UNIT IV

Plastic Processing, Ceramics and Powder Metallurgy

- Typesof plastics
- Plastics properties and their applications
- Processing of plastics
- Extrusion of plastics
- Transfer molding and compression molding
- Injection molding
- Thermoforming
- Rotational molding and blow molding

Ceramics: Classification of ceramic materials, properties and their application,

- Ceramic powder preparation;
- Processing of ceramic parts:
- Pressing,
- Casting,
- Sintering;
- Secondary processing of ceramics:
- Coatings,
- Finishing.

Powder Metallurgy: Principle, manufacture of powders, steps involved.

Plastic:

- Plastic is the general common term for a wide range of synthetic or semi synthetic organic amorphous solid materials suitable for the manufacture of industrial products.

- Plastics are typically polymers of high molecular weight, and may contain other substances to improve performance and/or reduce costs
- **Types of Plastics**
- Plastics can be divided into two major categories:
- **A.Thermoset or thermosetting plastics:**
- Once cooled and hardened, these plastics retain their shapes andcannot return to their original form. They are hard and durable. Thermosets can be used for auto parts, aircraft parts and tires.
- Examples include polyurethanes, polyesters, epoxy resins and phenolic resins.
- **B.Thermoplastics:**
- Less rigid than thermosets, thermoplastics can soften upon heating and return to their original form. They are easily molded and extruded into films, fibers and packaging.
- Examples include polyethylene (PE), polypropylene (PP) and polyvinyl chloride (PVC).
- **1. Polyurethane Plastics** :-
- Polyurethane plastics belong to the group that can be thermosetting. Polyurethane is the only plastic which can be made in both rigid and flexible foams. The flexible polyurethane foam is used in mattresses, carpets, furniture etc. The rigid polyurethane foam is used in chair shells, mirror frames and many more.
- Due to the property of high elasticity, some polyurethane plastics are used in decorative and protective coatings. The high elasticity makes these polyurethane plastics resistant to a chemical attack.

- **2. Epoxy:**
- Epoxies are used in numerous ways. In combination with glass fibers, it is capable of producing composites that are of high strength and that are heat resistant. This composite is typically used for filament wound rocket motor casings in missiles, in aircraft components, and in tanks, pipes, tooling jigs, pressure vessels, and fixtures.
- Epoxies are also found in gymnasium floors, industrial equipment, sealants, and protective coatings in appliances.
- **3. Phenolic:**
- Phenolic plastics are thermosetting resins used in potting compounds, casting resins, and laminating resins.
- They can also be used for electrical purposes and are a popular binder for holding together plies of wood for plywood.
- **B.Thermoplastics:**

  1.Vinyl Plastics :-
- Vinyl plastics belong to the thermoplastic group. Vinyl plastics are the sub-polymers of vinyl derivatives.
- These are used in laminated safety glasses, flexible tubing, molded products etc.

  2.Polyacrylics Plastics :-
- Polyacrylics belong to the group of thermoplastics. Polyacrylics are transparent and decorative.
- Polyacrylics plastics can be shaped in any form like the windshields for airplane pressure vessels, and fixtures. Epoxies are also found in gymnasium floors, industrial equipment, sealants, and protective coatings in appliances.

  3.Polyvinyl Chloride :

- Polyvinyl Chloride, commonly referred to as PVC or vinyl, was first invented in Germany around 1910. It didn't become a useful product in the United States, however, until the late 1920s. It became particularly useful during World War II when it was used as a substitute for rubber, which was in short supply. Polyvinyl Chloride is resistant to abrasion and is both weather and chemical resistant. Today, it is commonly found in upholstery, wall coverings, flooring, siding, pipe, and even apparel. In fact, vinyl is perhaps the best known of all plastics.

4.Polyethylene Terephthalate (PETE) :- PETE is one the most recycled plastic. It finds usage in various bottles like that of soda and cooking oil, etc.

5.High Density Polyethylene (HDPE) :- HDPE is generally used in detergent bottles and in milk jugs.

6.Polyvinyl Chloride (PVC) :-

- PVC is commonly used in plastic pipes, furniture, water bottles, liquid detergent jars etc.
- **7.Low Density Polyethylene (LDPE) :-**
- LDPE finds its usage in dry cleaning bags, food storage containers etc.
- **8.Polypropylene (PP) :-**
- PP is commonly used in bottle caps and drinking straws.
- **9.Polystyrene (PS) :-**
- PS is used in cups, plastic tableware etc.

Symbol	Type of Plastic	Properties	Common Uses	Recycled In
	PET Polyethylene Terephthalate	Clear, tough solvent resistant, barrier to gas and moisture, softens at around 80°C	Soft drink and water bottles, salad domes, biscuit trays, salad dressing and peanut butter containers	Pillow and sleeping bag filling, clothing, soft drink bottles carpet
	PE-HD High Density Polyethylene (HDPE)	Hard to semi-flexible, resistant to chemicals and moisture, waxy surface, opaque, softens at around 75°C, easily colored, processed and formed	Crinkly shopping bags, freezer bags, milk bottles, ice cream containers, juice bottles, shampoo, chemical and detergent bottles, buckets, rigid agricultural pipe, milk crates	Recycling bins, compost bins, buckets, detergent containers, posts, fencing, pipes
	PVC Unplasticised Polyvinyl Chloride PVC-U	Strong, tough, can be clear, can be solvent welded, softens at around 80°C	Cosmetic containers, electrical conduit, plumbing pipes and fittings, blister packs, wall cladding, roof sheeting, bottles	Flooring, film and sheets, cables, speed bumps, packaging, binders, mud flaps and mats
	Plasticised Polyvinyl Chloride PCV-P	Flexible, clear, elastic, can be solvent welded	garden hose, shoe soles, cable sheathing, blood bags and tubing, watch straps	

Characteristics of Plastics:

Mechanical properties:

Mechanical properties refer to displacement or breakage of plastic due to some mechanical change such as applying some load. Mechanical properties are dependent on the temperature, force (load), and the duration of time the load is applied. It may also be affected by ultra-violet radiation when used outside.

Thermal properties:

Thermal properties include heat resistance or combustibility. Thermoplastic has a larger coefficient of thermal expansion or combustibility and a smaller thermal conductivity or specific heat than other material such as metals.

Chemical properties:

Chemical resistance, environmental stress crack resistance , or resistance to environmental change are referred as chemical properties. When a plastic contacts chemicals, there is some kind of change. After having a plastic in contacted with chemicals under no stress for about a week, changes in appearance, weight and size of the plastic are examined. Such changes are referred to as chemical properties.

Electric properties:

Electric properties are also referred to as electromagnetic properties. Electric properties include insulation, conductivity and electro-static charges. Due to their good insulation property, plastics are often used in electric fields. However, plastics do have a defect; they are easily electrified.

Physical properties:

Specific gravity, index of refraction and moisture absorption are called physical properties. The specific gravity of the plastic is small, and it varies depending on the character of high polymer , or thermal and mechanical treatment of the plastic.

Materials for Processing Plastics :

Most Plastic resins have to be combined, compounded, or otherwise chemically treated with processing materials before they are ready for processing.

One of the following additions are usually employed;

1. Plasticizers

2. Fillers

3. Catalyst

4. Initiators

5. Dyes and Pigments

1. Plasticizers

i) Organic Solvents, resins, and even water are used as plasticizers.

ii) These substances act as internal lubricants improving flow of and giving toughness and flexibility to the material

iii)Plasticizers are also used to prevent crystallization by keeping the chains separated from one another.

2. Fillers:

i) Typical fillers which include wood floor, asbestos fiber, glass fiber, cloth fiber, mica, slate powders, may be added in high proportion to many plastics essentially to improve strength, dimensional stability, and heat resistance.

3. Catalyst :

These are usually added to promote faster and more complete polymerization.

As such they are also called accelerators and hardeners.

4. Initiators

It is used to initiate the reaction, i.e., to allow polymerization to begin

They stabilize the ends or reaction sites of the molecular chains.

H2O2 is a common initiator.

5. Dyes and Pigments

These are added in many cases, to color the material to different shades

Plastic Processes:

1. Moulding Process

2. Calendering Process

3. Thermoforming

4. Casting

5. Fabrication Process

1. Moulding Processes:

i.Compression Moulding

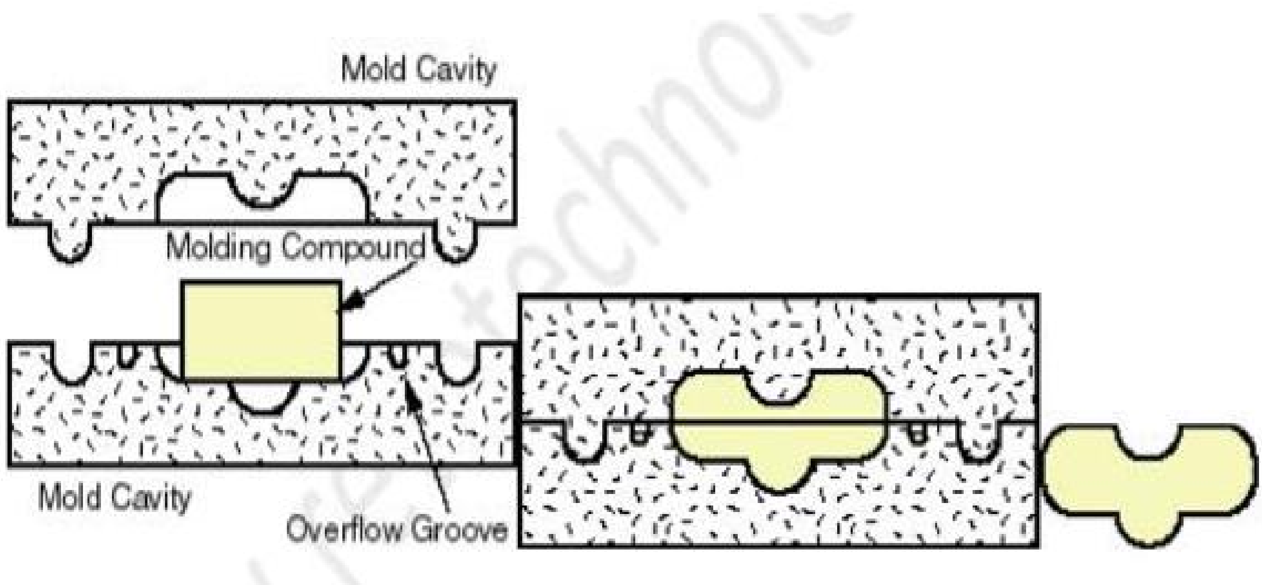
ii. Transfer Moulding

iii.Injection Moulding

iv. Jet Moulding Extrusion

i.Compression molding:

Compression molding is a method of molding in which the molding material, generally preheated, is first placed in an open, heated mold cavity. The mold is closed with a top force or plug member, pressure is applied to force the material into contact with all mold areas, while heat and pressure are maintained until the molding material has cured.



Common plastics used in compression molding processes include:

- Polyester
- Polyimide (PI)

- Polyamide-imide (PAI)
- Polyphenylene Sulfide (PPS)
- Polyetheretherketone (PEEK)
- Fiber reinforced plastics

Compression moldingPrinciple ofworking:

- The compression molding starts, with an allotted amount of plastic or gelatin placed over or inserted into a mold.
- Afterward the material is heated to a pliable state in and by the mold.
- Shortly there after the hydraulic press compresses the pliable plastic against the mold, resulting in a perfectly molded piece, retaining the shape of the inside surface of the mold.
- After the hydraulic press releases, an ejector pin in the bottom of the mold quickly ejects the finish piece out of the mold and then the process is finished.
- Also depending on the type of plunger used in the press there will or won't be excess material on the mold.

Factors affecting Compression Moulding:

- Amount of material
- Heating time and technique
- Force applied to the mold
- Cooling time and technique

Disadvantages of Compression Moulding

- Production speed is not up to injection molding standards
- Limited largely to flat or moderately curved parts with no undercuts

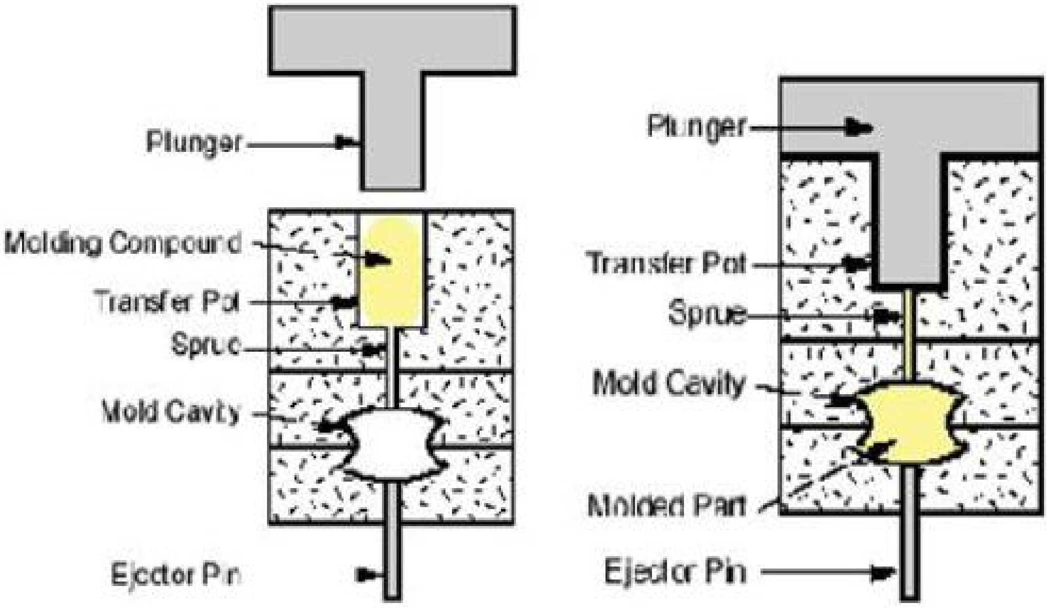
- Less-than-ideal product consistency

Advantages of Compression Moulding:

- Low initial setup costs
- Fast setup time
- Capable of large size parts beyond the capacity of extrusion techniques
- Allows intricate parts
- Good surface finish (in general)
- Wastes relatively little material
- Can apply to composite thermoplastics with unidirectional tapes, woven fabrics, randomly orientated fiber mat or chopped strand
- Compression molding produces fewer knit lines and less fiber-length degradation than injection molding.

ii.Transfer molding:

- Transfer molding is similar to compression molding in that a carefully calculated, pre-measured amount of uncured molding compound is used for the molding process.
- The difference is, instead of loading the polymer into an open mold, the plastic material is preheated and loaded into a holding champers called the pot.
- The material is then forced/transferred into the pre-heated mold cavity by a hydraulic plunger through a channel called sprue. The mold remains closed until the material inside is cured.



Process in Transfer molding:

1.The pre-heated, uncured molding compound is placed in the transfer pot.

2.A hydraulically powered plunger pushes the molding compound through the sprue(s) into the preheated mold cavity. The mold remains closed until the material inside is cured (thermosets) or cooled (thermoplastics).

3.The mold is split to free the product, with the help of the ejector pins.

4.The flash and sprue material is trimmed off.

Plastic used in this Process:

- Epoxy
- Polyester (Unsaturated)
- Phenol-formaldehyde Plastic (PF, Phenolic)
- Silicone rubber (SI)

Advantages:

- Product consistency better than compression molding, allowing tighter tolerance and more intricate parts

- Production speed higher than compression molding
- Fast setup time and lower setup costs than injection molding
- Lower maintenance costs than injection molding
- Ideal for plastic parts with metal inserts

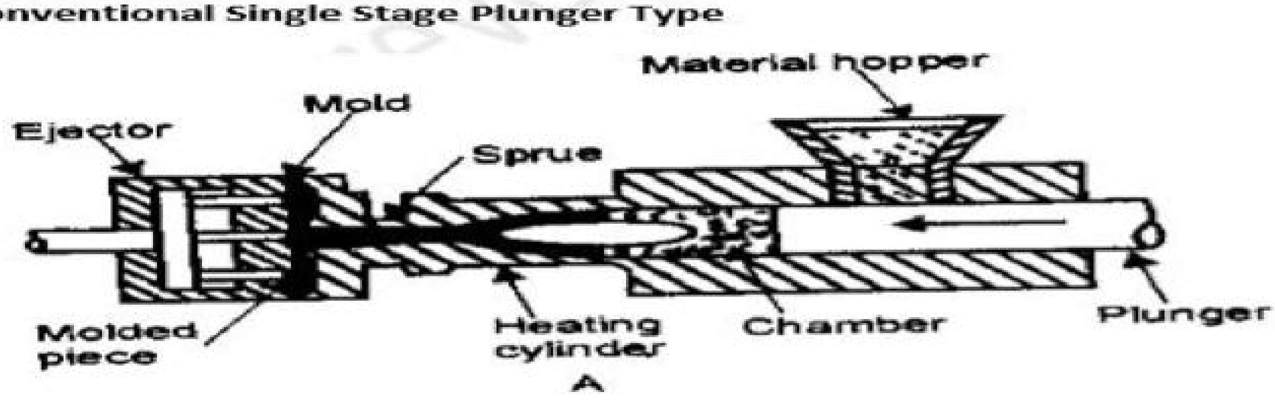
Disadvantages:

- Wastes more material than compression molding (scraps of thermosets are not re-useable).
- Production speed lower than injection molding

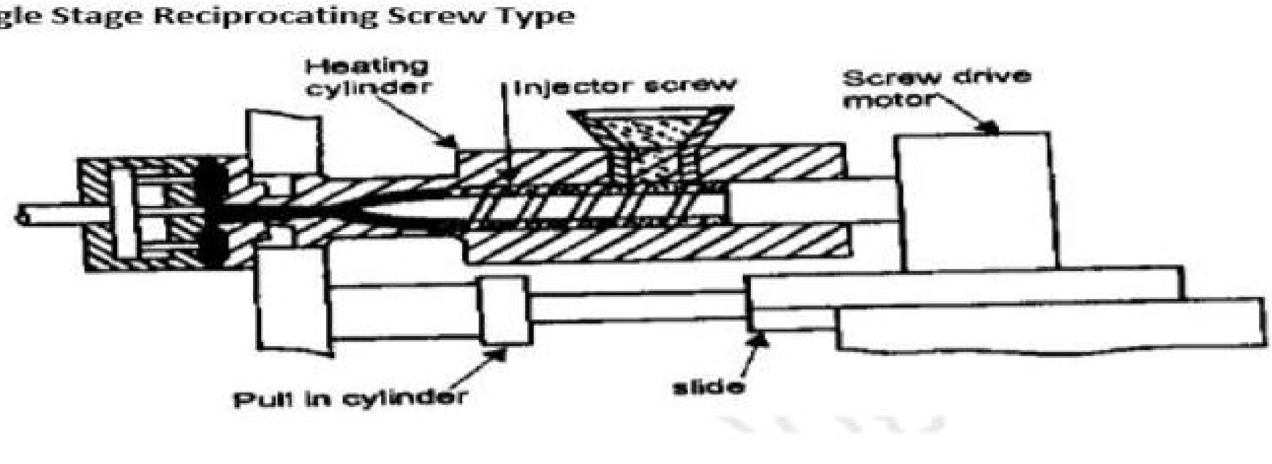
iii.Injection molding:

- • Injection molding is a manufacturing process for producing parts from both thermoplastic and thermosetting plastic materials.
- • Material is fed into a heated barrel, mixed, and forced into a mold cavity where it cools and hardens to the configuration of the mold cavity.

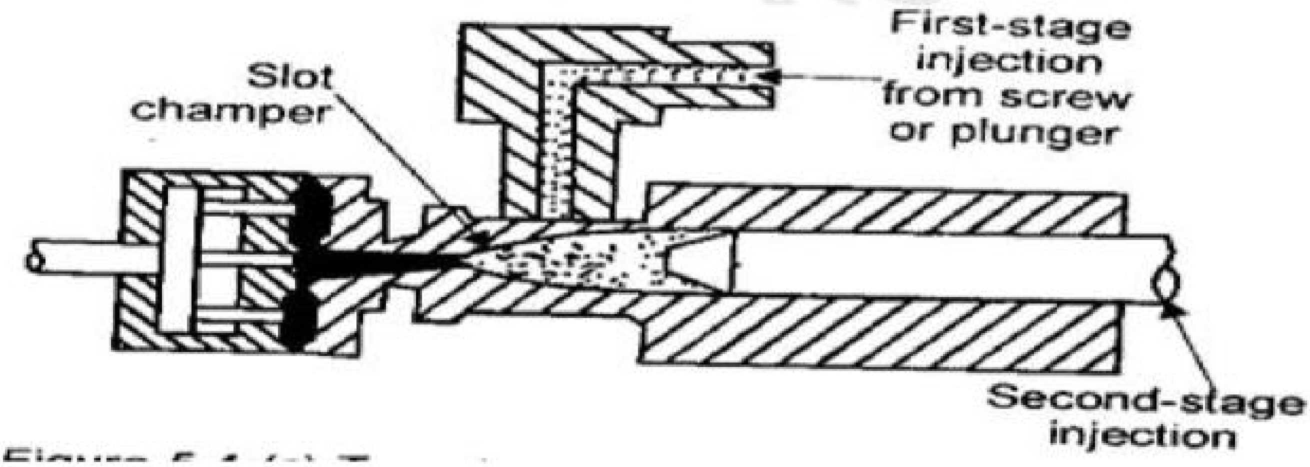
Conventional Single Stage Plunger Type



Single Stage Reciprocating Screw Type



Two stage plunger or Screw plasticiser type



iii.Process of Injection Moulding:

- The process start with feeding plastic pellets in the hopper above the heating cylinder of the machine.
- The resin falls into and is pushed along the heated tube by reciprocating screw until a sufficient volume of melted plastic available
- This may take from 10 Sec to 6 min.
- The entire screw is then plunged forward to force the plastic into the mould.
- Each shot may produce one or several parts, depending on the die used.
- The ram is held under pressure for a few seconds so that the moulded part can solidify.
- It then retracts slightly, and the mould open
- Knockout pins eject the moulded piece.

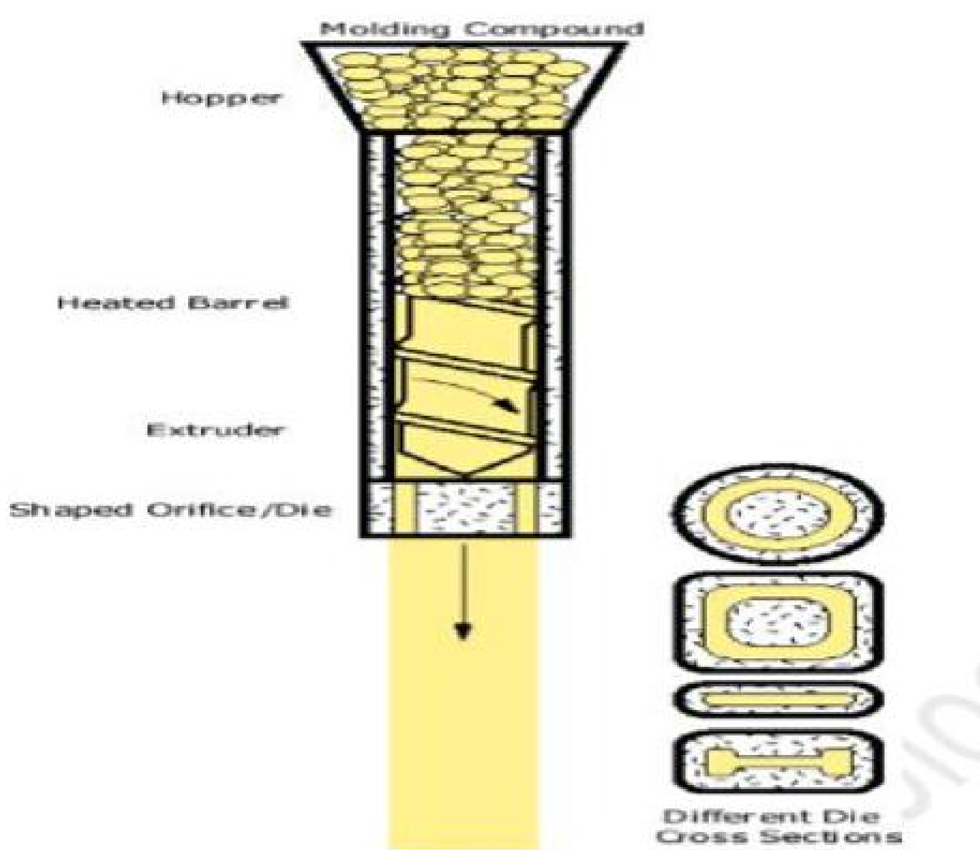
ApplicationsofProcess of Injection Moulding:

- Milk cartons,
- Packaging

- Bottle caps
- Automotive dashboards
- Pocket combs
- And most other plastic products available today.

iv.Extrusion Moulding:

- Extrusion is one of the most widely used manufacturing processes across many industries.
- Essentially, it is not much different from squeezing tooth paste out of the tube.
- Anything that is long with a consistent cross section is probably made by extrusion.
- Common examples are spaghetti, candy canes, chewing gums, drinking straws, plumbing pipes, door insulation seals, optical fibers, and steel or aluminum I-beams.



iv.Extrusion MouldingProcess:

- The plastic extrusion molding process

usually begins with a thermoplastic in the form of pelletsorgranules.

• They are usually stored in a hopper (a funnel-shaped receptacle)

before they are delivered to a heated barrel.

• The molten plastic is then forced through a shaped orifice, usually a custom steel die with shape of the cross section of the

intended part, forming a tube-like or rod-like continuous work piece.

• Cooling of the work piece should be as even as possible.

Plastics used in Extrusion MouldingProcess:

- Acrylonitrile Butadiene Styrene (ABS)
- Acrylic
- Polycarbonate (PC)
- Polyethylene (PE)
- Polypropylene (PP)
- Polyester
- Polystyrene (PS)
- Polyvinylchloride (PVC)

Advantages

- Low initial setup costs
- Fast setup time
- Low production costs

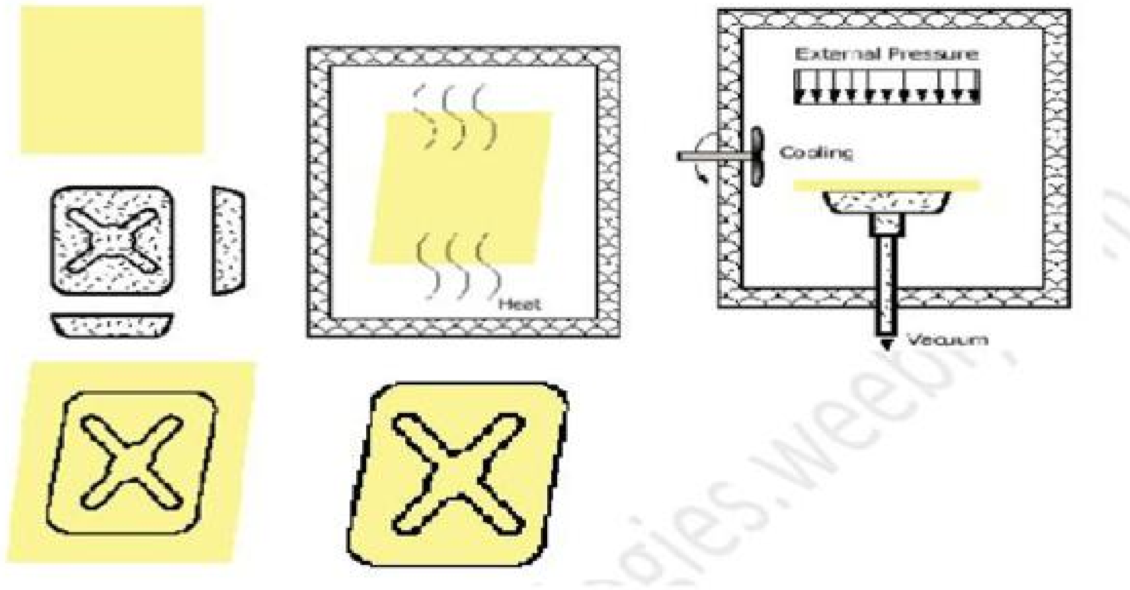
Disadvantages

- Moderate production speed

- Average precision
- Limited to parts with a uniform cross section

V.Thermoforming Process:

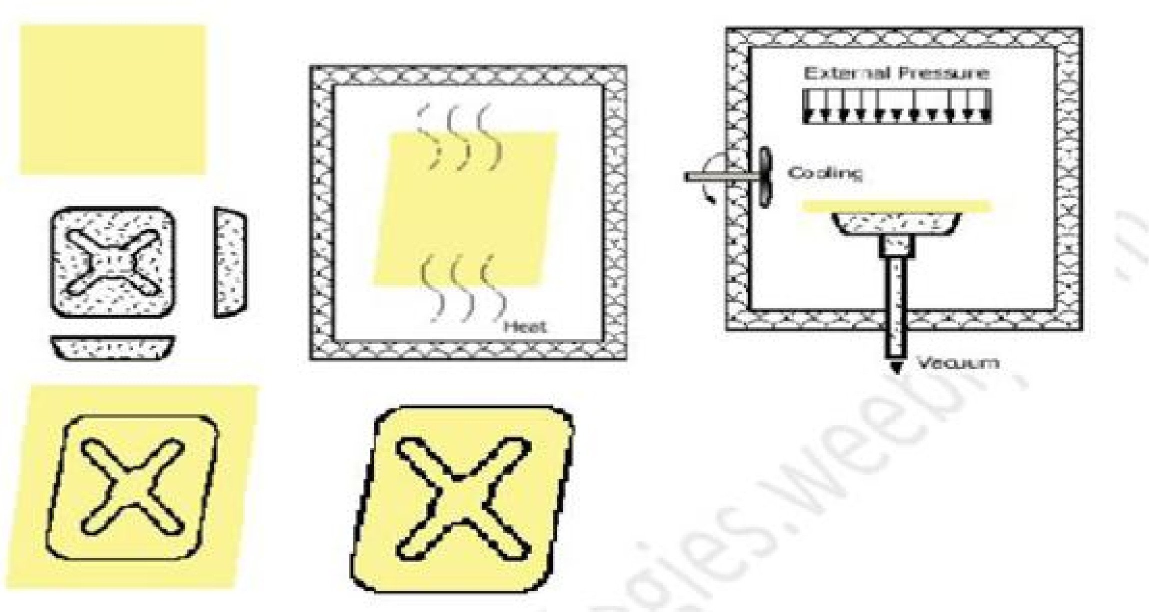
- A plastic thermoforming process usually begins with a sheet of thermoplastic material formed by the extrusion process using a slotted die.
- Thin-gage materials (less than 1/16 inch thick) usually come in rolls; and heavy-gage materials (up to 1/2 inch thick) normally come in sheets.
- The sheet of plastic material is first heated to become a flexible membrane.
- This soft, rubber-like membrane is placed on the mold and stretched to cover the entire surface.
- Vacuum, external air pressure, and mechanical forces are used to rid the air bubbles and improve the surface quality.
- The plastic part remains in the mold until it solidifies. Excess material is trimmed after the part is removed from the mold.



- Average precision
- Limited to parts with a uniform cross section

V.Thermoforming Process:

- A plastic thermoforming process usually begins with a sheet of thermoplastic material formed by the extrusion process using a slotted die.
- Thin-gage materials (less than 1/16 inch thick) usually come in rolls; and heavy-gage materials (up to 1/2 inch thick) normally come in sheets.
- The sheet of plastic material is first heated to become a flexible membrane.
- This soft, rubber-like membrane is placed on the mold and stretched to cover the entire surface.
- Vacuum, external air pressure, and mechanical forces are used to rid the air bubbles and improve the surface quality.
- The plastic part remains in the mold until it solidifies. Excess material is trimmed after the part is removed from the mold.



Vi.Process in Thermoforming

1.The plastic sheets used in thermoforming is usually made by extrusion.

The one-sided mold is usually made by aluminum.

2.This sheet of plastic material is first heated to become a flexible membrane. It is soft but still not liquid or gooey.

3.The soft, rubber-like membrane is placed on the mold and stretched to fit. Vacuum, external air pressure, and mechanical forces are used to rid the air bubbles.

4.The plastic part is removed from the mold after it cools and hardens.

5.Trimming, drilling, and other finishing processes may be needed to obtain the final product

Plastics used inThermoforming process:

- Acrylonitrile Butadiene Styrene (ABS)
- Acrylic Polycarbonate (PC)
- Polyethylene (PE)
- Polypropylene (PP)
- Polystyrene (PS)
- Polyvinylchloride (PVC)

Advantages

- Low initial setup costs
- Fast setup time
- Low production costs
- Less thermal stresses than injection molding and compression molding

- More details and better cosmetics than rotational-molded products

Disadvantages

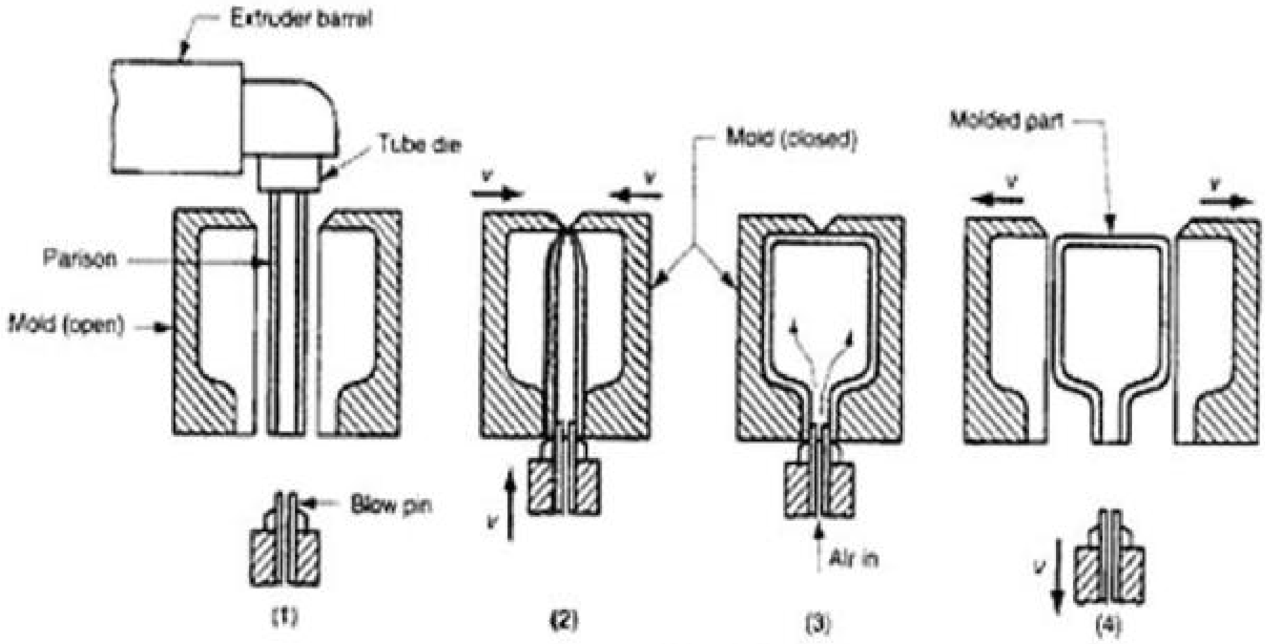
- Geometries limited to thin shells or shallow shapes
- One side of the product can be precisely controlled by the mold dimensions while the other side can not.

VII.Blow Moulding:

- Blow molding, also known as blow forming, is a manufacturing process by which hollow plastic parts are formed. It is a process used to produce hollow objects from thermoplastic.
- In general, there are three main types of blow molding:
- VII.i. Extrusion Blow Molding,
- VII.ii. Injection Blow Molding, And
- VII.iii. Stretch Blow Molding

VII.IExtrusion Blow Molding:

- Extrusion Blow Molding is the simplest type of blow molding. A hot tube of plastic material is dropped from an extruder and captured in a water cooled mold. Once the molds are closed, air is injected through the top or the neck of the container; just as if one were blowing up a balloon. When the hot plastic material is blown up and touches the walls of the mold the material "freezes" and the container now maintains its rigid shape.



.Extrusion Blow molding allows for a wide variety of container shapes, sizes and neck openings, as well as the production of handle-ware. Some extrusion machines can produce 300 to 350 bottles per hour. Extrusion blown containers can also have their gram weights adjusted through an extremely wide range, Extrusion blow molds are generally much less expensive than injection blow molds and can be produced in a much shorter period of time.

Advantages of extrusion blow molding

- high rate of production,
- low tooling cost, and a vast majority of machine manufactures. Some disadvantages usually include a high scrap rate, a limited control over wall thickness, and some difficulty of trimming away excess plastic.

Disadvantages

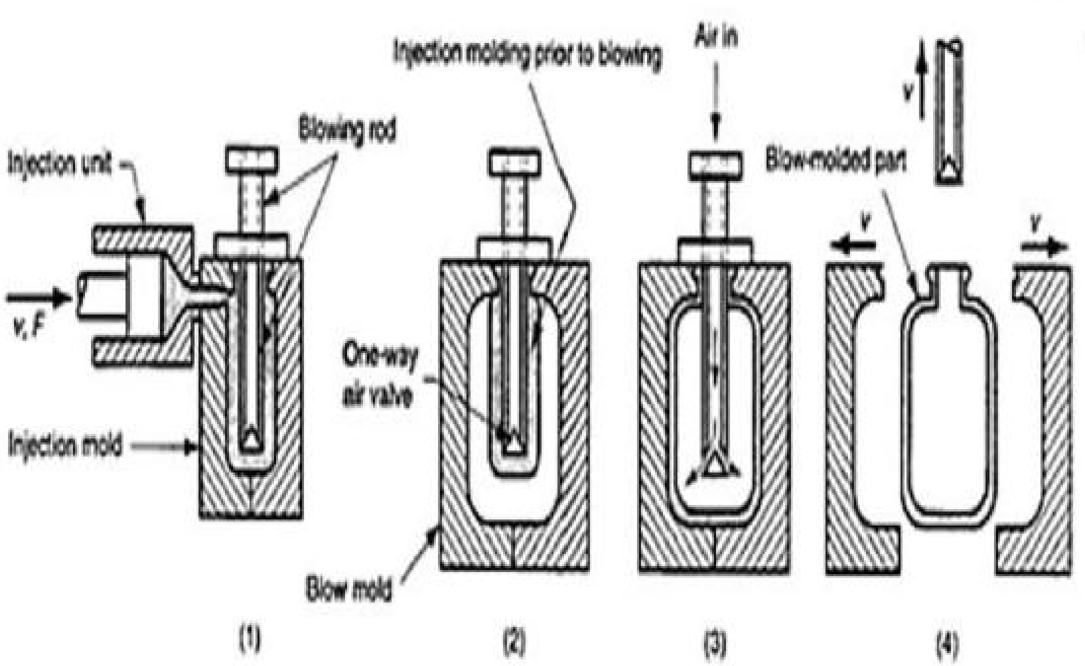
- include a high scrap rate,
- a limited control over wall thickness,

and some difficulty of trimming away excess plastic.

VII.II.Injection Blow Molding:

- Injection blow molding is part injection molding and part blow molding. Injection blow molding is generally suitable for smaller containers and absolutely no handles ware. Injection blow molding is often used for containers that have close tolerance threaded necks, wide mouth openings; solid handles, and highly styled shapes.

- Injection blown containers usually have a set gram weight which cannot be changed unless a whole new set of blow stems are built. Generally injection blow molded container's material is distributed evenly throughout, and generally do not need any trimming or reaming. The air is injected into the plastic at a rate between 75 to 150 PSI.



Injection molding can be broken down into three stages.

- The first stage is where the melted plastic is injected into a split steel mold cavity from the screw extruder.
- The mold produces a perform parison which resembles a test tube with a screw finish on the top.
- The perform is then transferred on a core rod to the second part of the injection blow molding stage. The perform is then placed inside another cold and usually aluminum blow mold cavity.
- Air is then injected through the core rod till the perform takes the shape of the cavity. While still on the core rod, the

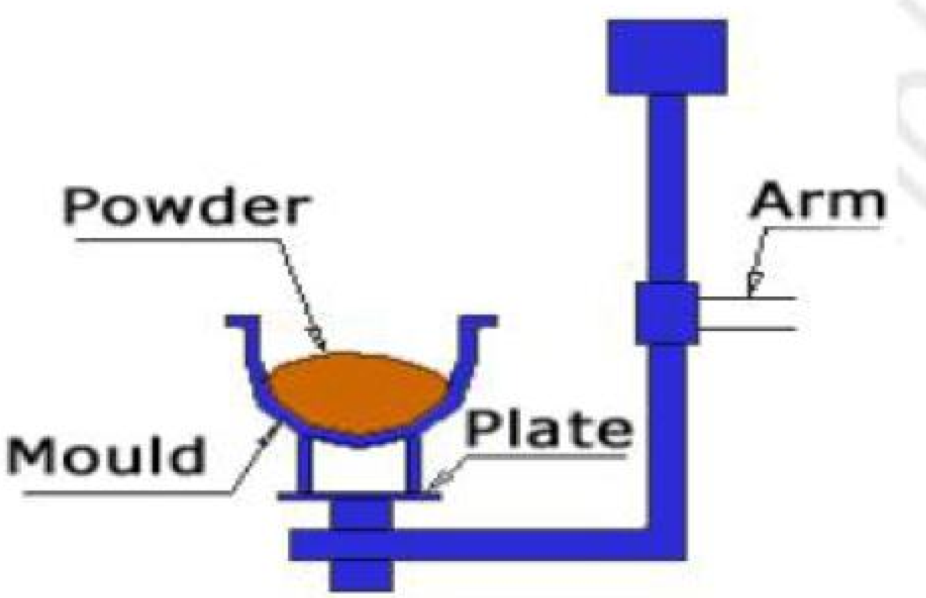
container is then transferred to a desired location for the third stage, where it is ejected from the machine.

VII.III.Stretch Blow Moulding:

- Stretch blow molding is best known for producing PET bottles commonly used for water, juice and a variety of other products. Stretch blow molding has been used since the early 1970's especially for packaging detergent, and has grown in existence with the primary use for making carbonated beverage bottles.
- One of the major advantages of stretch blow molding is the ability to stretch the perform in both the hoop direction and the axial direction. This biaxial stretching of material increases the tensile strength, barrier properties, drop impact, clarity, and top load in the container. With these increases it is usually possible to reduce the overall weight in a container by 10 to 15 percent less then when producing a container in another way

VIII.Rotation Moulding :

- Rotational molding or moulding is a versatile process for creating many kinds of mostly hollow items, typically of plastic. The phrase is often shortened to rotomolding or rotomoulding.



VIII.Rotation Moulding：

1. **Mould charging:** A predetermined charge of cold plastic powder is placed in one half of a cold mould, which is then closed

2. Mould rotation and heating: The arm with the mould is then inserted into the oven, where the plastic is warmed up to the right melting temperature. The mould is rotated biaxial in this heated oven. Thus, the plastic powder inside the mould starts to melt and coat the inside surface of the mould. The rotation of the mould continues until all plastic powder has melted and is evenly divided inside the mould.

3. Mould cooling: As the biaxial rotation continues, the arm with the mould is transferred to a cooled environment. There, air, water or a combination of both is used to cool the mould and the molten plastic. The cooling process continues until the plastic has solidified and the plastic product maintains its form.

4. De-moulding of the final product: After the cooling, the rotational arm is transferred to the load and unload station. The mould is opened and the product is de-moulded. When the product is de-moulded, the mould can be charged again with powder and the process can start all over again.

VIII. Advantages ofRotation Moulding：

- Rotational molding offers design advantages over other molding processes.
- With proper design, parts assembled from several pieces can be molded as one part, eliminating high fabrication costs.
- The process also has inherent design strengths, such as consistent wall thickness and strong outside corners that are virtually stress free.

- For additional strength, reinforcing ribs can be designed into the part. Along with being designed into the part, they can be added to the mold.

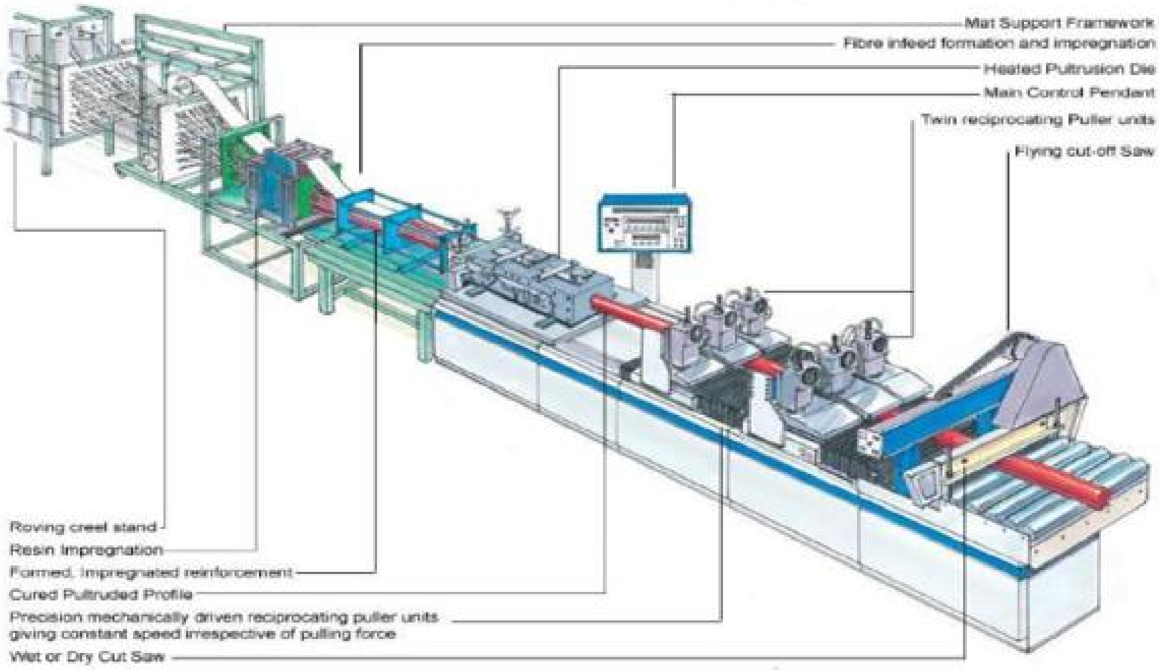
VIII. Limitations ofRotation Moulding :

- Rotationally molded parts have to follow some restrictions that are different from other plastic processes.
- As it is a low pressure process, sometimes designers face hard to reach areas in the mold. Good quality powder may help overcome some situations, but usually the designers have to keep in mind that it is not possible to make some sharp threads used in injection molded goods.
- Some products based on polyethylene can be put in the mold before filling it with the main material. This can help to avoid holes that otherwise would appear in some areas.
- This could be also achieved using molds with movable sections another limitation lies in the molds themselves.
- Unlike other processes where only the product needs to be cooled before being removed, with rotational molding the entire mold must be cooled.
- While water cooling processes are possible, there is still a significant down time of the mold. Additionally, this increases both financial and environmental costs.
- Some plastics will degrade with the long heating cycles or in the process of turning them into a powder to be melted.

IX.Laminating:

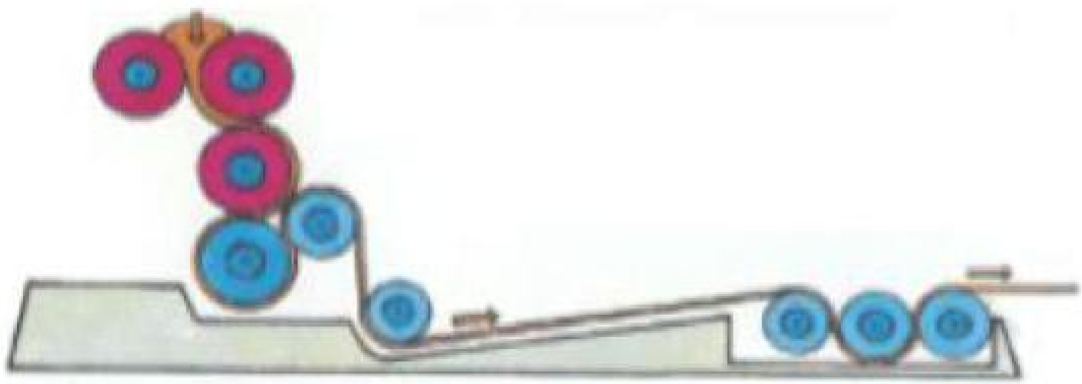
In most cases, a hot laminator is used to seal the pouch and bind the layers together so that your document is laminated. The actual pouch consists of pockets of laminating film into which the item to be laminated is placed.

Laminating



X.Calendaring:

- A PVC blend is pre-gelatinised and then kneaded to form a viscous material. It is laminated through a series of cylinders and transformed into a continuous sheet, which is cooled and then rolled up. The sheets may be mono-oriented during the process.
- As with extrusion, calendaring is a continuous process Calendaring is a finishing process used on cloth where fabric is folded in half and passed under rollers at high temperatures and pressures.
- Calendaring is used on fabrics such as moiré to produce its watered effect and also on cambric and some types of sateen's.



- In preparation for calendaring, the fabric is folded lengthwise with the front side, or face, inside, and stitched together along the edges.
- The fabric can be folded together at full width, however this isn't done as often as it is more difficult.
- The fabric is then run through rollers that polish the surface and make the fabric smoother and more lustrous.
- High temperatures and pressure are used as well.
- Fabrics that go through the calendaring process feel thin, glossy and papery.

Ceramics:

Ceramics are compounds of metallic and nonmetallic elements. The term ceramics (from the Greek words keramos, meaning “potter'sclay,” and keramikos, meaning “clayproducts”)refersbothtothematerialandtotheceramicproductitself.Because of the large number of possible combinations of elements, awide variety of ceramics now is available for abroad range of consumer and industrial applications.

The earliest use of ceramics was in pottery and bricks, dating back to before 4000 B.C. Ceramics have been used for many years in automotive spark plugs, both as an electrical insulator and for their high-temperature strength. They have become increasingly important in tool and die materials, heat engines, and automotive components (such as exhaust-port liners, coated pistons, and cylinder liners).

Raw Materials:

Among the oldest of the raw materials used for making ceramics is clay, which has a fine-grained sheet like structure. The most common example is kaolinite (from Kaoling, a hill in

China), a white clay consisting of silicate of aluminum with alternating weakly bonded layers of silicon and aluminum ions. When added to kaolinite, water attaches itself to the layers (adsorption). This makes the layers slippery and gives wet clay both its well-known softness and the plastic properties (hydro plasticity) that make it formable.

Other major raw materials for ceramics that are found in nature are flint (a rock composed of very fine grained silica,) and feldspar (a group of crystalline minerals consisting of aluminum silicates and potassium, calcium, or sodium). Porcelain is a white ceramic composed of kaolin, quartz, and feldspar; its largest use is in appliances and kitchen and bath ware. In their natural state, these raw materials generally contain impurities of various kinds, which have to be removed prior to further processing of the materials into useful products with reliable performance.

Types and General Characteristics of Ceramics

Type	General characteristics
Oxide ceramics	
Alumina	High hardness and moderate strength; most widely used ceramic; cutting tools; abrasives; electrical and thermal insulation.
Zirconia	High strength and toughness; thermal expansion close to cast iron; suitable for high-temperature applications.
Carbides	
Tungsten carbide	Hardness, strength, and wear resistance depend on cobalt binder content; commonly used for dies and cutting tools.
Titanium carbide	Not as tough as tungsten carbide; has nickel and molybdenum as the binder; used as cutting tools.
Silicon carbide	High-temperature strength and wear resistance; used for heat engines and as abrasives.
Nitrides	
Cubic boron nitride	Second-hardest substance known, after diamond; used as abrasives and cutting tools.
Titanium nitride	Gold in color; used as coatings because of low frictional characteristics.
Silicon nitride	High resistance to creep and thermal shock; used in high-temperature applications.
Sialon	Consists of silicon nitrides and other oxides and carbides; used as cutting tools.
Cermets	Consist of oxides, carbides, and nitrides; used in high-temperature applications.
Silica	High-temperature resistance; quartz exhibits piezoelectric effect; silicates containing various oxides are used in high-temperature nonstructural applications.
Glasses	Contain at least 50 percent silica; amorphous structures; several types available with a wide range of mechanical and physical properties.
Glass ceramics	Have a high crystalline component to their structure; good thermal-shock resistance and strong.
Graphite	Crystalline form of carbon; high electrical and thermal conductivity; good thermal-shock resistance.
Diamond	Hardest substance known; available as single crystal or in polycrystalline form; used as cutting tools and abrasives and as dies for fine wire drawing.
Carbon nanotubes	Unique crystalline form of graphite, with high electrical and thermal conductivity; under investigation for MEMS and microelectronics applications and in composite materials.

Properties of Various Ceramics at Room Temperature							
Material	Symbol	Transverse rupture strength (MPa)	Compressive strength (MPa)	Elastic modulus (GPa)	Hardness (HK)	Poisson's ratio, ν	Density (kg/m^3)
Aluminum oxide	Al_2O_3	140–240	1000–2900	310–410	2000–3000	0.26	4000–4500
Cubic boron nitride	cBN	725	7000	850	4000–5000	—	3480
Diamond	—	1400	7000	830–1000	7000–8000	—	3500
Silica, fused	SiO_2	—	1300	70	550	0.25	—
Silicon carbide	SiC	100–750	700–3500	240–480	2100–3000	0.14	3100
Silicon nitride	Si_3N_4	480–600	—	300–310	2000–2500	0.24	3300
Titanium carbide	TiC	1400–1900	3100–3850	310–410	1800–3200	—	5500–5800
Tungsten carbide	WC	1030–2600	4100–5900	520–700	1800–2400	—	10,000–15,000
Partially stabilized zirconia	PSZ	620	—	200	1100	0.30	5800

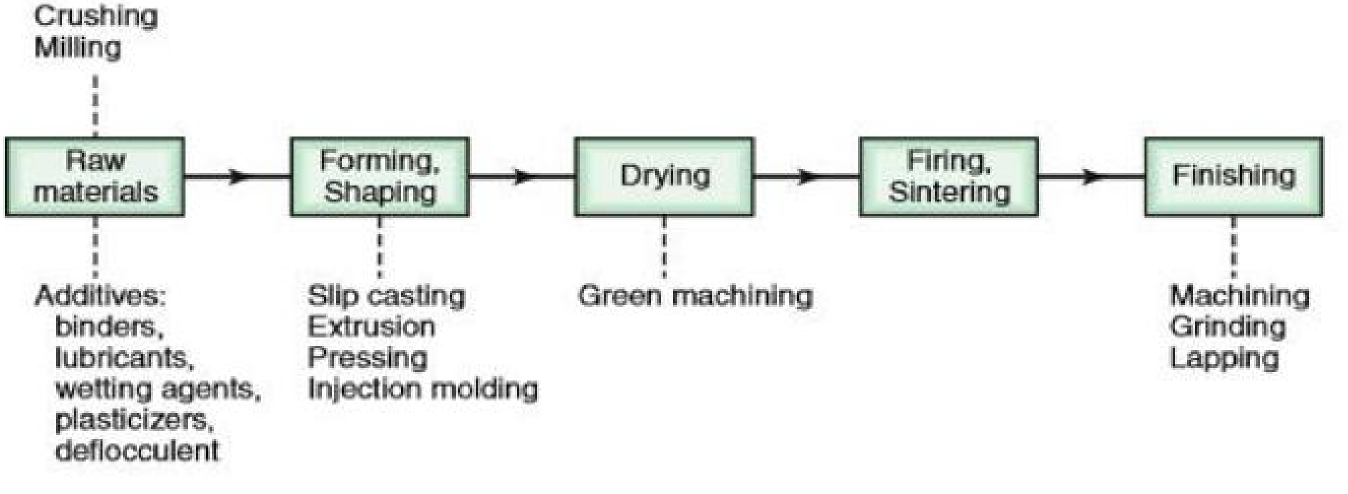
Ceramics Applications:

- Applicationsof Ceramics have numerous consumer and industrial applications.
- Various types of ceramics are used in the electrical and electronics industries, because they have high electrical resistivity, high dielectric strength (voltage required for electrical breakdown per unit thickness), and magnetic properties suitable for such applications as magnets for speakers.
- The capability of ceramics to maintain their strength and stiffness at elevated temperatures makes them very attractive for high-temperature applications.

Ceramics Applications:

- The higher operating temperatures made possible by the use of ceramic components mean more efficient combustion of fuel and reduction of emissions in automobiles.

- Currently, internal combustion engines are only about 30% efficient, but with the use of ceramic components, the operating performance can be improved by at least 30%.
- Ceramics that are being used successfully, especially in automotive gas-turbine engine components (such as rotors), are silicon nitride, silicon carbide, and partially stabilized zirconium.
- Other attractive properties of ceramics are their low density and high elastic modulus. They enable product weight to be reduced and allow the inertial forces generated by moving parts to be lower.
- Ceramic turbochargers, for example, are about 40% lighter than conventional ones. High-speed components for machine tools also are candidates for ceramics.
- Furthermore, the high elastic modulus of ceramics makes them attractive for improving the stiffness of machines, while reducing the weight.
- Their high resistance to wear makes them suitable for applications such as cylinder liners, bushings, seals, bearings, and liners for gun barrels.
- Coating metal with ceramics is another application, often done to reduce wear, prevent corrosion, or provide a thermal barrier.



Processing steps involved in making ceramic parts.

General Characteristics of Ceramics Processing		
Process	Advantages	Limitations
Slip casting	Large parts, complex shapes, low equipment cost	Low production rate, limited dimensional accuracy
Extrusion	Hollow shapes and small diameters, high production rate	Parts have constant cross section, limited thickness
Dry pressing	Close tolerances, high production rates (with automation)	Density variation in parts with high length-to-diameter ratios, dies require abrasive-wear resistance, equipment can be costly
Wet pressing	Complex shapes, high production rate	Limited part size and dimensional accuracy, tooling costs can be high
Hot pressing	Strong, high-density parts	Protective atmospheres required, die life can be short
Isostatic pressing	Uniform density distribution	Equipment can be costly
Jiggering	High production rate with automation, low tooling cost	Limited to axisymmetric parts, limited dimensional accuracy
Injection molding	Complex shapes, high production rate	Tooling can be costly

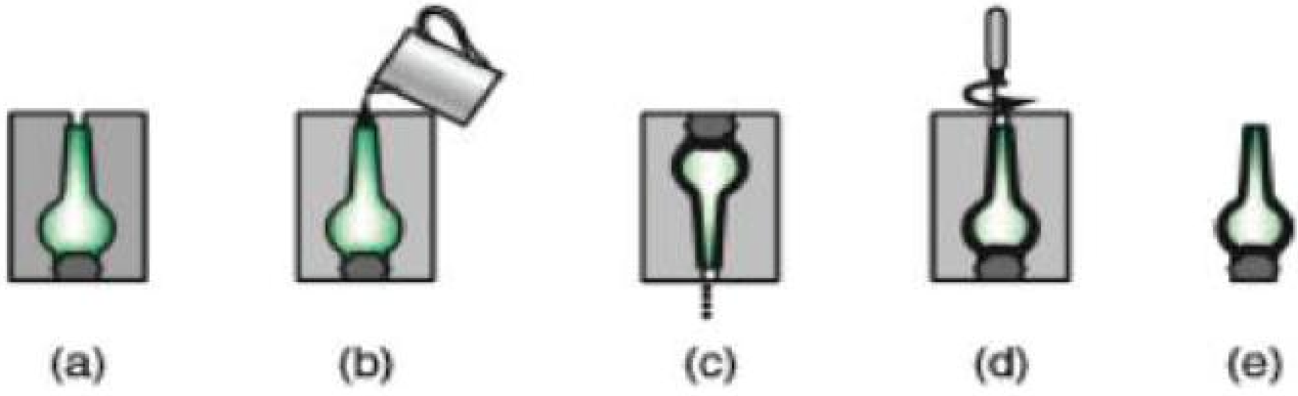
Shaping processes for ceramics:

The three basic shaping processes for ceramics are

i. casting
ii. plastic forming, and
iii. pressing.

i.Casting:

The most common casting process is slip casting (also called drain casting), as illustrated in Fig. A slip is a suspension of colloidal (small particles that do not settle) ceramic particles in an immiscible liquid (insoluble in each other), which is generally water. The slip is poured into a porous mold, typically made of plaster of pairs. Molds also may consist of several components.



The slip must have sufficient fluidity and low enough viscosity to flow easily into the mold, much liketheimportanceoffluidityofmoltenmetalsincasting operations as described in Section 10.3. Pouring the slip must be done properly,asair entrapment can beasignificantproblemduringcasting.

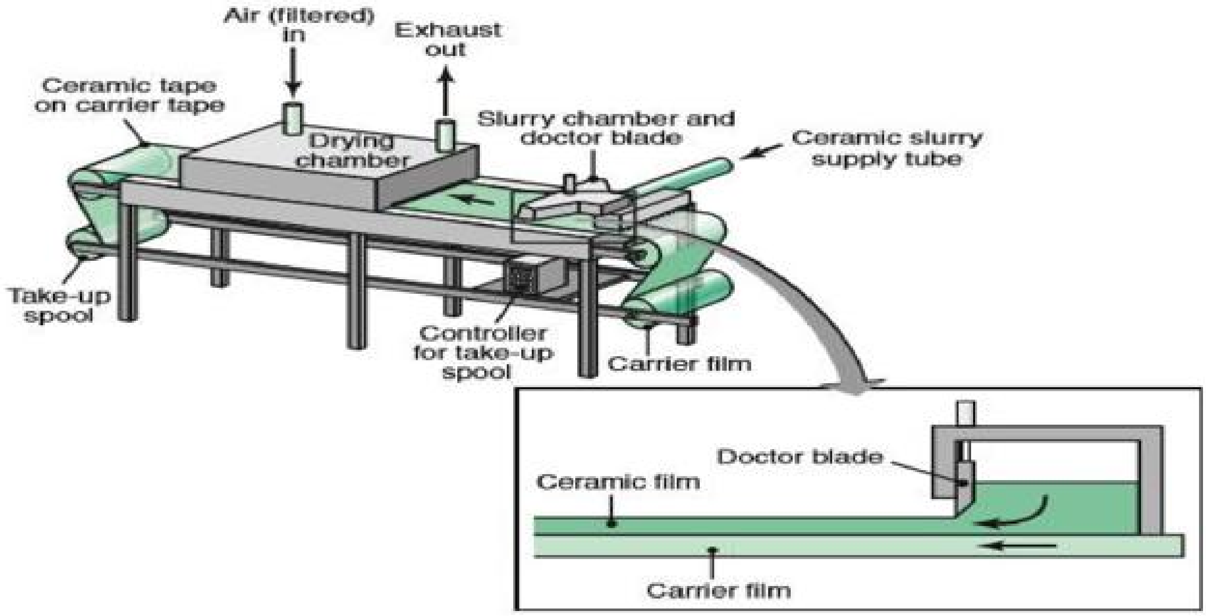
- After the mold has absorbed some of the water from the outer layers of the suspension, it is inverted and the remaining suspension is poured out.
- The product is a hollow object, as in the slush casting of metals described in Section 11.4.3.
- The top of the part is then trimmed (note the trimming tool in Fig. 18.3d), the mold is opened, and the part is removed. Large and complex parts (such as plumbing ware, art objects, and dinnerware) can be made by slip casting.
- Although mold and equipment costs are low, dimensional control is poor and the production rate is low.
- In some applications, components of the product (such as handles for cups and pitchers) are made separately and then joined, using the slip as an adhesive.
- Molds also may consist of multiple components
- For solid-ceramic parts, the slip is supplied continuously into the mold to replenish the absorbed water; otherwise, the part

will shrink. At this stage, the part is described as either a soft solid or semirigid.

- The higher the concentration of solids in theslip,thelesswaterhastoberemoved.
- Thepartremovedfromthemoldisreferred to as a green part and is associated with the light-green tint in decorative ceramic slip casts at this stage.
- While the ceramic parts are still green, they may be machined to produce certain features or to give dimensional accuracy to the parts.
- Because of the delicate nature of the green compacts, however, machining usually is done manually or with simple tools. For example, the flashing in a slip casting may be removed gently with a fine wire brush, or holes can be drilled in the mold.
- Detailed work (such as the tapping of threads) generally is not done on green compacts because warpage (due to firing) makes such machining not viable.

ii.Plastic Forming:

- Plastic forming (also called soft, wet, or hydro plastic forming) can be carried out by various methods, such as extrusion, injection molding, or molding and jiggering (Fig. 18.5).
- Plastic forming tends to orient the layered structure of clay along the direction of material flow and, hence, tends to cause anisotropic behavior of the material both in subsequent processing and in the final properties of the ceramic product.
- In extrusion, the clay mixture (containing 20 to 30% water) is forced through a die opening by a screw-type piece of equipment.



Production of ceramic sheets through the doctor-blade process.

- The cross section of the extruded product is constant, and there are limitations to wall thickness for hollow extrusions. The extruded products may be subjected to additional shaping operations. Tooling costs are low, and production rates are high.

iii.**Pressing**:

- Dry Pressing. This is a technique similar to powder-metal compaction, as described in Section 17.3.
- Dry pressing is used for relatively simple shapes, such as whiteware, refractoriness for furnaces, and abrasive products. The moisture content of the mixture generally is below 4%, but it may be as high as 12%.
- Organic and inorganic binders (such as stearic acid, wax, starch, and polyvinyl alcohol) usually areadded to the mixture; these additives also act as lubricants.
- This process has the same high production rates and close control of dimensional tolerances as does powder metallurgy. The recommended maximum ratio is 2:1. Several methods may be used to minimize density variations, including

(a) proper design of tooling,

(b) vibratory pressing and impact forming (particularly for nuclear-reactor fuel elements), and
(c) isostatic pressing.

iii.a.WetPressing:

In wet pressing, the part is formed in a mold while under high pressure in a hydraulic or mechanical press. This process generally is used to make intricate shapes. Moisture content usually ranges from 10 to 15%. Production rates are high; however,

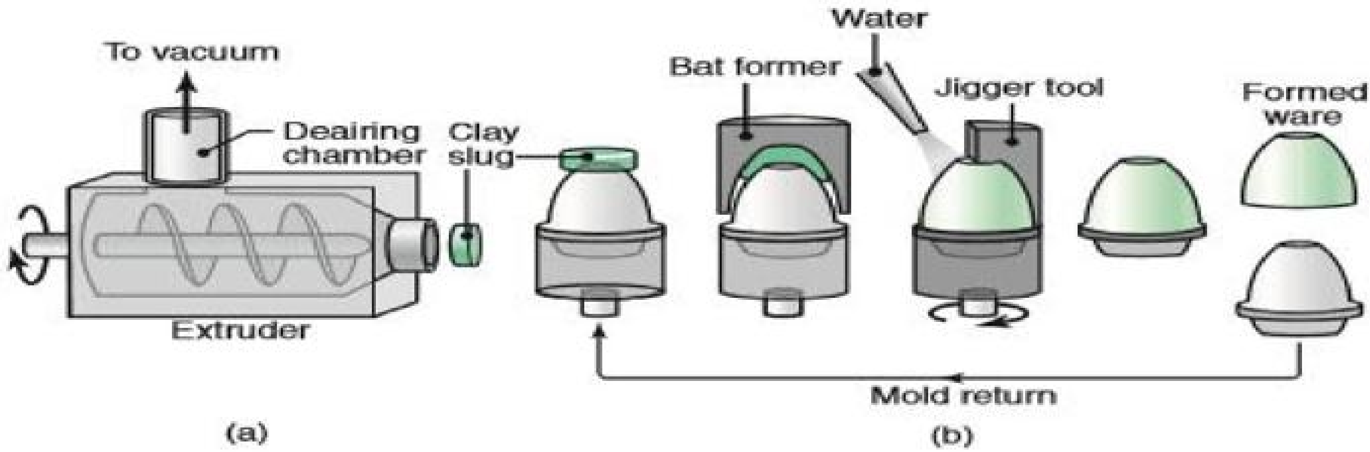
(a) part size is limited,
(b) dimensional control is difficult to achieve because of shrinkage during drying, and
(c) tooling costs can be high

iii.b. Isostatic Pressing:

Used extensively in powder metallurgy, isostatic pressing also is used for ceramics in order to obtain a uniform density distribution throughout the part during compaction. For example, automotive spark-plug insulators are made by this method at room temperature, while silicon-nitride vanes for high-temperature applications (see Fig. 8.1) are made by hot isostatic pressing.

iii.c. Jiggering:

A series of steps is needed to make ceramic plates. First, clay slugs are extruded and formed into a bat over a plaster mold. Then they are jiggered on a rotating mold (see Fig. 18.5b). Jiggering is a motion in which the clay bat is formed by means of templates or rollers. The part then is dried and fired. The jiggering process is confined to axisymmetric parts and has limited dimensional accuracy. The operation is automated for improved productivity.



(a) Extruding and (b) jiggering operations

iii.d.Injection Molding:

- Injection molding is used extensively for the precision forming of ceramics in high-technology applications, such as for rocket-engine components.
- Therawmaterialsmixedwithabider,suchasathermoplasticpolyme r(polypropylene, low-density polyethylene, or ethylene vinyl acetate) or wax.
- The binder usually is removed by pyrolysis (inducing chemical changes by heat); the part is then sintered by firing.
- The injection-molding process can produce thin sections [typically less than 10 to 15 mm (0.4 to 0.6 in.) thick] from most engineering ceramics, such as alumina, zirconium, silicon nitride, silicon carbide, and salon. Thicker sections require careful control of the materials used and of the processing parameters in order to avoid defects, such as internal voids and cracks—especially those due to shrinkage.

iii.e.Hot Pressing:

- In this process (also called pressure sintering), the pressure and the heat are applied simultaneously, thereby reducing porosity and making the part denser and stronger.
- Graphite commonly is used as a punch and die material, and protective atmospheres usually are employed during pressing. Hot isostatic pressing (Section 17.3.2) also may be used, particularly to improve shape accuracy and the quality of high-technology ceramics, such as silicon carbide and silicon nitride.
- Glass-encapsulated HIP processing has been shown to be effective for this purpose.

iv.Drying:

- Drying is a critical stage because of the tendency for the part to warp or crack from variations in moisture content and in thickness. Control of atmospheric humidity and of ambient temperature is important in order to reduce warping and cracking.
- Loss of moisture during drying causes shrinkage of the part by as much as 20% from the original, moist size (Fig. 18.6). In a humid environment, the evaporation rate is low, and consequently, the moisture gradient across the thickness of the part is lower than that in a dry environment.
- This low moisture gradient, in turn, prevents a large, uneven gradient in shrinkage from the surface to the interior during drying.
- A ceramic part that has been shaped by any of the methods described thus far is in the green state. The part can be machined in order to bring it closer to a near net shape. Although the green part should be handled carefully, machining it is not particularly difficult, because of its relative softness.

V.Firing(also called sintering):

involves heating the part to an elevated temperature in a controlled environment. Some shrinkage occurs during firing. Firing gives the ceramic part its strength and hardness.
This improvement in properties results from
(a) the development of a strong bond between the complex oxide particles in the ceramic and
(b) reduced porosity. A more recent technology (although not yet commercialized) involves the microwave sintering of ceramics in furnaces operating at more than 2 GHz.
Its cost-effectiveness depends on the availability of inexpensive furnace insulation.

VI.Finishing Operations

Because firing causes dimensional changes, additional operations may be performed to
(a)give the ceramic part its final shape,
(b) improve its surface finish and dimensional tolerances, and
(c) remove any surface flaws. Although they are hard and brittle, major advances have been made in producing machinable ceramics and grindable ceramics,thusenablingtheproductionofceramiccomponentswith highdimensional accuracy and agood surface finish. An example is silicon carbide, which can be machined into final shapes from sintered blanks.

The finishing processes employed can be one or more of the following operations:

1.Grinding (using a diamond wheel)
2. Lapping and honing
3. Ultrasonic machining
4. Drilling (using a diamond-coated drill)
5. Electrical-discharge machining

6. Laser-beam machining

- Process selection is an important consideration because of the brittle nature of most ceramics and the additional costs involved in some of these processes.
- The effect of the finishing operation on the properties of the product also must be considered.
- For instance, because of notch sensitivity, the finer the finish, the higher the part's strength and load-carrying capacity—particularly its fatigue strength
- Ceramic parts also may undergo static fatigue, as described for glass.
- To improve their appearance and strength and to make them impermeable, ceramic products often are coated with a glaze or enamel, which forms a glassy coating after firing

Powder Metallurgy

4.1. DEFINITION

Powder metallurgy *is defined as the art of making objects by the heat treatment of compressed metallic powders.*

"Powder metallurgy" includes the blending and mixing of powders, pressing or compacting powder into an appropriate shape, sintering the pressed-powder compact, and perhaps final sizing or finishing of the product to meet specified dimensional tolerances.

The process is applicable to a single metal powder, to mixtures of metals and non-metals. The operation of pressing may be carried out at ordinary or elevated temperatures depending upon the composition and properties desired in the product.

AdvantagesofPowder Metallurgy

Advantages :

The advantages of powder metallurgy are :

1. Such parts which have special properties can be produced which otherwise cannot be obtained.
2. Machining operations are eliminated.
3. Scrap losses are reduced and often results in lower unit cost for a given part in comparison to any other production method.
4. Metals and alloys can be mixed together in any proportion which is difficult and sometimes not possible by melting.
5. Metals and non-metals can be mixed together in any proportion.
6. There is better control of composition and structure of the component by this process.
7. Articles of any desired porosity can be manufactured.
8. Super-hard cutting bits, which can never be manufactured by any other methods are made by powder metallurgy, *e.g.*, sintered carbides, satellites.
9. This process is suitable for mass production because the stroke of the pressing or compacting consists of a press at a speed of 60 strokes/minute.
10. Antifriction alloy strips made by powder metallurgy can be made to adhere on a strong alloy backing piece.
11. The process is very economical and the loss of material is lesser as compared to other processes.
12. Diamond impregnated tools for cutting porcelain, glass and tungsten carbides are made possible only by powder metallurgy.

Disadvantages/Limitations :

The process has the following *disadvantages/limitations :*

1. Owing to the fairly high compacting pressures required to press the powder, the wear on the dies is high.
2. Due to high rate of wear of dies, high costs for dies and presses the method is rendered uneconomical particularly for small runs.
3. Since the compacted parts must be ejected from the die without fracture, therefore, the shapes that may be made by this method are limited.
4. Equipments required are very costly.
5. A completely dense product is not possible without heating the product after pressing operation.
6. The physical properties obtained by this process are lower than those obtained by other processes.
7. In the low melting powders like tin, zinc and cadmium, sometimes certain thermal difficulties appear.
8. Pressed and sintered powder can approximately achieve the properties of the wrought alloy but at the cost of increased production cost.
9. The intricate shapes cannot be made by compacting since metal powders cannot flow like fluid under compact load.
10. The products are of small size because for large size bigger equipments and tools would be necessary involving very heavy investment.
11. Many metal powders are explosive at room temperature.
12. A few metals cannot be compressed because they have a tendency to cold-weld to the walls of the die causing wear on the die.

APPLICATIONS OF POWDER METALLURGY

Powder metallurgy has the following present day *applications :*

1. Porous and graphite containing metal bearings.
2. Electrical contacts consisting of a current and heat-conducting matrix in which are embedded wear resisting particles.
3. Tungsten wires.
4. Rotors of gear pump.
5. Diamond impregnated tools.
6. Magnetic materials.
7. Refractory metal composites.
8. Metal to glass seals.
9. Motor brushes.
10. Metallic filters.
11. Metallic coatings.
12. Babitted bearings for automobiles.
13. Cemented carbides.
14. Friction materials.

MANUFACTURE OF PARTS BY POWDER METALLURGY

The manufacture of parts by powder metallurgy involve the following *steps* :

1. Production of metal powders.
2. Blending powders.
3. Pressing or compacting of metal powders.
4. Sintering.
5. Finishing operations.

4.4.1. Production of Metal Powders

The methods of powder production are :

1. Atomising
2. Gaseous reduction
3. Electrolysis process
4. Carbonyl process
5. Stamp and ball mills
6. Granulation process
7. Mechanical alloying
8. Other methods.

1. **Atomising process.** In this process the molten metal is forced through an orifice into a stream of high-velocity air, steam or inert gas. This causes extremely rapid cooling and disintegration into a very fine powder.
   - The use of this process is usually *limited to metals* with low melting point.
2. **Gaseous reduction.** This process consists of grinding the metallic oxide to a finely divided state and then *reducing* it by hydrogen or carbonmonoxide.
   - It is employed for metals such as *iron*, *tungsten* and *copper* (whose melting points are near or above 1100°C).
3. **Electrolysis process.** In this process of producing powders the conditions of electrode position are controlled in such a way that a soft spongy deposit is formed ; which is then pulverised to form the powder. The particle size can be varied over a wide range by varying the electrolyte composition and various electrical parameters.
   - The powders of copper, iron and other metals are made by this process.
4. **Carbonyl process.** This process is based upon the fact that a number of metals can react with carbon monoxide to form what are known as *carbonyls*. For example, the iron carbonyl is made from iron reduced from ferric oxide. Carbon monoxide at a pressure of 48–200 bar is then passed over heated iron. The resulting carbonyl is decomposed by heating to a temperature of 200°C to 300°C.
   - This process yields powders of high purity but entails a heavy cost.
5. **Stamp and ball mills.** These are mechanical methods which produce a relatively coarse powder. The ball mill is employed for brittle materials while stamp mill for more ductile materials.
   - The cost is usually high, and the powders produced by these methods are usually treated to remove the cold work-hardening received in the process.
6. **Granulation process.** This process consists in the formation of an oxide film on individual particles when a bath of metal is stirred in contact with air.
   - This process produces a relatively coarse powder with a high percentage of oxide.
7. **Mechanical alloying.** In this method, powders of two or more pure metals are mixed in a ball mill. Under the impact of the hard balls, the powders repeatedly fracture and weld together by diffusion, forming alloy powders.
8. **Other methods.** Other, less commonly used methods include :

   (i) ***Precipitation** from a chemical solution.*

   (ii) *Production of fine metals by **machining.***

   (iii) ***Vapour condensation.***

   - New developments include techniques based on high temperature *extractive metallurgical processes*. Metal powders are being produced using high temperature processing techniques based on :

   — The reaction of volatile halides with liquid metals ;

   — The controlled reduction and reduction/carburization of solid oxides.

   - Recent developments include the production of ***nanopowders*** of various metals such as copper, aluminium, iron and titanium. When the metals are subjected to large plastic deformation at stress levels of 5500 MN/m^2, their particle size is reduced, and the material becomes pore free and thus possesses enhanced properties.

4.4.2. Blending of Metal Powders

The process of blending (mixing) powders is carried out for the following *purposes* :

(*i*) To obtain *uniformity* (since the powders made by various processes may have different sizes and shapes).

(*ii*) To *impart special physical and mechanical properties and characteristics* to the powder metallurgy product.

(*iii*) Addition of lubricants (*e.g.*, stearic acid, zinc stearate in proportion of 0.25 to 0.5% by weight) to the powders improve the flow characteristics of the powders. Such blends result in reduced friction between the metal particles, improved flow of powder metals into the dies, and longer die life.

- In order to avoid contamination and deterioration, powder mixing must be carried out under controlled conditions.
- The metal powders like aluminium, magnesium, titanium, zirconium, and thorium powders are *explosive* owing to their *high surface area to volume ratio* consequently, a great case must be exercised during their blending, storage and handling.

4.4.3. Pressing or Compaction of Metal Powders

The principal object of pressing or compacting is to effect cold-pressure welds between th particles so that some cohesion is conferred, this is usually measured by the strength of the gree compact and is termed the *green strength*.

Compacting exercises the following *effects* :

(*i*) Reduces voids between powder particles and increases density of the compact.

(*ii*) Produces adhesion and cold welding of the powder and sufficient green strength.

(*iii*) Plastically deforms the powder to allow recrystallisation during subsequent heating.

(*iv*) Plastically deforms the powder to increase the contact areas between the powder part cles, increasing green strength and facilitating subsequent sintering.

- *Pressing or compacting* is carried out by pouring a measured amount of the metal powder into the die cavity and then compacting the metal powder into coherent mass by means of one or more plungers (Fig. 4.1). Compressing from both top and bottom (Fig. 4.2) of the compact is better than compressing from the top only (Fig. 4.1), as pressure distribution and porosity distribution are more uniform.

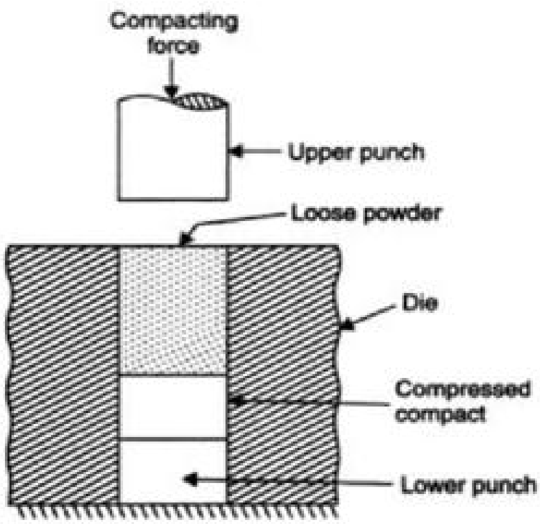


Fig. 4.1. Pressing or compacting by one or more plungers.

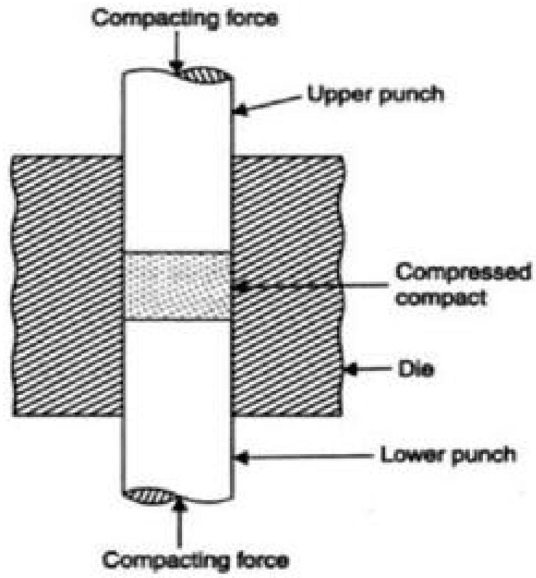


Fig. 4.2. Pressing or compacting from top and bottom.

— To improve uniformity of pressure and porosity through the piece the use of lubricants graphite, strearatex and zinc, aluminium and lithium strearate is made. Bond strength between particles is affected by the area of contact and by the cleanliness of particles (oxide layers being common sources of difficulty).

— The *compacting pressure required depends on the characteristics and shape of the particles, the methods* of *blending, and the lubrication.* The pressure required for pressing metal powders range from 70 MN/m^2 for aluminium to 800 MN/m^2 for high-density iron parts.

- In compacting powders in steel dies at room temperatures pressures from 7.5 to 37.5 (sometimes 150) kN/cm^2 are employed. Mechanical presses are employed for 500 kN and hydraulic presses for higher pressures. The moulding of small parts at great speeds and at relatively low pressures can be best accomplished in the mechanical press. However, large parts and parts to be moulded at higher pressures are best moulded in hydraulic presses.

— Extremely hard powders are slower and more difficult to press ; some organic binder is usually required to hold the hard particles together after pressing until the heat of sintering creates atomic bonds and promotes welding.

— In hot pressing if the powder is heated to proper temperature the pressure for complete densification is only 150 to 300 bar. Hot pressing requires a die material having appreciable high strength. Since even sturdy dies (made of graphite) usually sustain only one operation, therefore, *hot pressing is limited to the manufacture of articles of costly metals.*

4.4.4. Sintering

***Sintering** means the heating of pressed compact to below the melting temperature of any constituent of the compact, or atleast below the melting temperature of all principal constituents of the compact.* Such heating facilitates *bonding action* between the individual powder particles and *increases the strength of the compact.* Heating is carried out *in a controlled, inert or reducing atmosphere, or in vacuum to prevent oxidation.*

— Prior to sintering, the compact is brittle, and its strength, known *as green strength* is low. The nature and strength of the bond between the particles, and hence of sintered product, depend on the *mechanism of diffusion plastic flow, evaporation of volatile materials in the compact, recrystallization, grain growth, and pure shrinkage.*

During the sintering process bonding of the individual powder particles takes places in any of the following three ways :

(*i*) Melting of a minor constituent ;

(*ii*) Diffusion ;

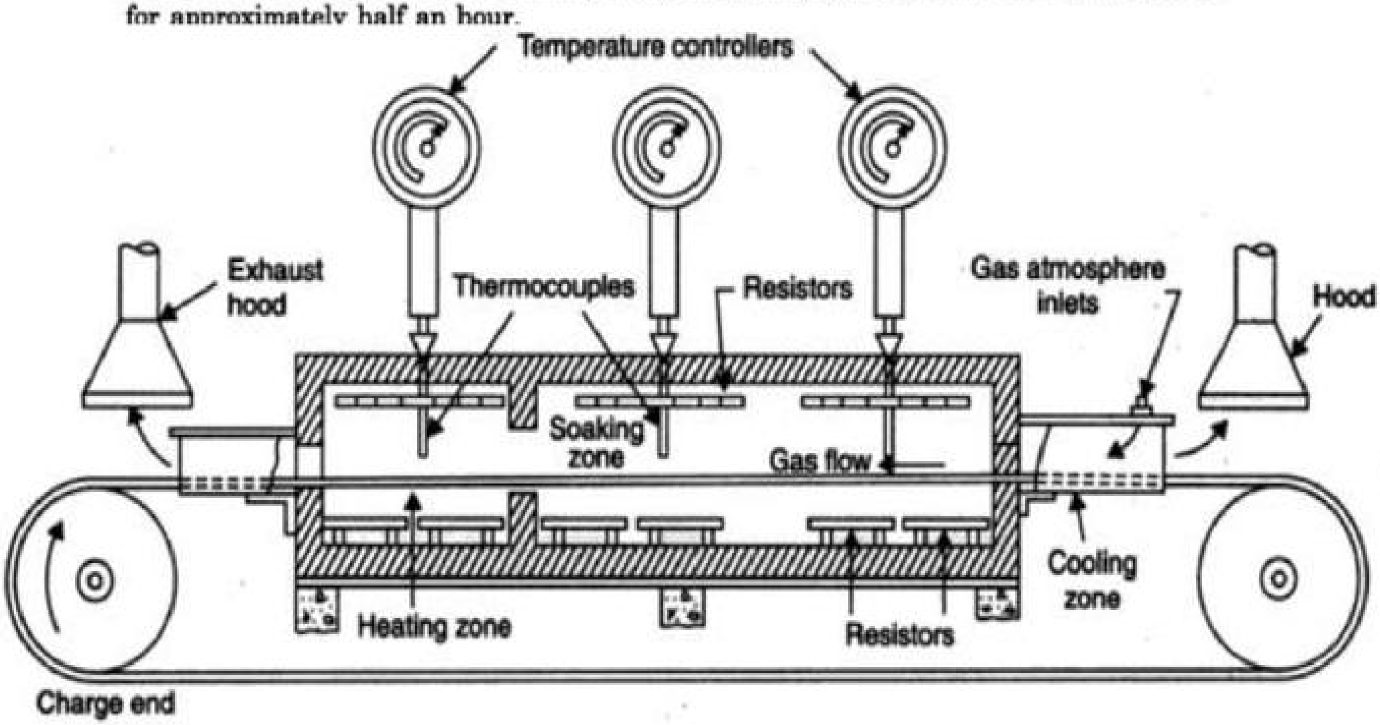
(*iii*) Mechanical bonding.

The important factors which control sintering are : (*a*) *temperature,* (*b*) *time, and* (*c*) *furnace atmosphere.* The sintering temperatures used vary with the compressive loads used, the type of powders, and strength required of the finished part.

— Aluminium and aluminium alloys can be sintered at temperatures from 350° to 500°C for periods upto 24 hours.

— Copper and copper alloys can be sintered at temperatures ranging from 700°C to temperatures that may melt one of the constituent metals.

— Compacts of iron powders are usually sintered at temperatures from 1000°C to 1200°C for approximately half an hour.



Sinteringfurnace

4.4.5. Finishing Operations

After sintering, the following additional operations may be carried out to further improve the properties of powder metallurgy products :

(*i*) **Re-pressing.** The purpose of this operation (also called *coining* and *sizing*) is to impart dimensional accuracy to the sintered part and to improve the part's strength and surface finish by *additional densification*.

(*ii*) **Forging.** This process involves the use of unsintered or sintered alloy-powder preforms that are subsequently hot forged in heated, confined dies to the desired final shapes ; the preforms may also be shaped by impact forging. The process is usually referred to as *powder-metallurgy forging*, and when the preform is sintered, the process is usually referred to as *sinter forging*.

(*iii*) **Infiltration.** In this process a metal slug with a lower melting point than that of the part is placed against the sintered part, and the assembly is heated to a temperature sufficient to melt the slug. The molten metal infiltrates the pores by *capillary action*, resulting in a relatively pore-free part with good density and strength.

(*iv*) Powdered-metal parts may be subjected to other operations including *heat treating*, *machining* and *finishing*.

4.5. DESIGN CONSIDERATIONS FOR POWDER METALLURGY

While using metal powders, because of their unique properties, the following *design principles* should be followed :

1. In order to facilitate easy ejection, narrow and deep sections should be avoided.
2. As far as possible, abrupt changes in section thickness should be avoided.
3. In order to increase tool and die life and reduce production costs, the powder metallurgy parts should be made with the widest dimensional tolerances, consistent with their intended applications.
4. In designing flat sections of high density, enough section thickness should be provided, otherwise the punch will break under pressure.
5. The design should be consistent with the capabilities and limitations of the available equipment.
6. Very close dimensional tolerances in the direction of pressing should be avoided.

7. The designed dimensions of parts should carry adequate allowances to compensate for the likely changes in dimensions due to shrinkage during sintering.
8. Holes should not be designed in the direction of pressing.
9. Production of very small holes through pressing should preferably be avoided.
10. Walls should not be less than 1.5 mm thick, although walls as thin as 0.34 mm have been successfully provided on components 1 mm in length.
    — Walls with length-to-thickness ratio greater than 8 : 1 are difficult to press, and density variations are virtually unavoidable.

11. The meeting plane between moulding punches should be on a flat or cylindrical surface and never on a spherical surface.
    - Dimensional tolerances of sintered powder metallurgy parts are usually of the order of ± 0.05–0.1 mm. Tolerances improve significantly with additional operations such as sizing, machining, and grinding.
    - Die and punch surfaces must be tapped or polished in the direction of tool movements for improved die life and overall performance.