UNIT-4 *CERAMICS AND COMPOSITES*

Introduction – powder metallurgy - modern ceramic materials – cermets - cutting tools – glass ceramic – production of semi fabricated forms - plastics and rubber – carbon/carbon composites, fabrication processes involved in metal matrix composites - shape memory alloys – applications in aerospace vehicle design, open and close mould processes.

Ceramic materials

An inorganic compound consisting of a metal (or semi-metal) and one or more nonmetals
Important examples: –Silica - silicon dioxide (SiO_2), the main ingredient in most glass products –Alumina - aluminum oxide (Al_2O_3), used in various applications from abrasives to artificial bones –More complex compounds such as hydrous aluminum silicate ($Al_2Si_2O_5 (OH)_4$), the main ingredient in most clay products

Ceramic materials are inorganic, non-metallic materials made from compounds of a metal and a non metal. Ceramic materials may be crystalline or partly crystalline. They are formed by the action of heat and subsequent cooling. Clay was one of the earliest materials used to produce ceramics, as pottery, but many different ceramic materials are now used in domestic, industrial and building products. Ceramic materials tend to be strong, stiff, brittle, chemically inert, and non-conductors of heat and electricity, but their properties vary widely. For example, porcelain is widely used to make electrical insulators, but some ceramic compounds are superconductors.

A ceramic material may be defined as any inorganic crystalline material, compounded of a metal and a non-metal. It is solid and inert. Ceramic materials are brittle, hard, and strong in compression, weak in shearing and tension. They withstand chemical erosion that occurs in an acidic or caustic environment. In many cases withstanding erosion from the acid and bases applied to it. Ceramics generally can withstand very high temperatures such as temperatures that range from 1,000 °C to 1,600 °C. Exceptions include inorganic materials that do not have oxygen such as silicon carbide. Glass by definition is not a ceramic because it is an amorphous solid (non-crystalline). However, glass involves several steps of the ceramic process and its mechanical properties behave similarly to ceramic materials.
Traditional ceramic raw materials include clay minerals such as kaolinite, more recent materials include aluminium oxide, more commonly known as alumina. The modern ceramic materials, which are classified as advanced ceramics, include silicon carbide and tungsten carbide. Both are valued for their abrasion resistance, and hence find use in applications such as the wear plates of crushing equipment in mining operations. Advanced ceramics are also used in the medicine, electrical and electronics industries.

IMPORTANT PROPERTIES

Ceramics can withstand high temperatures, are good thermal insulators, and do not expand greatly when heated. This makes them excellent thermal barriers, for applications that range from lining industrial furnaces to covering the space shuttle to protect it from high reentry temperatures.

Glasses are transparent, amorphous ceramics that are widely used in windows, lenses, and many other familiar applications. Light can induce an electrical response in some ceramics, called photoconductivity. Fiber optic cable is rapidly replacing copper for communications, as optical fibers can carry more information for longer distances with less interference and signal loss than traditional copper wires.

Ceramics are strong, hard, and durable. This makes them attractive structural materials. The one significant drawback is their brittleness, but this problem is being addressed by the development of new materials such as composites

Ceramics vary in electrical properties from excellent insulators to superconductors. Thus, they are used in a wide range of applications. Some are capacitors, others semiconductors in electronic devices. Piezoelectric materials can convert mechanical pressure into an electrical signal and are especially useful for sensors. There is now a strong research effort to discover new high Tc superconductors and to develop possible applications.

The processing of crystalline ceramics follows the basic steps that have been used for ages to make clay products. The materials are selected, prepared, formed into a desired shape, and sintered at high temperatures. Glasses are processed by pouring in a molten state, working into shape while hot, and then cooling. New methods such as chemical vapor deposition and sol-gel processing are presently being developed.

The diversity in their properties stems from their bonding and structure.

CLASSIFICATION

Ceramic materials can be divided into two classes: crystalline and amorphous (non-crystalline). In crystalline materials, a lattice point is occupied either by atoms or ions depending on the bonding mechanism. These atoms (or ions) are arranged in a regularly repeating pattern in three dimensions (i.e., they have long-range order). In contrast, in amorphous materials, the atoms exhibit only short-range order. Some ceramic materials, like silicon dioxide (SiO2), can exist in either form. A crystalline form of SiO2 results when this material is slowly cooled from a temperature (T >Tmp @1723 ° C). Rapid cooling favors non-crystalline formation since time is not allowed for ordered arrangements to form.

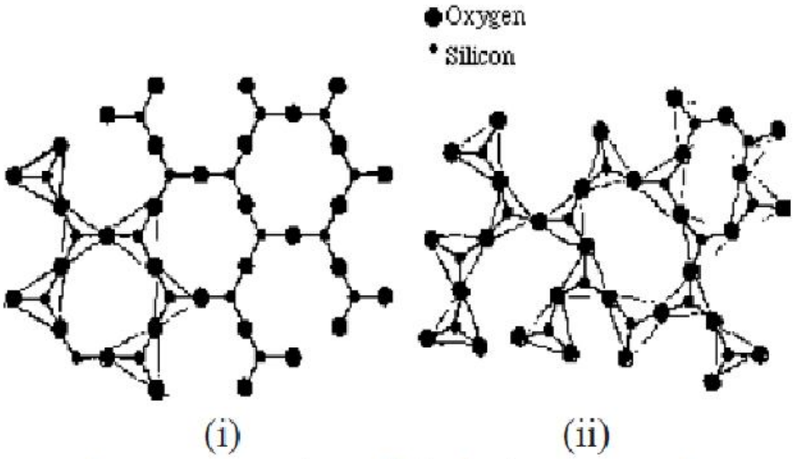


Figure 1: Comparison of physical structures of (i) crystalline silicon dioxide (regular pattern) and (ii) amorphous silicon dioxide (random pattern)

Properties of Ceramic Materials

- High hardness, electrical and thermal insulating, chemical stability, and high melting temperatures
- Brittle, virtually no ductility - can cause problems in both processing and performance of ceramic products
- Some ceramics are translucent, window glass (based on silica) being the clearest example

Ceramic materials developed synthetically over the last several decades

- The term also refers to improvements in processing techniques that provide greater control over structures and properties of ceramic materials
- In general, new ceramics are based on compounds other than variations of aluminum silicate, which form most of the traditional ceramic materials
- New ceramics are usually simpler chemically than traditional ceramics; for example, oxides, carbides, nitrides, and borides

Oxide Ceramics

- Most important oxide new ceramic is alumina
- Although also included as a traditional ceramic, alumina is today produced synthetically from bauxite, using an electric furnace method
- Through control of particle size and impurities, refinements in processing methods, and blending with small amounts of other ceramic ingredients, strength and toughness of alumina are improved substantially compared to its natural counterpart
- Alumina also has good hot hardness, low thermal conductivity, and good corrosion resistance

Products of Oxide Ceramics

- Abrasives (grinding wheel grit)
- Bioceramics (artificial bones and teeth)
- Electrical insulators and electronic components
- Refractory brick
- Cutting tool inserts
- Spark plug barrels
- Engineering components

Carbides

- Silicon carbide (SiC), tungsten carbide (WC), titanium carbide (TiC), tantalum carbide (TaC), and chromium carbide (Cr3C2)
- Although SiC is a man-made ceramic, its production methods were developed a century ago, and it is generally included in traditional ceramics group
- WC, TiC, and TaC are valued for their hardness and wear resistance in cutting tools and other applications requiring these properties
- WC, TiC, and TaC must be combined with a metallic binder such as cobalt or nickel in order to fabricate a useful solid product

Nitrides

- The important nitride ceramics are silicon nitride (Si3N4), boron nitride (BN), and titanium nitride (TiN)
- Properties: hard, brittle, high melting temperatures, usually electrically insulating, TiN being an exception

Applications:

- Silicon nitride: components for gas turbines, rocket engines, and melting crucibles
- Boron nitride and titanium nitride: cutting tool material and coatings

Glass

- A state of matter as well as a type of ceramic
- As a state of matter, the term refers to an amorphous (non-crystalline) structure of a solid material

  The glassy state occurs in a material when insufficient time is allowed during cooling from the molten state for the crystalline structure to form
- As a type of ceramic, glass is an inorganic, nonmetallic compound (or mixture of compounds) that cools to a rigid condition without crystallizing
- Silica is the main component in glass products, usually comprising 50% to 75% of total chemistry
- It naturally transforms into a glassy state upon cooling from the liquid, whereas most ceramics crystallize upon solidification

Other Ingredients in Glass

- Sodium oxide (Na_2O), calcium oxide (CaO), aluminum oxide (Al_2O_3), magnesium oxide (MgO), potassium oxide (K_2O), lead oxide (PbO), and boron oxide (B_2O_3)

Functions:

- Act as flux (promoting fusion) during heating
- Increase fluidity in molten glass for processing
- Improve chemical resistance against attack by acids, basic substances, or water
- Add color to the glass
- Alter index of refraction for optical applications

Glass-Ceramics

A ceramic material produced by conversion of glass into a polycrystalline structure through heat treatment

- Proportion of crystalline phase range = 90% to 98%,remainder being unconverted vitreous material
- Grain size - usually between 0.1 - 1.0 µm (4 and 40µ-in), significantly smaller than the grain size ofconventional ceramics
- This fine crystal structure makes glass-ceramicsmuch stronger than the glasses from which theyare derived
- Also, due to their crystal structure, glass-ceramics areopaque (usually grey or white) rather than clear

Processing of Glass Ceramics

- Heating and forming operations used in glass working create product shape
- Product is cooled and then reheated to cause a dense network of crystal nuclei to form throughout

  High density of nucleation sites inhibits grain growth, leading to fine grain size
- Nucleation results from small amounts of nucleating agents in the glass composition, such as TiO_2, P_2O_5, and ZrO_2
- Once nucleation is started, heat treatment is continued at a higher temperature to cause growth of crystalline phases

Advantages of Glass-Ceramics

- Efficiency of processing in the glassy state
- Close dimensional control over final product shape
- Good mechanical and physical properties
  - High strength (stronger than glass)
  - Absence of porosity; low thermal expansion
  - High resistance to thermal shock
- Applications:
  - Cooking ware
  - Heat exchangers
  - Missile radomes

CERMET

A cermet is a composite material composed of ceramic (cer) and metal (met) materials.

A cermet is ideally designed to have the optimal properties of both a ceramic, such as high temperature resistance and hardness, and those of a metal, such as the ability to undergo plastic deformation. The metal is used as a binder for an oxide, boride, or carbide. Generally, the metallic elements used are nickel, molybdenum, and cobalt. Depending on the physical structure of the material, cermets can also be metal matrix composites, but cermets are usually less than 20% metal by volume.

Cermets are used in the manufacture of resistors (especially potentiometers), capacitors, and other electronic components which may experience high temperature.

Cermets are used instead of tungsten carbide in saws and other brazed tools due to their superior wear and corrosion properties. Titanium nitride (TiN), titanium carbonitride (TiCN), titanium carbide (TiC) and similar can be brazed like tungsten carbide if properly prepared however they require special handling during grinding.

Cermets are used in situations where neither metals nor ceramics alone would be ideal. For example, metal is not capable of resisting the heat produced in space rockets and airplane engines, although it is highly versatile. On the other hand, ceramics are excellent at withstanding extremely high temperatures. Additionally, ceramics are more resistant to chemical attacks and oxidation, which could lead to corrosion damage.

Therefore, industries that require materials with great strength and flexibility as well as resistance to high temperature often use cermets. In addition to benefits already mentioned, cermets also have high resistance to plastic deformation and impressive toughness.

Cermets play a vital role in the electronics industry because they can be applied in electrical components. Electronic elements may get very hot, so they must act like ceramics, but they also have to act as conductors of electricity. The most ideal applications of cermets are in vacuum tubes and resistors. Another application is in machine tools. For instance, a great number of drilling, boring, milling, turning and cutting tools are made of cermets.

Cermet's ability to reduce friction wear is highly notable. It can reduce friction in equipment parts as it behaves like a metal-ceramic conditioner in order to prevent corrosion and wear in machine parts

Cermet is a cutting tool material composed mainly of TiC (Titanium Carbide) and TiN (Titanium Nitride).Cutting performance is also in the mid-range of ceramic's and carbide's. The advantages of this material grade are high-quality and excellent surface finishes can be achieved with elevated cutting speeds. Cermets provide extended tool life.

Features

High quality surface finish

The main components, TiC and TiN, have good BUE resistance as they have low affinity with work materials. Thus, machining with cermets brings high quality surface finish over extended periods of time.

High speed cutting

The main components, TiC and TiN, are more resistant to wear and oxidation at high temperature than WC (tungsten carbide), which is the main component of carbide tools. Because of excellent wear and oxidation resistance, cermet grades are less reactive with work materials and make stable high speed machining possible.

PLASTICS

Plastic is material consisting of any of a wide range of synthetic or semi-synthetic organic compounds that are malleable and so can be molded into solid objects.

Plasticity is the general property of all materials which can deform irreversibly without breaking but, in the class of moldable polymers, this occurs to such a degree that their actual name derives from this specific ability.

Plastics are typically organic polymers of high molecular mass and often contain other substances. They are usually synthetic, most commonly derived from petrochemicals, however, an array of variants are made from renewable materials such as polylactic acid from corn or cellulosic from cotton linters.

Natural plastics - these are naturally occurring materials that can be said to be plastics because they can be shaped and moulded by heat. An example of this is amber, which is a form of fossilised pine tree resin and is often used in jewellery manufacture.

Semi synthetic plastics - these are made from naturally occurring materials that have been modified or changed but mixing other materials with them. An example of this is cellulose acetate, which is a reaction of cellulose fibre and acetic acid and is used to make cinema film.

Synthetic plastics - these are materials that are derived from breaking down, or ’cracking’ carbon based materials, usually crude oil, coal or gas, so that their molecular structure changes. This is generally done in petrochemical refineries under heat and pressure, and is the first of the manufacturing processes that is required to produce most of our present day, commonly occurring plastics.

Synthetic and semi synthetic plastics can be further divided into two other categories. These two categories are defined by the ways in which different plastics react when heated.

Thermoplastics - these are plastics that can be softened and formed using heat, and when cool, will take up the shape that they have been formed into.

But if heat is reapplied they will soften again. Examples of thermoplastics are acrylic and styrene, probably the most common plastics found in school workshops.

Thermosetting plastics - these are plastics that soften when heated, and can be moulded when soft, and when cool they will set into the moulded shape. But if heat is reapplied they will not soften again, they are permanently in the shape that they have been moulded into. Why this happens we will look at later. Examples of thermosetting plastics are polyester resins used in glass reinforced plastics work, and melamine formaldehyde used in the manufacture of Formica for kitchen work surfaces.

‘Polymers’ is a general term for all plastic materials and means that they are organic, carbon based compounds whose molecules are linked together in long chain patterns. Later on in this book we will look more closely at the molecular structure of plastics so that we can understand how we can make this work to our advantage when designing and making things. When we talk about plastics in general we will call them polymers, and when we talk about specific plastic materials we will give them their real names, such as nylon or polythene.

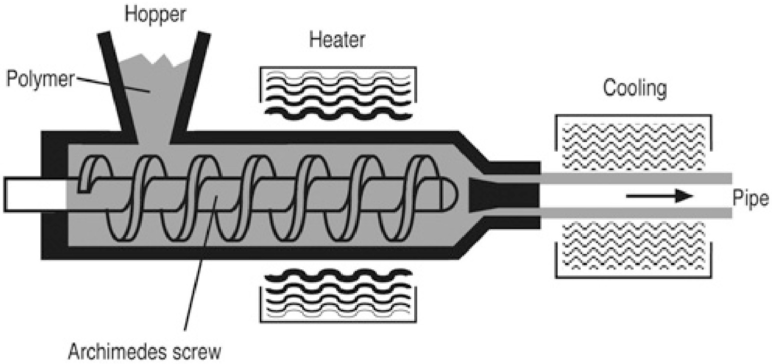
Plastics Processing

Because of the properties of polymers it is possible to mould them and change their shape using a number of different repetitious manufacturing processes.

The most important of these are extrusion, injection moulding, blow moulding, vacuum forming, extrusion blow moulding, rotational moulding, calendaring, foaming and compression moulding.

Extrusion.

Extrusion is a process that can be compared to squeezing toothpaste out of a tube. Thermoplastic granules are forced through a heated barrel and the fused polymer is then squeezed through a die that is the profile of the extruded component.

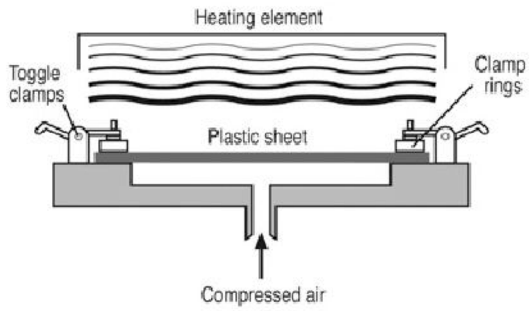


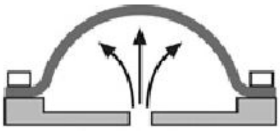
Extruding a pipe

The extrusion is cooled by water or air as it leaves the die and is finally cut to the required length. The shape of the die can be varied from a simple hole with a centrally supported core to produce tubes such as pipes, to very complex sections for curtain tracks or hollow window frames.

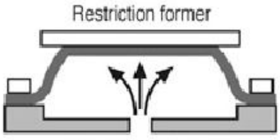
Blow moulding.

Blow moulding is a simple process where compressed air is introduced underneath a warmed sheet of thermoplastic material forcing the material into a mould cavity, or allowing it to expand freely into the shape of a hemisphere. It is a good way of forming large domes, which when made out of clear acrylic sheet are often used in shop displays.

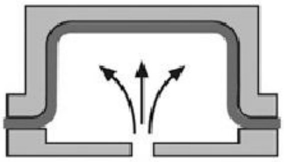




Free blown form



Restricted form

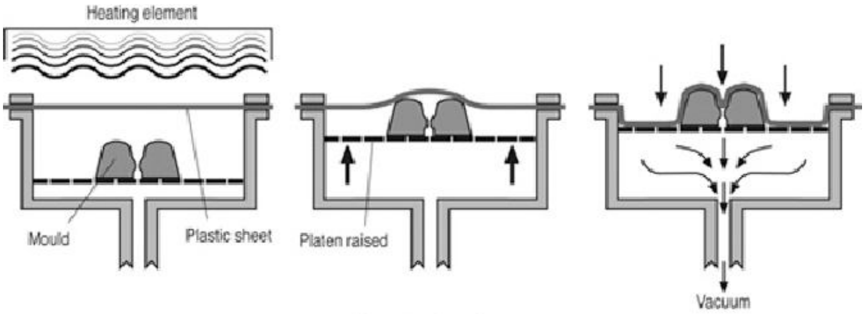


Blowing into a mould

Vacuum forming.

This is a very common manufacturing process used, for example, to make a range of plastics packaging. Think of the boxes sandwiches come in, or the inner in a chocolate box, or your acrylic bath. It is really the opposite of blow moulding. Instead of the warmed plastic sheet being forced into a mould by air pressure, in vacuum forming the air is drawn out from under the softened plastic sheet, so it is forced over or into a mould by atmospheric pressure.

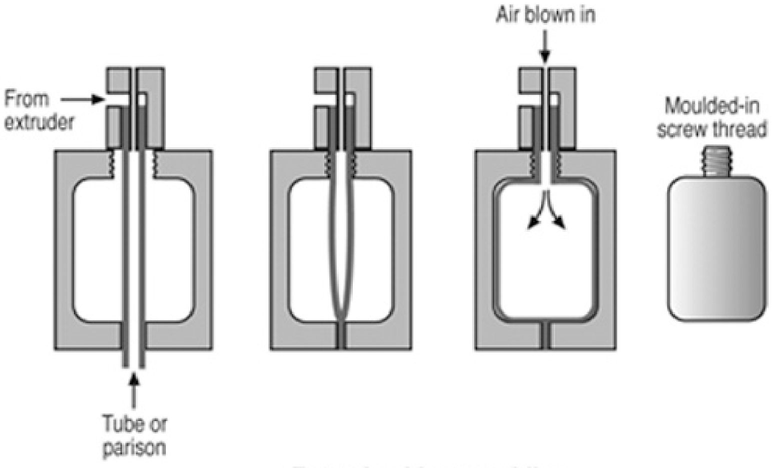
Vacuum forming is a very common and effective way of producing complex shapes in thermoplastic sheeting.



Vacuum forming

Extrusion blow moulding.

This is a combination of extrusion and blow moulding and is often used where the article to be made has a narrow neck, such as a bottle. The plastic material is first extruded as a tube shape into an open die. The die is then closed to seal the ends of the tube and air is blown in forcing the plastic tube to take up the shape of the die cavity. As the material is extruded first and then blow moulded, the process is known as extrusion blow moulding.

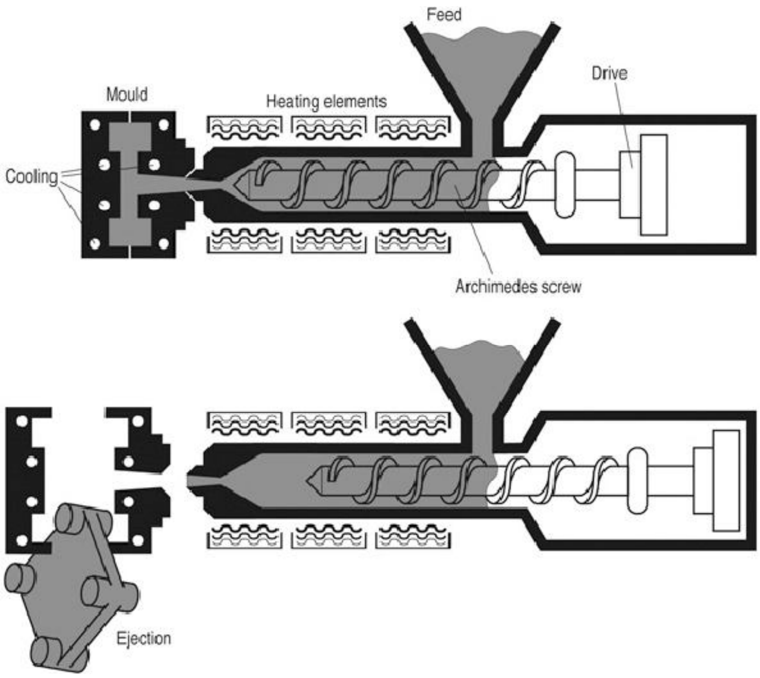


Extrusion blow moulding

Injection Moulding.

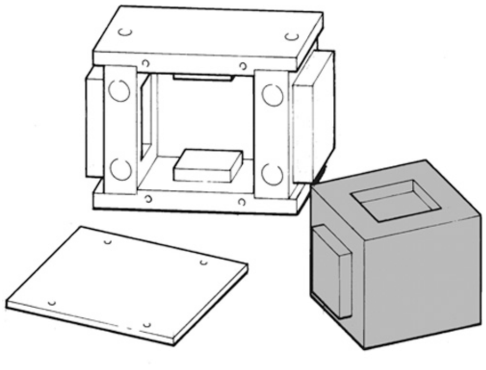
This process is one of the most common of all plastics manufacturing processes. The polymer, in granule form, is heated until fused and forced into a closed mould. Because of the viscous (thick, syrupy) nature of the fused polymer, very high pressures are needed to make it flow, which means that the machine and mould have to be very strong to withstand the forces involved.

A typical industrial injection moulding machine uses a screw to force the granules along a heated barrel, and when the granules become fused the screw is used as a plunger to force the polymer into the mould. The moulds are usually made from high-grade steel to withstand the forces involved and must also be highly polished to produce a very good finish on the product, as any scratches will show up in the moulded plastic surface. Because of the ability of the plastic to show even the smallest of marks very fine detail can be cut into the surface of the mould, for example in the form of trade marks, lettering or textures.



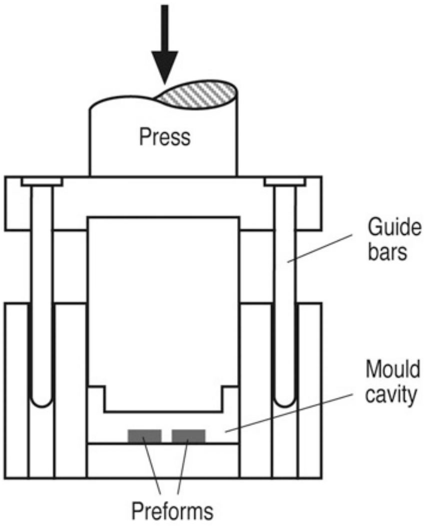
Rotational Moulding.

Rotational moulding is used to produce hollow thermoplastic products such as drums, storage tanks and litterbins. A carefully calculated amount of plastic is placed in a closed mould that is heated in an oven and rotated slowly around both a vertical and horizontal axes. The plastic material fuses and sticks to the hot mould surface, building up the required thickness. The mould is then gradually cooled by air or water while still rotating. The mould is opened, the finished product removed and the mould reloaded and closed for the next cycle. The time it takes to make one of the product is known as the product's cycle time.



Compression moulding.

Compression moulding is one of the oldest manufacturing technologies associated with plastics and was used in 1854, for example, by Samuel Peck to make picture frames from shellac mixed with wood flour. The process is almost always used with thermosetting plastics. A carefully weighed amount of thermosetting polymer is placed into a preheated lower mould cavity. The mould is then closed by the placing of the upper half and subjected to further heat, and pressure provided by a press, often of several hundred tons capacity. The pressure and heat causes polymerisation and the flow of the plasticized material within the mould.



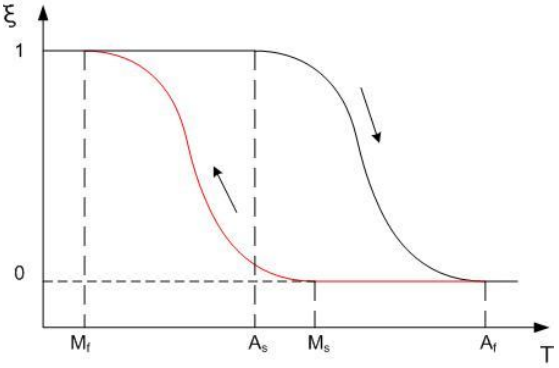
Compression moulding

Raw thermoplastic materials containing fillers may be compressed whilst cold into small blocks of predetermined weight called preforms. Using preforms in
23 compression moulds saves having to weigh out powdered material each time the mould is filled and decreases the cycle time, as the preforms may be preheated.
A development of compression moulding is transfer moulding. In this process the thermosetting polymer is first loaded into a heating chamber above the mould cavity and allowed to polymerise. It is then squeezed through channels into the mould cavity by the action of a powerful press. Transfer moulding is used when complex mouldings are required and the polymer needs to flow quickly around the mould cavity. Many plastic articles have metal parts included within them during the
moulding process. These metal parts are called inserts, and may, for example, be in the form of captive nuts used in conjunction with bolts to hold other parts of the final product assembly. The inserts are placed in recesses in the lower mould either by hand or by using loading jigs before the polymer is introduced into the mould. Compression and transfer moulding are manufacturing techniques that lend themselves to the inclusion of moulded inserts. When inserts are used the technique is often termed insert moulding.

SHAPE MEMORY ALLOYS

A shape memory alloy (SMA, smart metal, memory metal, memory alloy, muscle wire, smart alloy) is an alloy that "remembers" its original, cold-forged shape: returning the pre- deformed shape by heating. This material is a lightweight, solid-state alternative to conventional actuators such as hydraulic, pneumatic, and motor-based systems. Shape memory alloys have applications in industries including medical and aerospace.

The three main types of shape memory alloys are the copper-zinc aluminium-nickel, copper-aluminium-nickel, and nickel-titanium (NiTi) alloys but SMA's can also be created by alloying zinc, copper, gold, and iron. NiTi alloys are generally more expensive and change from austenite to martensite upon cooling; Mf is the temperature at which the transition to Martensite is finished during cooling. Accordingly, during heating As and Af are the temperatures at which the transformation from Martensite to Austenite starts and finishes. Repeated use of the shape memory effect may lead to a shift of the characteristic transformation temperatures (this effect is known as functional fatigue, as it is closely related with a change of microstructural and functional properties of the material)



In this figure, ξ (T) represents the martensite fraction. The difference between the heating transition and the cooling transition gives rise to the hysteresis effect where some of the mechanical energy is lost in the process. The shape of the curve depends on the material properties of the shape memory alloy, such as the alloying and work hardening

One way memory effect

- When a shape memory alloy is in its cold state (below As), the metal can be bent or stretched and will hold this shape until heated above the transition temperature.
- Upon heating, the shape changes to its original.
- When the metal cools again, it will remain in the hot shape until deformed again.
- In this case, cooling from high temperature does not cause macroscopic shape change.

Two way memory effect

- This is the effect that the material remembers two shapes: one at high temp and the other at low temperature.
- These metals show shape memory effect during both cooling and heating.
- The metal can be trained to leave some reminders of the deformed low temp condition in the high temp phases.
- Above a certain temp, the metal loses the 2 way memory effect. This is called “amnesia”

Aircraft

Boeing, General Electric Aircraft Engines, Goodrich Corporation, NASA, and All Nippon Airways developed the Variable Geometry Chevron using shape memory alloy that reduces aircraft's engine noise.

Robotics

There have also been limited studies on using these materials in robotics (such as "Roboterfrau Lara"), as they make it possible to create very light robots. Weak points of the technology are energy inefficiency, slow response times, and large hysteresis.

Medicine

Shape memory alloys are applied in medicine, for example, as fixation devices for osteotomies in orthopaedic surgery, in dental braces to exert constant tooth-moving forces on the teeth and in stent grafts where it gives the ability to adapt to the shape of certain blood vessels when exposed to body temperature.

Alloys of metals having the memory effect at different temperatures and at different percentages of its solid solution contents:

- Ag-Cd 44/49 at.% Cd
- Au-Cd 46.5/50 at.% Cd
- Cu-Al-Ni 14/14.5 wt.% Al and 3/4.5 wt.% Ni
- Cu-Sn approx. 15 at.% Sn
- Cu-Zn 38.5/41.5 wt.% Zn
- Cu-Zn-X (X = Si, Al, Sn)
- Fe-Pt approx. 25 at.% Pt
- Mn-Cu 5/35 at.% Cu

Two or more chemically distinct materials combined to have improved properties

- Natural/synthetic
- Wood is a natural composite of cellulose fiber and lignin.

Cellulose provides strength and the lignin is the "glue" that bonds and stabilizes the fiber.

Bamboo is a wood with hollow cylindrical shape which results in a very light yet stiff structure. Composite fishing poles and golf club shafts copy this design.

A composite material consists of two phases:

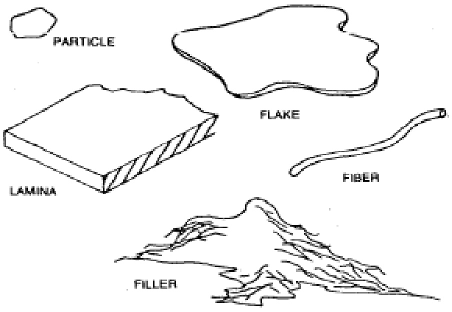
Primary

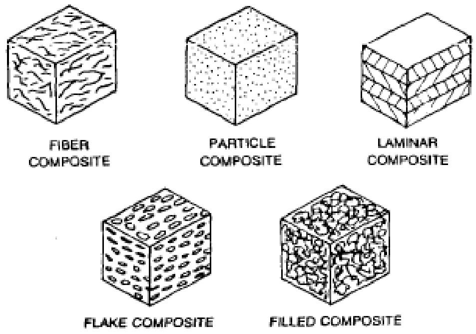
- Forms the matrix within which the secondary phase is imbedded
- Any of three basic material types: polymers, metals, or ceramics

Secondary

- Referred to as the imbedded phase or called the reinforcing agent
- Serves to strengthen the composite (fibers, particles, etc.)
- Can be one of the three basic materials or an element such as carbon or boron

There are five basic types of composite materials: Fiber, particle, flake, laminar or layered and filled composites.





Classification of composite material

Metal Matrix Composites (MMCs)
- Mixtures of ceramics and metals, such as cemented carbides and other cermets
- Aluminum or magnesium reinforced by strong, high stiffness fibers

Ceramic Matrix Composites (CMCs)
- Least common composite matrix
- Aluminum oxide and silicon carbide are materials that can be imbedded with fibers for improved properties, especially in high temperature applications

Polymer Matrix Composites (PMCs)
- Thermosetting resins are the most widely used polymers in PMCs.
- Epoxy and polyester are commonly mixed with fiber reinforcement

Matrix material serves several functions in the composite
- Provides the bulk form of the part or product
- Holds the imbedded phase in place
- Shares the load with the secondary phase

The reinforcing phase
- The imbedded phase is most commonly one of the following shapes:
- Fibers, particles, flakes
- Orientation of fibers:
- One-dimensional: maximum strength and stiffness are obtained in the direction of the fiber
- Planar: in the form of two-dimensional woven fabric
- Random or three-dimensional: the composite material tends to posses isotropic properties

Types of phases

Currently, the most common fibers used in composites are glass, graphite (carbon), boron and Kevlar 49.

- Glass – most widely used fiber in polymer composites called glass fiber-reinforced plastic (GFRP)
- E-glass – strong and low cost, but modulus is less than other (500,000 psi)
- S-glass – highest tensile strength of all fiber materials (650,000 psi). UTS~ 5 X steel ; r ~ 1/3 x steel
- Carbon/Graphite –Graphite has a tensile strength three to five times stronger than steel and has a density that is one-fourth that of steel.
- Boron – Very high elastic modulus, but its high cost limits its application to aerospace components
- Ceramics – Silicon carbide (SiC) and aluminum oxide (Al2O3) are the main fiber materials among ceramics. Both have high elastic moduli and can be used to strengthen low-density, low- modulus metals such as aluminum and magnesium
- Metal – Steel filaments, used as reinforcing fiber in plastics

Manufacturing of composites

1. Open Mold Processes- some of the original FRP manual procedures for laying resins and fibers onto forms
2. Closed Mold Processes- much the same as those used in plastic molding
3. Filament Winding- continuous filaments are dipped in Manufacturing of composites liquid resin and wrapped around a rotating mandrel, producing a rigid, hollow, cylindrical shape
4. Pultrusion Processes- similar to extrusion only adapted to include continuous fiber reinforcement
5. Other PMC Shaping Processes

Open Mold Processes

Family of FRP shaping processes that use a single positive or negative mold surface to produce laminated FRP structures

- The starting materials (resins, fibers, mats, and woven rovings) are applied to the mold in layers, building up to the desired thickness
- This is followed by curing and part removal
- Common resins are unsaturated polyesters and epoxies, using fiberglass as the reinforcement

Open Mold FRP Processes

1. Hand lay-up
2. Spray-up
3. Vacuum Bagging – uses hand-lay-up, uses atmosphericpressure to compact laminate.
4. Automated tape-laying machines the differences are in the methods of applying thelaminations to the mold, alternative curing techniques,and other differences

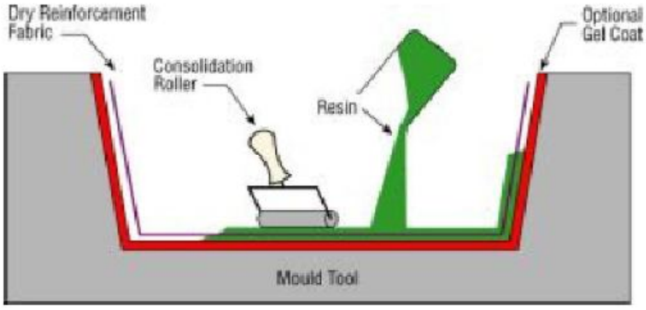
Hand Lay-Up Method

Open mold shaping method in which successive layers ofresin and reinforcement are manually applied to an openmold to build the laminated FRP composite structure

- Labor-intensive
- Finished molding must usually be trimmed with a powersaw to size outside edges
- Oldest open mold method for FRP laminates, dating tothe 1940s when it was first used for boat hulls

Hand Lay-up

Hand lay–up, or contact molding, is the oldest andsimplest way of making fiberglass–resin composites.Applications are standard wind turbine blades, boats,etc.)



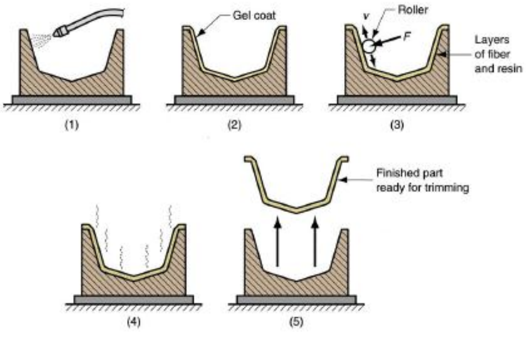
Hand lay-up:

(1) mold is treated with mold release agent;

(2) thin gel coat (resin)is applied, to the outside surface of molding;

(3) when gel coat has partiallyset, layers of resin and fiber are applied, the fiber is in the form of mat or cloth;each layer is rolled to impregnate the fiber with resin and remove air;

(4) partis cured; (5) fully hardened part is removed from mold.



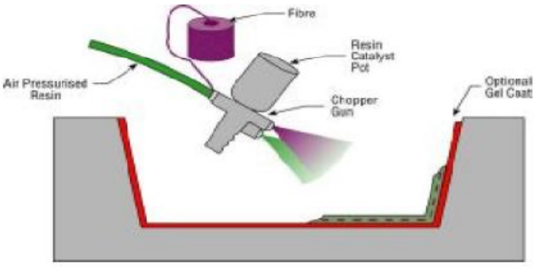
- Generally large in size but low in production quantity -not economical for high production
- Applications:
  - Boat hulls
  - Swimming pools
  - Large container tanks
  - Movie and stage props
  - Other formed sheets

Spray-Up Method

Liquid resin and chopped fibers are sprayed onto an openmold to build successive FRP laminations

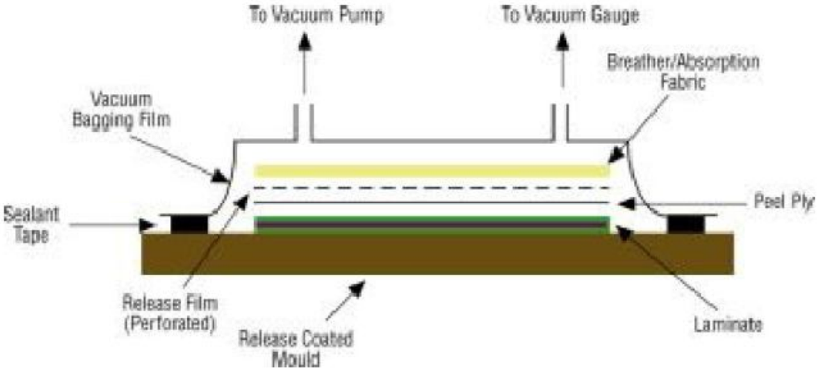
- Attempt to mechanize application of resin-fiber layersand reduce lay-up time
- Alternative for step (3) in the hand lay-up procedure

In Spray–up process, chopped fibers and resins aresprayed simultaneously into or onto the mold. Applicationsare lightly loaded structural panels, e.g. caravan bodies,truck fairings, bathtubes, small boats, etc.



Vacuum-Bag Molding

The vacuum–bag process was developed for makinga variety of components, including relatively largeparts with complex shapes. Applications are largecruising boats, racecar components, etc.

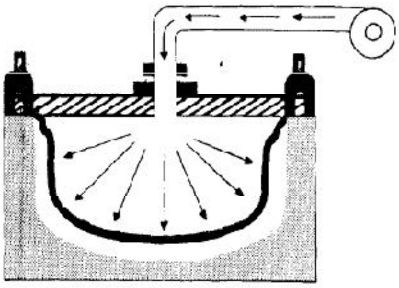


Use atmospheric pressure to suck air from under vacuumbag, to compact composite layers down and make ahigh quality laminate

Layers from bottom include: mold, mold release,composite, peel-ply, breather cloth, vacuum bag, alsoneed vacuum valve, sealing tape.

Pressure-Bag Molding

Pressure–bag process is virtually a mirror image ofvacuum–bag molding. Applications are sonar domes,antenna housings, aircraft fairings, etc.



Curing in Open Mold Processes

- Curing is required of all thermosetting resins used inFRP laminated composites
- Curing cross-links the polymer, transforming it from itsliquid or highly plastic condition into a hardened product
- Three principal process parameters in curing:
    - Time
    - Temperature
    - Pressure

Curing at Room Temperature

• Curing normally occurs at room temperature for the TSresins used in hand lay-up and spray-up procedures

- Moldings made by these processes are often large(e.g., boat hulls), and heating would be difficult due toproduct size
- In some cases, days are required before roomtemperature curing is sufficiently complete to removethe part

Closed Mold Processes

- Performed in molds consisting of two sections that openand close each molding cycle
- Tooling cost is more than twice the cost of a comparableopen mold due to the more complex equipment requiredin these processes
- Advantages of a closed mold are: (1) good finish on allpart surfaces, (2) higher production rates, (3) closercontrol over tolerances, and (4) more complexthree-dimensional shapes are possible

Classification of Closed MoldProcesses

Three classes based on their counterparts inconventional plastic molding:

1. Compression molding
2. Transfer molding
3. Injection molding

The terminology is often different when polymer matrixcomposites are moldedCompression Molding PMCProcesses

A charge is placed in lower mold section, and the sectionsare brought together under pressure, causing charge totake the shape of the cavity

- Mold halves are heated to cure TS polymer

– When molding is sufficiently cured, the mold isopened and part is removed

- Several shaping processes for PMCs based oncompression molding

– The differences are mostly in the form of the startingmaterials

Injection Molding PMCProcesses

- Injection molding is noted for low cost production ofplastic parts in large quantities
- Although most closely associated with thermoplastics,the process can also be adapted to thermosets
- Processes of interest in the context of PMCs:
    - Conventional injection molding
    - Reinforced reaction injection molding

Conventional Injection Molding

- Used for both TP and TS type FRPs
- Virtually all TPs can be reinforced with fibers
- Chopped fibers must be used
    - – Continuous fibers would be reduced by the action ofthe rotating screw in the barrel
- During injection into the mold cavity, fibers tend tobecome aligned as they pass the nozzle
    - – Part designers can sometimes exploit this feature tooptimize directional properties in the part