness. TPM aims at maximization of machine utilization and not merely machine availability maximization. As one of the pillars of TPMactivities, Kaizen pursues efficient equipment, operator and material and energy utilization, that isextremes of productivity and aims at achieving substantial effects. Kaizen activities try to thoroughly eliminate 16 major losses.

16 Major losses in a organisation:

Loss	***Category***
1. Failure losses - Breakdown loss 2. Setup / adjustment losses 3. Cutting blade loss 4. Start up loss 5. Minor stoppage / Idling loss. 6. Speed loss - operating at lowspeeds. 7. Defect / rework loss 8. Scheduled downtime loss	Losses that impede equipment efficiency
9. Management loss 10. Operating motion loss 11. Line organization loss 12. Logistic loss 13. Measurement and adjustment loss	Loses that impede human work efficiency
14. Energy loss 15. Die, jig and tool breakage loss 16. Yield loss.	Loses that impede effective use of production resources

Classification of losses :

Aspect	**Sporadic Loss**	**Chronic Loss**
Causation	Causes for this failure can be easily traced. Cause-effect relationship is simple to trace.	This loss cannot be easily identified and solved. Even if various counter measures areapplied
Remedy	Easy to establish a remedialmeasure	This type of losses are caused because of hidden defects in machine, equipment and methods.
Impact / Loss	A single loss can be costly	A single cause is rare - a combination of causes trends tobe a rule
Frequency of occurrence	The frequency of occurrence is low and occasional.	The frequency of loss is more.

Corrective action	Usually the line personnel in the production can attend to this problem.	Specialists in process engineering, quality assuranceand maintenance people are required.

PILLAR 4 - PLANNED MAINTENANCE :

It is aimed to have trouble free machines and equipments producing defect free products for total customer satisfaction. This breaks maintenance down into 4 "families" or groups which was defined earlier.

1. Preventive Maintenance
2. Breakdown Maintenance
3. Corrective Maintenance
4. Maintenance Prevention

With Planned Maintenance we evolve our efforts from a reactive to a proactive method and use trained maintenance staff to help train the operators to better maintain their equipment.

Policy :

1. Achieve and sustain availability of machines
2. Optimum maintenance cost.
3. Reduces spares inventory.
4. Improve reliability and maintainability of machines.

Target :

1. Zero equipment failure and break down.
2. Improve reliability and maintainability by 50 %
3. Reduce maintenance cost by 20 %
4. Ensure availability of spares all the time.

Six steps in Planned maintenance :

1. Equipment evaluation and recoding present status.
2. Restore deterioration and improve weakness.
3. Building up information management system.
4. Prepare time based information system, select equipment, parts and members and mapout plan.
5. Prepare predictive maintenance system by introducing equipment diagnostic techniquesand
6. Evaluation of planned maintenance.

PILLAR 5 - QUALITY MAINTENANCE :

It is aimed towards customer delight through highest quality through defect free manufacturing. Focus is on eliminating non-conformances in a systematic manner, much like Focused Improvement. We gain understanding of what parts of the equipment affect product quality and begin to eliminate current quality concerns, then move to potential quality concerns. Transition is from reactive to proactive (Quality Control to Quality Assurance).

QM activities is to set equipment conditions that preclude quality defects, based on the basic concept of maintaining perfect equipment to maintain perfect quality of products. The condition are checked and measure in time series to very that measure values are within standard values to prevent defects. The transition of measured values is watched to predict possibilities of defects occurring and to take counter measures before hand.

Policy :

1. Defect free conditions and control of equipments.
2. QM activities to support quality assurance.
3. Focus of prevention of defects at source
4. Focus on poka-yoke. (fool proof system)
5. In-line detection and segregation of defects.
6. Effective implementation of operator quality assurance.

Target :

1. Achieve and sustain customer complaints at zero
2. Reduce in-process defects by 50 %
3. Reduce cost of quality by 50 %.

Data requirements :

Quality defects are classified as <u>*customer end defects*</u> and <u>*in house*</u> defects. For customer-end data, we have to get data on

1. Customer end line rejection
2. Field complaints.

In-house, data include data related to products and data related to process

Data related to product :

1. Product wise defects
2. Severity of the defect and its contribution - major/minor
3. Location of the defect with reference to the layout
4. Magnitude and frequency of its occurrence at each stage of measurement
5. Occurrence trend in beginning and the end of each production/process/changes. (Likepattern change, ladle/furnace lining etc.)
6. Occurrence trend with respect to restoration of breakdown/modifications/periodicalreplacement of quality components.

Data related to processes:

1. The operating condition for individual sub-process related to men, method,

material andmachine.

2. The standard settings/conditions of the sub-process

3. The actual record of the settings/conditions during the defect occurrence.

PILLAR 6 - TRAINING :

It is aimed to have multi-skilled revitalized employees whose morale is high and who has eager to come to work and perform all required functions effectively and independently. Education is givento operators to upgrade their skill. It is not sufficient know only "Know-How" by they should also learn "Know-why". By experience they gain, "Know-How" to overcome a problem what to be done. This they do without knowing the root cause of the problem and why they are doing so.
Hence it become necessary to train them on knowing "Know-why". The employees should betrained to achieve the four phases of skill. The goal is to create a factory full of experts. The different phase of skills are

Phase 1 : Do not know.
Phase 2 : Know the theory but cannot do. Phase 3 : Can do but cannot teach Phase 4 : Can do and also teach.

Policy :

1. Focus on improvement of knowledge, skills and techniques.
2. Creating a training environment for self learning based on felt needs.
3. Training curriculum / tools /assessment etc conductive to employee revitalization
4. Training to remove employee fatigue and make work enjoyable.

Target :

1. Achieve and sustain downtime due to want men at zero on critical machines.
2. Achieve and sustain zero losses due to lack of knowledge / skills / techniques
3. Aim for 100 % participation in suggestion scheme.

Steps in Educating and training activities :

1. Setting policies and priorities and checking present status of education and training.
2. Establish of training system for operation and maintenance skill up gradation.
3. Training the employees for upgrading the operation and maintenance skills.
4. Preparation of training calendar.
5. Kick-off of the system for training.
6. Evaluation of activities and study of future approach.

PILLAR 7 - OFFICE TPM :

Office TPM should be started after activating four other pillars of TPM (JH, KK, QM, PM). Office TPM must be followed to improve productivity, efficiency in the administrative functions and identify and eliminate losses. This includes analyzing processes and procedures towards increased office automation. Office TPM addresses twelve major losses. They are

1. Processing loss
2. Cost loss including in areas such as procurement, accounts, marketing, sales leading tohigh inventories
3. Communication loss
4. Idle loss
5. Set-up loss
6. Accuracy loss
7. Office equipment breakdown
8. Communication channel breakdown, telephone and fax lines
9. Time spent on retrieval of information
10. Non availability of correct on line stock status
11. Customer complaints due to logistics
12. Expenses on emergency dispatches/purchases

How to start office TPM ?

A senior person from one of the support functions e.g. Head of Finance, MIS, Purchase etc should be heading the sub-committee. Members representing all support functions and peoplefrom Production & Quality should be included in sub committee. TPM co-ordinate plans and guides the sub committee.

1. Providing awareness about office TPM to all support departments
2. Helping them to identify P, Q, C, D, S, M in each function in relation to plant performance
3. Identify the scope for improvement in each function
4. Collect relevant data
5. Help them to solve problems in their circles
6. Make up an activity board where progress is monitored on both sides - results andactions along with Kaizens.
7. Fan out to cover all employees and circles in all functions.

Kobetsu Kaizen topics for Office TPM :

- Inventory reduction
- Lead time reduction of critical processes
- Motion & space losses
- Retrieval time reduction.

- Equalizing the work load
- Improving the office efficiency by eliminating the time loss on retrieval of information, by achieving zero breakdown of office equipment like telephone and fax lines.

Office TPM and its Benefits :

1. Involvement of all people in support functions for focusing on better plant performance
2. Better utilized work area
3. Reduce repetitive work
4. Reduced inventory levels in all parts of the supply chain
5. Reduced administrative costs
6. Reduced inventory carrying cost
7. Reduction in number of files
8. Reduction of overhead costs (to include cost of non-production/non capital equipment)
9. Productivity of people in support functions
10. Reduction in breakdown of office equipment
11. Reduction of customer complaints due to logistics
12. Reduction in expenses due to emergency dispatches/purchases
13. Reduced manpower
14. Clean and pleasant work environment.

P Q C D S M in Office TPM :

P - Production output lost due to want of material, Manpower productivity, Production output lostdue to want of tools.

Q - Mistakes in preparation of cheques, bills, invoices, payroll, Customer returns/warranty attributable to BOPs, Rejection/rework in BOP's/job work, Office area rework.

C - Buying cost/unit produced, Cost of logistics - inbound/outbound, Cost of carrying inventory,Cost of communication, Demurrage costs.

D - Logistics losses (Delay in loading/unloading)

- Delay in delivery due to any of the support functions
- Delay in payments to suppliers
- Delay in information

S - Safety in material handling/stores/logistics, Safety of soft and

hard data.M - Number of kaizens in office areas.

How office TPM supports plant TPM :

Office TPM supports the plant, initially in doing Jishu Hozen of the machines (after getting trainingof Jishu Hozen), as in Jishu Hozen at the

1. Initial stages machines are more and manpower is less, so the help of commercialdepartments can be taken, for this

2. Office TPM can eliminate the lodes on line for no material and logistics.

Extension of office TPM to suppliers and distributors :

This is essential, but only after we have done as much as possible internally. With suppliers it will lead to on-time delivery, improved 'in-coming' quality and cost reduction. With distributors it will lead to accurate demand generation, improved secondary distribution and reduction in damages during storage and handling. In any case we will have to teach them based on our experience and practice and highlight gaps in the system which affect both sides. In case of some of the larger companies, they have started to support clusters of suppliers.

PILLAR 8 - SAFETY, HEALTH AND ENVIRONMENT :

Target :

1. Zero accident,
2. Zero health damage
3. Zero fires.

In this area focus is on to create a safe workplace and a surrounding area that is not damaged byour process or procedures. This pillar will play an active role in each of the other pillars on a regular basis.

A committee is constituted for this pillar which comprises representative of officers as well as workers. The committee is headed by Senior vice President (Technical). Utmost importance to Safety is given in the plant. Manager (Safety) is looking after functions related to safety. To create awareness among employees various competitions like safety slogans, Quiz, Drama, Posters, etc. related to safety can be organized at regular intervals.

Conclusion:

Today, with competition in industry at an all time high, TPM may be the only thing that stands between success and total failure for some companies. It has been proven to be a program that works. It can be adapted to work not only in industrial plants, but in construction, building maintenance, transportation, and in a variety of other situations. Employees must be educated and convinced that TPM is not just another "*program of the month*" and that management is totally committed to the program and the extended time frame necessary for full implementation. If everyone involved in a TP[illegible] do [illegible] ed to reso[illegible]