Composites

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What is a composite Material?

A broad definition of composite is: Two or more chemically distinct materials which when combined have improved properties over the individual materials. Composites could be natural or synthetic.

Wood is a good example of a natural composite, combination of cellulose fiber and lignin. The cellulose fiber provides strength and the lignin is the "glue" that bonds and stabilizes the fiber.

Bamboo is a very efficient wood composite structure. The components are cellulose and lignin, as in all other wood, however bamboo is hollow. This results in a very light yet stiff structure. Composite fishing poles and golf club shafts copy this natural design.

The ancient Egyptians manufactured composites! Adobe bricks are a good example. The combination of mud and straw forms a composite that is stronger than either the mud or the straw by itself.

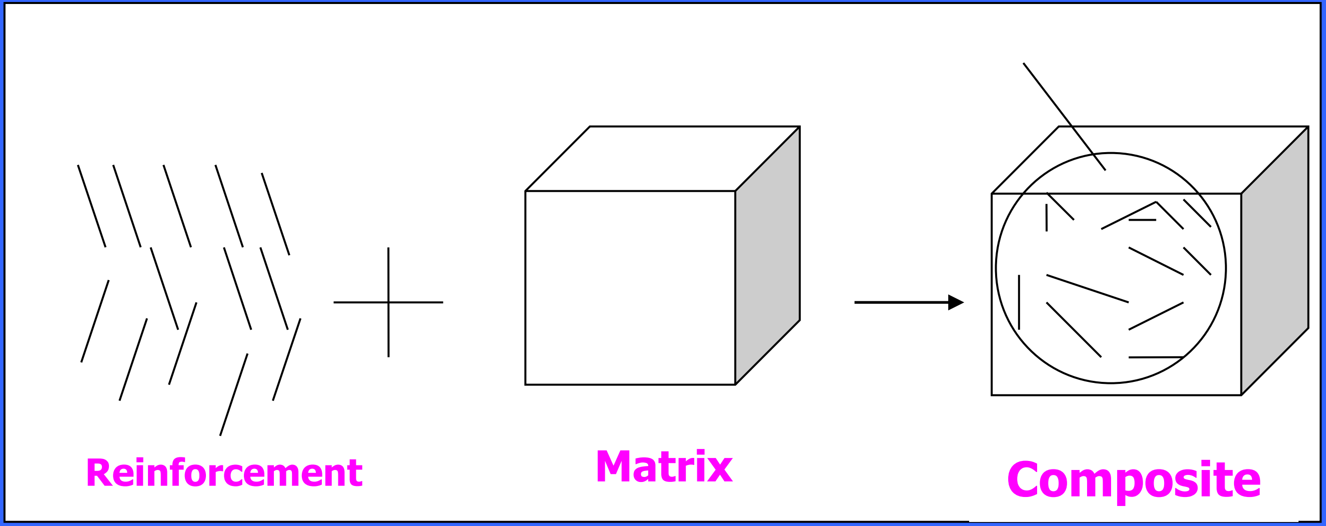
Composites

Composites are combinations of two materials in which one of the material is called the **reinforcing phase**, is in the form of fibers, sheets, or particles, and is embedded in the other material called the **matrix phase**.

Typically, reinforcing materials are strong with low densities while the matrix is usually a ductile or tough material. If the composite is designed and fabricated correctly, it combines the strength of the reinforcement with the toughness of the matrix to achieve a combination of desirable properties not available in any single conventional material.

COMPOSITES

Heterogeneous structural materials which are made up of a matrix containing reinforcing agents and are often better suited for specific applications than any of the original components



Composites

The essence of the concept of composites is that the load is applied over a large surface area of the matrix. Matrix then transfers the load to the reinforcement, which being stiffer, increases the strength of the composite. It is important to note that there are many matrix materials and even more fiber types, which can be combined in countless ways to produce just the desired properties.

Components of composite materials

Reinforcement: fibers

- Glass
- Carbon
- Organic
- Boron
- Ceramic
- Metallic

Matrix materials

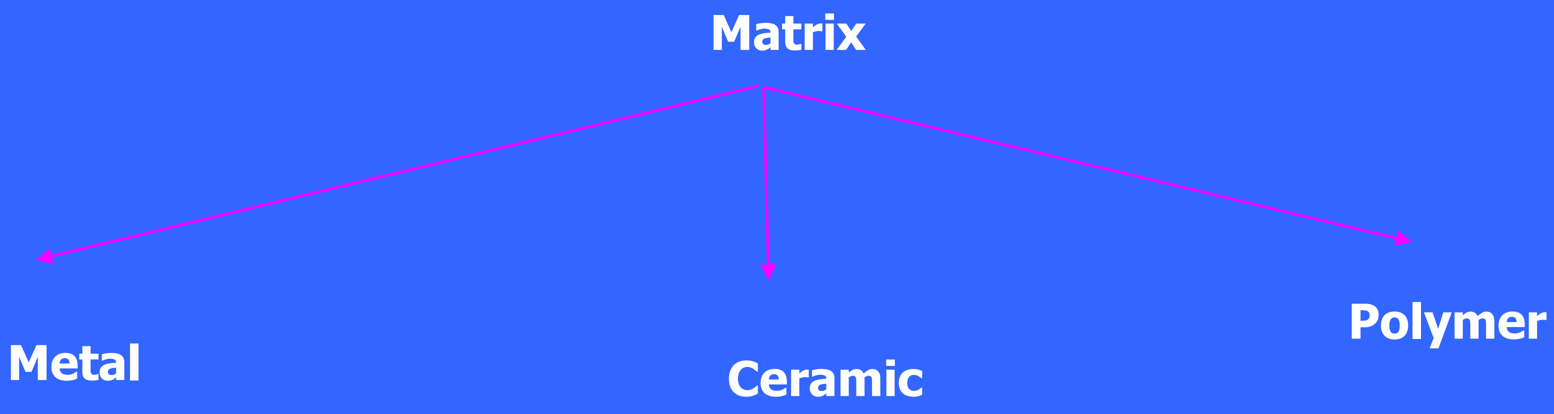
- Polymers
- Metals
- Ceramics

Interface

- Bonding surface

Matrix

- It is continuous
- Binds the reinforcements together
- Acts as a stress transfer medium



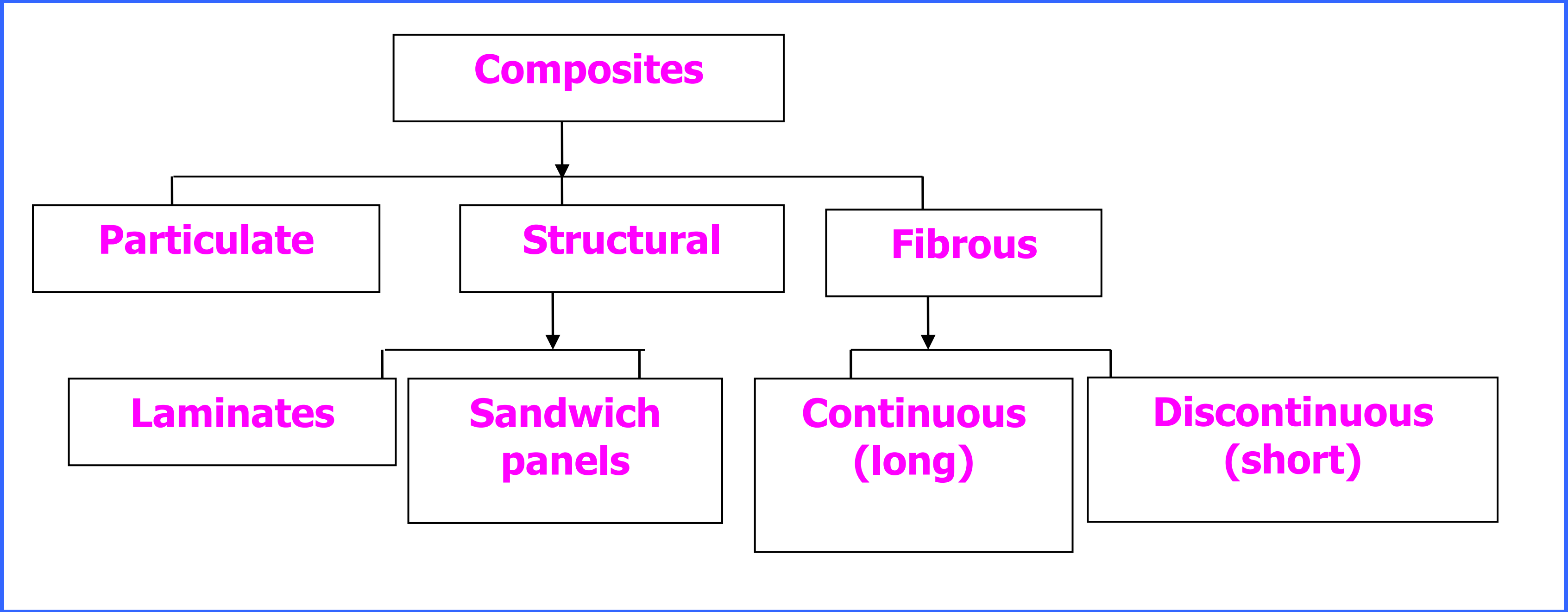
- **Generally matrix is the continuous phase, which carries the dispersed phase.**
- **The matrix determines the overall service temperature limitations of the composite.**
- **It also controls the environmental resistance of the composites.**
- **Matrix phase serves the following functions in a composite**
- **Binds the dispersed particles together by virtue of its Cohesive and adhesive characteristics.**
- **Acts as a medium by which an externally applied load is transmitted and distributed to the dispersed phase.**
- **Protects the individual dispersed constituents from chemical reactions with the environment and from surface damage to an extent.**
- **Keeps the dispersed constituents in the proper position and orientation.**
- **Provides inter laminar shear strength to the composites.**

Comparison of different matrices

	Pros	Cons
Metals	Ductile High moduli Resist thermal shock Easy to manufacture	High density Costly manufacturing process Material costs
Ceramics	Thermal stability Load bearing capacity Stiffness	Brittle Costly manufacturing process Material costs Not stable against mechanical shock
Polymers	Low cost Light weight Corrosion resistant Easily proccessible	Low strength and stiffness Low thermal stability Low load bearing capacity

Reinforcing agent

- Load carrying agent
- Resists the breaking and bending under an applied load
- Protects the matrix from sudden failure



Types of fibres

Glass	Carbon	Kevlar	Boron	SiC

Composites

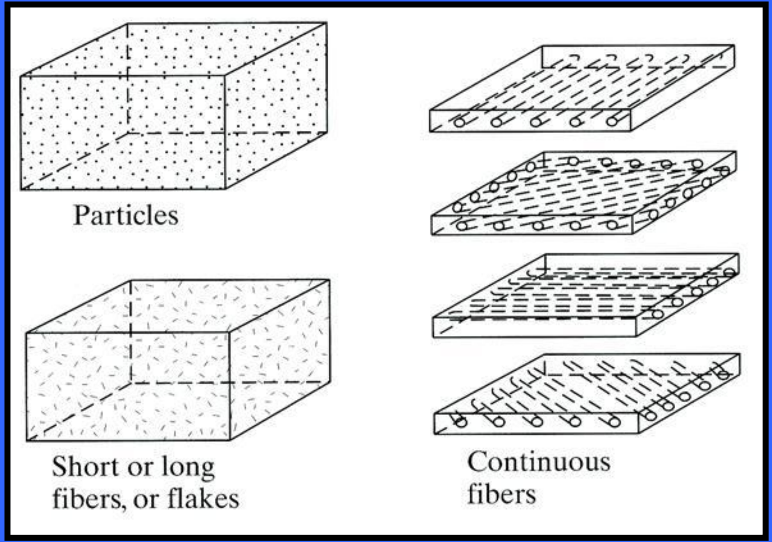
Material	Characteristics
Fibers	
Glass	High strength, low stiffness, high density; lowest cost; E (calcium aluminoborosilicate) and S (magnesia-aluminosilicate) types commonly used.
Graphite	Available as high-modulus or high-strength; low cost; less dense than glass.
Boron	High strength and stiffness; highest density; highest cost; has tungsten filament at its center.
Aramids (Kevlar)	Highest strength-to-weight ratio of all fibers; high cost.
Other fibers	Nylon, silicon carbide, silicon nitride, aluminum oxide, boron carbide, boron nitride, tantalum carbide, steel, tungsten, molybdenum.
Matrix materials	
Thermosets	Epoxy and polyester, with the former most commonly used; others are phenolics, fluorocarbons, polyethersulfone, silicon, and polyimides.
Thermoplastics	Polyetheretherketone; tougher than thermosets but lower resistance to temperature.
Metals	Aluminum, aluminum-lithium, magnesium, and titanium; fibers are graphite, aluminum oxide, silicon carbide, and boron.
Ceramics	Silicon carbide, silicon nitride, aluminum oxide, and mullite; fibers are various ceramics.

Polymer Matrix Composites

Polymer matrix is used in more than 95% of the composite products. Within a short span of time, polymeric materials have witnessed considerable growth in the field of material science. Versatility of polymers is such that they have replaced natural substances like wood, cotton, metal etc. Polymer materials are equipped with better physical and mechanical properties than many of their natural counterparts and thus play a key role in the field of high technology. A large number of high performance and specialty polymers are in the market today for very specific applications

Composites – Polymer Matrix

Polymer matrix composites (PMC) and fiber reinforced plastics (FRP) are referred to as ***Reinforced Plastics.*** Common fibers used are glass (GFRP), graphite (CFRP), boron, and aramids (Kevlar). These fibers have *high specific strength* (strength-to-weight ratio) and *specific stiffness* (stiffness-to-weight ratio)



Matrix materials are usually thermoplastics or thermosets; polyester, epoxy (80% of reinforced plastics), fluorocarbon, silicon, phenolic.

Composites – Polymer Matrix

Reinforcing fibers

Glass – most common and the least expensive, high strength, low stiffness and high density. GFRP consists 30-60% glass fibers by volume.

Graphite (99% carbon) or Carbon (80-95% carbon) – more expensive than glass fibers, but lower density and higher stiffness with high strength. The composite is called carbon-fiber reinforced plastic (CFRP).

Boron – boron fibers consist of boron deposited on tungsten fibers, high strength and stiffness in tension and compression, resistance to high temperature, but they are heavy and expensive.

Aramids (Kevlar) – highest specific strength, toughest fiber, undergoes plastic deformation before fracture, but absorbs moisture, and is expensive.

The average diameter of fibers used is usually less than .0004 inch (.01 mm). The tensile strength of a glass fiber could be as high as 650 ksi (bulk glass S_u = 5-150 ksi)

Silicon carbide (SiC)

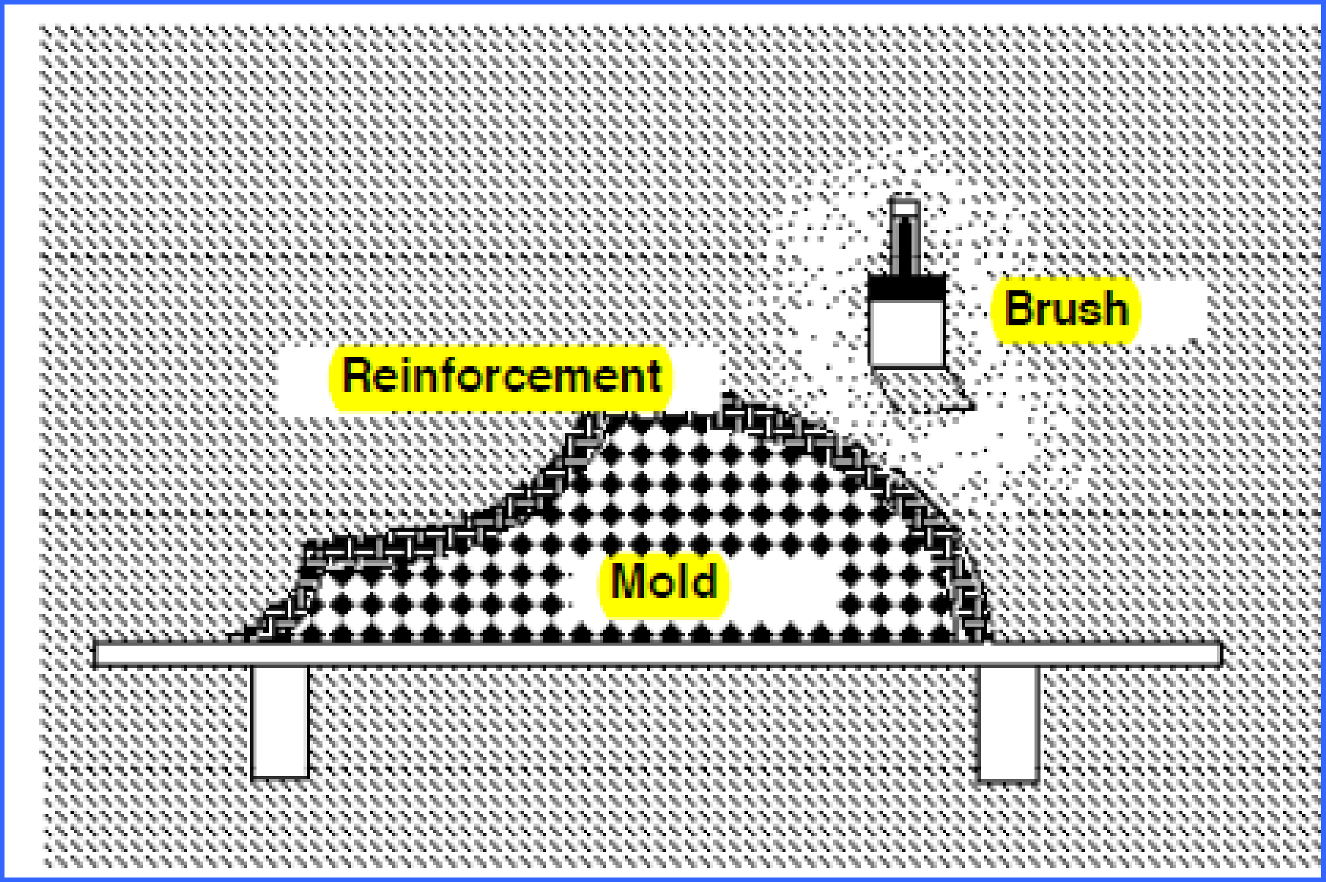
It is a ceramic material that has great potential for overcoming the current inadequacies of abrasive products due to its inherent characteristic of being chemically inert and consequently resistant to improve mechanical and wear resistance material. It has an excellent abrasive nature and has been produced for grinding wheels and other for more than hundred years. Now-a-days the material has been developed into a high quality technical grade ceramic with very good mechanical properties. It is used in abrasives, ceramics, refractories, and other high-performance applications. Silicon carbide is composed of tetrahedra of carbon and silicon atoms with strong bonds in the crystal lattice.

Fabrication of Composites

1. Hand lay-up Molding
2. Spray-up Molding
3. Compression Molding, Transfer Molding, Resin Transfer Molding
4. Injection Molding, Plunger-type Injection Molding
5. Reaction Injection Molding
6. Pultrusion
7. Filament Winding

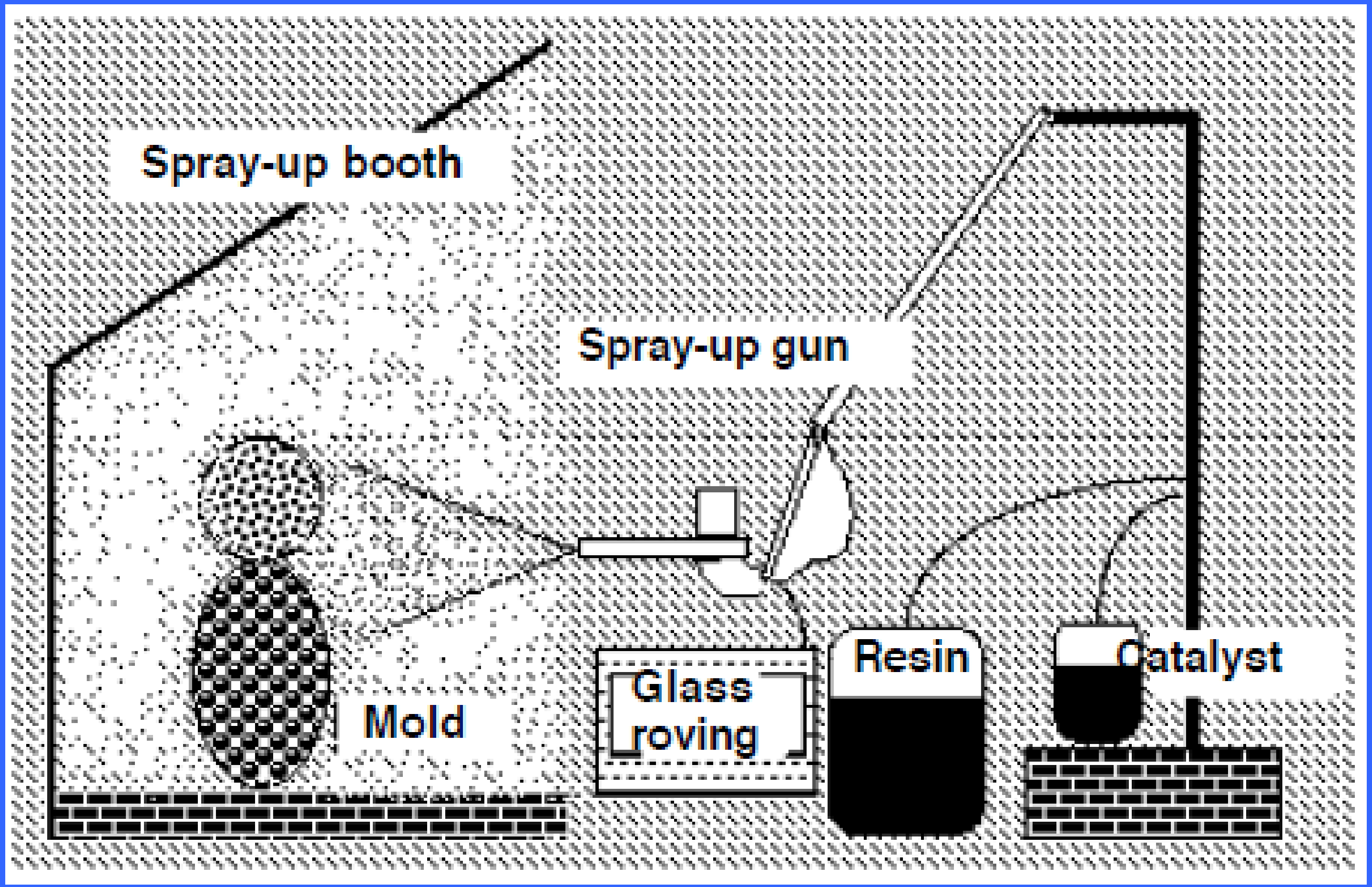
Hand Lay-up Molding

It is the method of laying down fabrics made of reinforcement and painting with the matrix resin layer by layer until the desired thickness is obtained. This is the most time and labor consuming composite processing method, but majority of aerospace composite products are made by this method in combination with the autoclave method. Due to the hand assembry involved in the lay-up procedure, one can align long fibers with controlled orientational quality. Another advantage of this method is the ability to accommodate irregular-shaped products. Such advantages are utilized in low performance composites including fiber-glass boat and bath tub manufacturing.

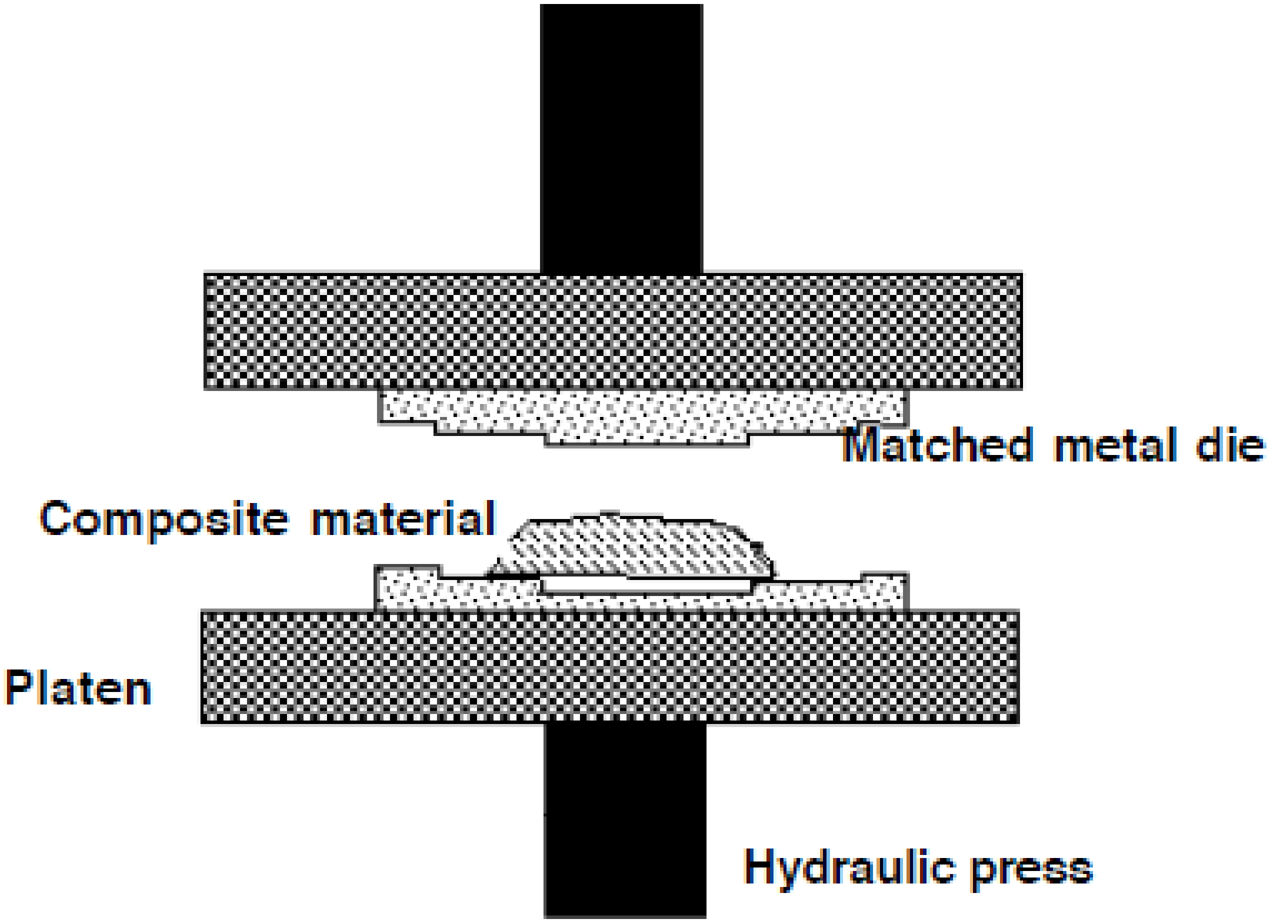

Brush
Reinforcement
Mold

Spray Up Moulding

It is much less labour intensive than hand lay up technique. It utilises a spray gun and fiber cutter. Only short fibre composites can be made. The choped fibre is sprayed upon a mould with the stream of resin mist and catalyst sprayed from differnt nozzles. The sprayed mixture is cured at room temperature to give the product.


Spray-up booth
Spray-up gun
Resin
Catalyst
Glass
roving
Mold

Compression molding uses a press to compress either a dough of resin and fiber mixtu or the layers placed by a hand lay-up method or mechanical means, typically at an elevat cure temperature. With the compressive force, the void content is lower than the ordina atmospheric pressure processing method.



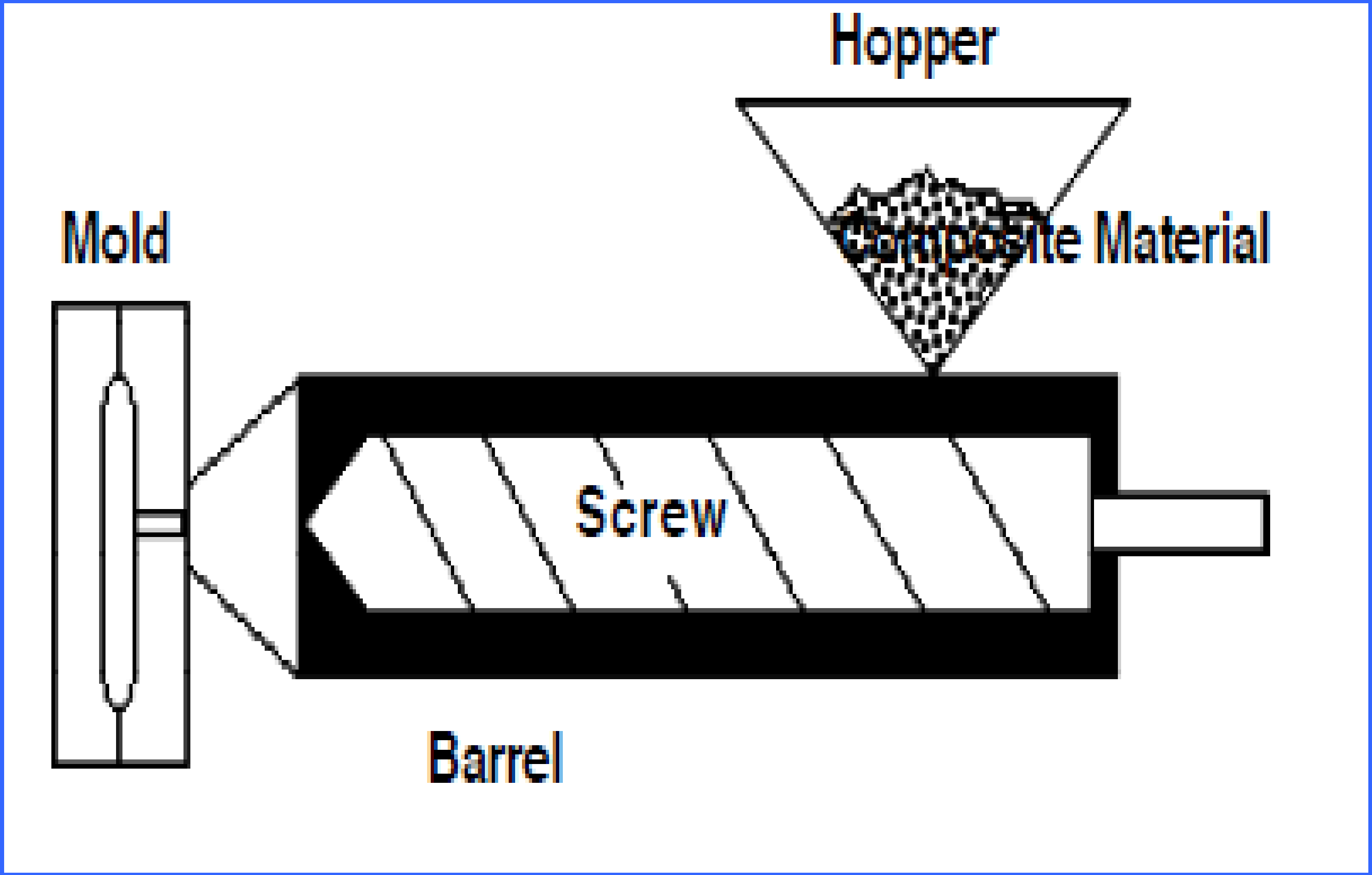
Transfer Moulding

Transfer molding is the improved version of compression molding from the material metering point of view as the fiber/resin mixture is transfered from the reservoir into the mold cavity by the press. However, a long-fiber reinforced composite cannot be made. This method is nearly identical to a *plunger-type injection molding* operation based on the material flow. The term "transfer molding" is used for a compression press operation while plunger-type injection molding is obviously carried out in an injection molding machine.

Resin transfer molding is the same as the ordinary transfer molding except that only the resin is transfer molded into the mold cavity where fabrics are placed beforehand. Preforms of glass fibers and other reinforcements can be made with short fibers and sometimes continuous fibers. Preforms must be made to withstand the pressure of resin injection in order to avoid compression of the fibers during mold filling which would lead to inhomogeneous fiber distributions in the final part. Curing proceeds typifcally after filling at an elevated temperature.

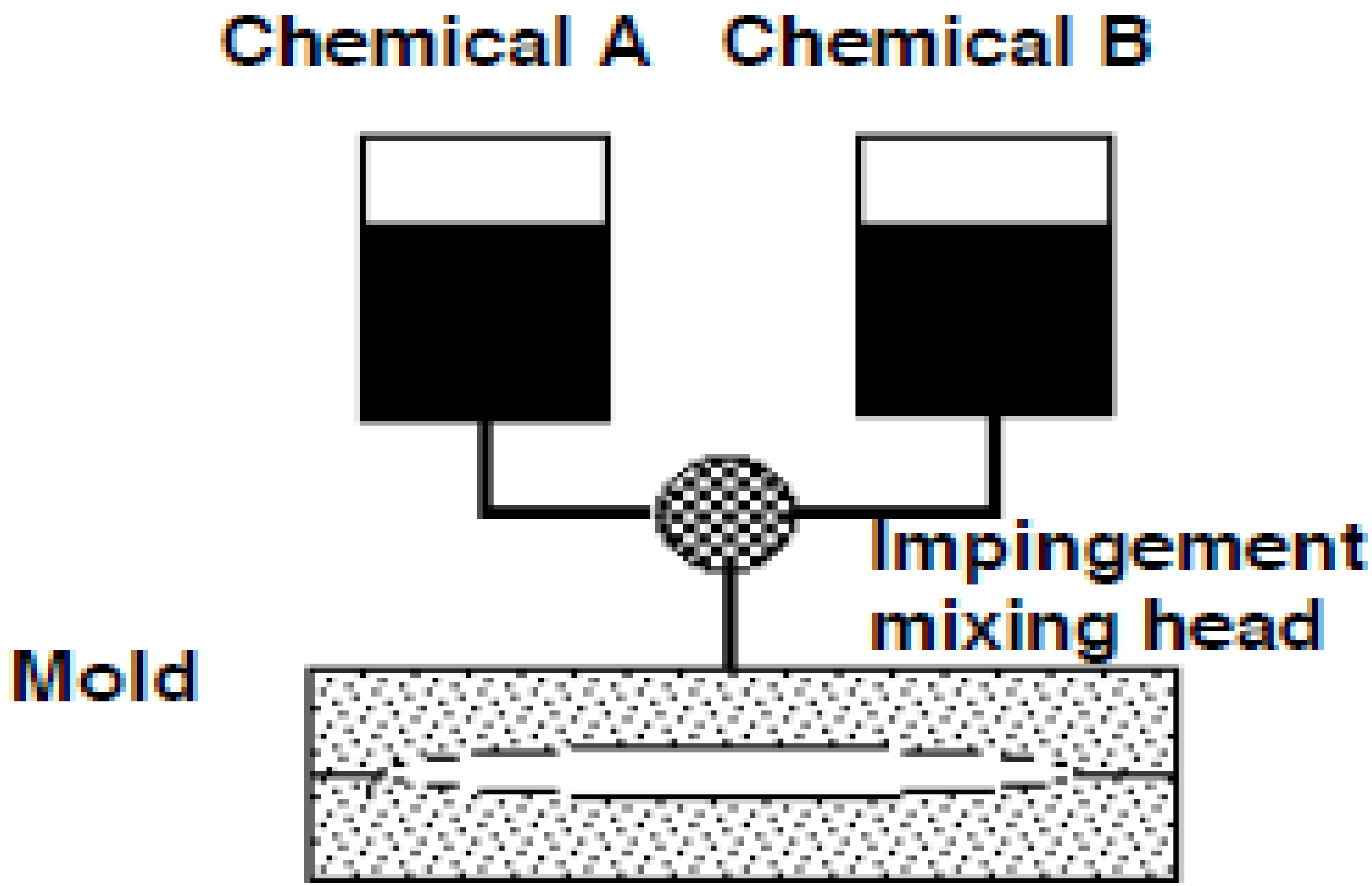
Injection Moulding

Injection molding is probably the most extensively used method for processing short-fiber reinforced thermoplastics. The fiber/resin mixture, whether it is preblended or fed as a physical mixture, is fed into the hopper and transfered into the heated barrel. The material softens by the heat transfer from the barrel wall. At the same time, the screw rotates to apply high-shear process to further heat the material and fill the barrel. The molten material is collected in front of the screw by the rotation of the screw, and then injected with a high pressure into the mold cavity through the runner and the gate. The mold is cooled below the solidification temperature of the resin in case of thermoplastics composites. The level of automation of this method is the highest among many processing methods. Due to the intensive mixing with high-shear and passage through a narrow gate, extensive fiber damage occurs, therefore, injection molding for composite materials is suitable only with short fiber reinforced or particulate-filled polymers.


Hopper
Mold
Composite Material
Screw
Barrel

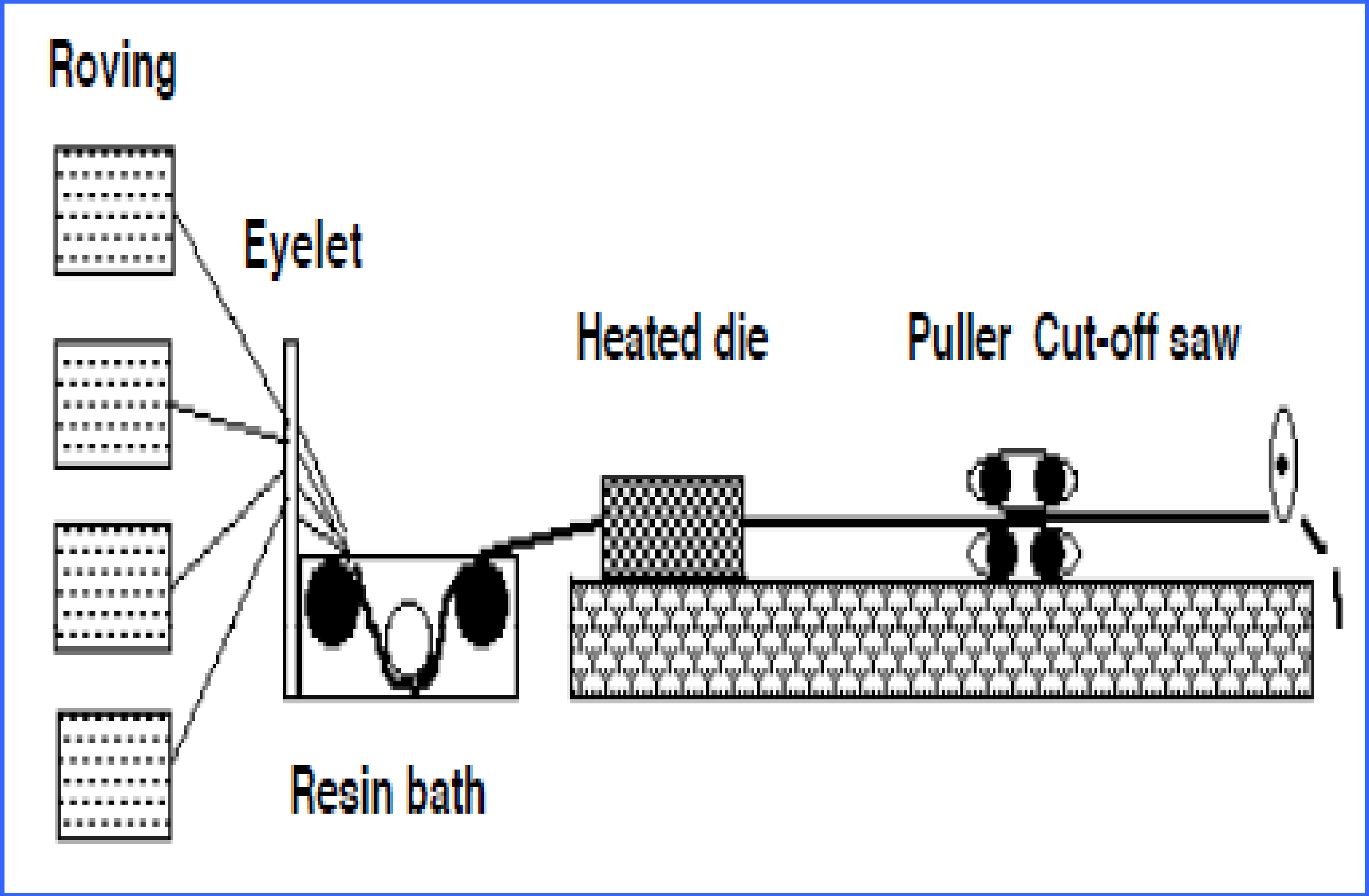
Reaction Injection Moulding

Reaction injection molding (RIM) is one of the newest processing methods. Instead of using already polymerized materials as matrices, highly reactive monomeric or oligomeric ingredients are placed in two tanks which are then quickly mixed by impingement, and injected into the mold cavity. As soon as the two materials are mixed, chemical reaction begins to form a polymeric matrix, which completes typically within 5-30 seconds. Thus, the major portion of the RIM machine is a high pressure pump and a metering system. Again, with high intensive shear, only short fibers and fillers can be used as reinforcements. However, RIM utilizes low viscosity chemicals and this allows the preplacement of continuous fiber-woven fabrics in the mold in the same manner as resin transfer molding. Distinction is made between these two methods based on the preparation of the resin precursor. When the resin formulation is already made, the method is called resin transfer molding while if the resin is prepared in-situ by an impingement or static mixer, the method is termed RIM.


Chemical A
Chemical B
Impingement
mixing head
Mold

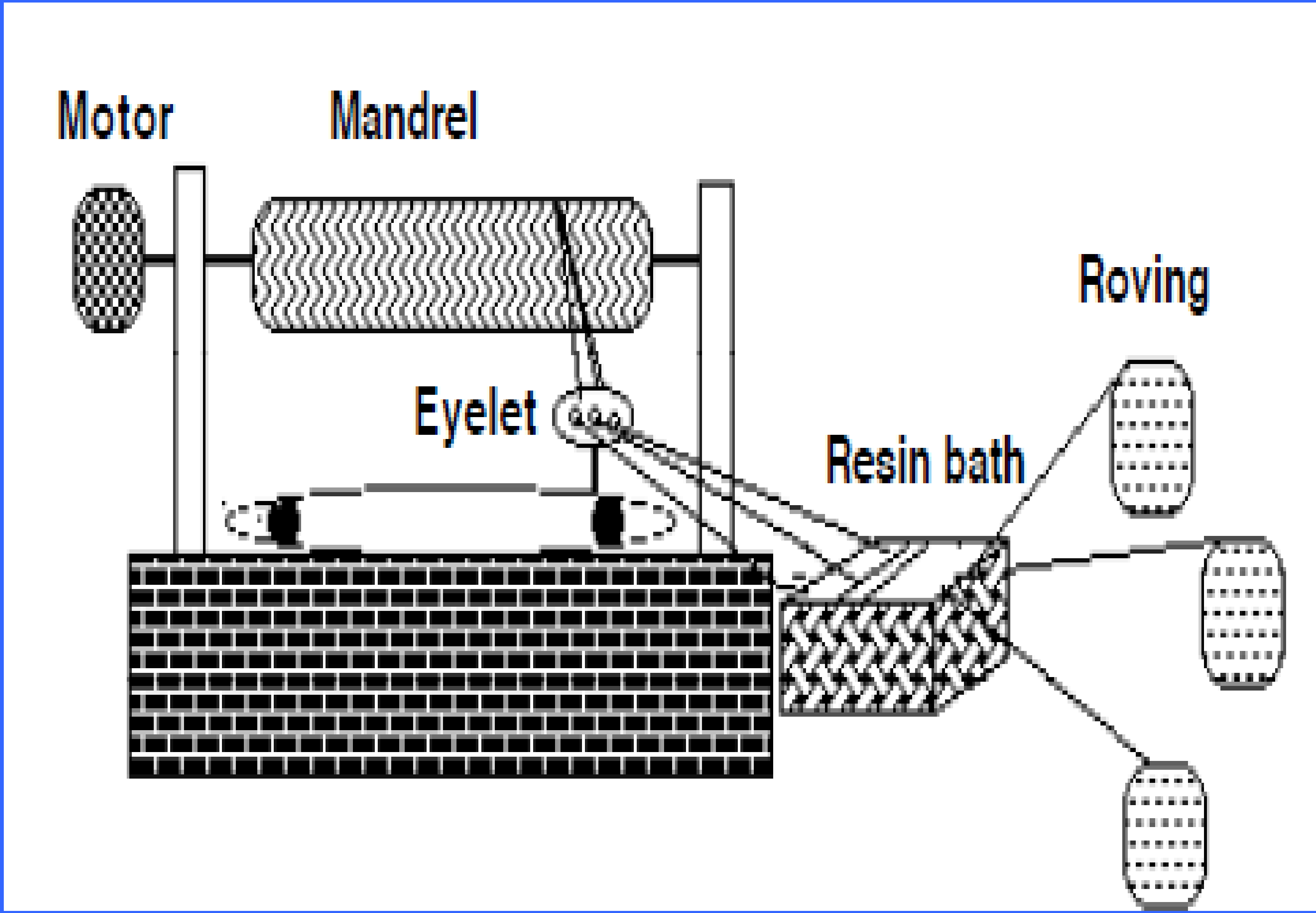
Pultrusion

Pultrusion is used only for polymer composite processing. A bundle of fiber *rovings* is passed through a wet resin bath, squeezed into a desired shape, passed through a heated die, and cured into a final composite. The solidified composite, typically reinforced unidirectionally with continuous fibers or sometimes bidirectionally, is pulled by a puller to continuously feed the uncured portion of the wet fibers into the hot die, thus the name, "pultrusion". This is one of very few continuous processing methods for continuous fiber reinforced composites. Only constant cross-sectional products can be made; the shape of the cross-section does not necessarily have to be the same, however.


Roving
Eyelet
Heated die
Puller
Cut-off saw
Resin bath

Filament Winding

Resin wet rovings are wound around a mandrel in a definite pattern. It is then placed in an oven and cured to a solid composite. Due to the controlled tension, squeezing action and controlled winding pattern the fiber content can be very high to produce composites with high mechanical properties.


Motor
Mandrel
Roving
Eyelet
Resin bath

Applications of Reinforced Plastics

Phenolic as a matrix with asbestos fibers was the first reinforced plastic developed. It was used to build an acid-resistant tank. In 1920s it was Formica, commonly used as counter top., in 1940s boats were made of fiberglass. More advanced developments started in 1970s.

Consumer Composites

Typically, although not always, consumer composites involve products that require a cosmetic finish, such as boats, recreational vehicles, bathwear, and sporting goods. In many cases, the cosmetic finish is an in-mold coating known as gel coat.

Industrial Composites

A wide variety of composites products are used in industrial applications, where corrosion resistance and performance in adverse environments is critical. Generally, premium resins such as isophthalic and vinyl ester formulations are required to meet corrosion resistance specifications, and fiberglass is almost always used as the reinforcing fiber. Industrial composite products include underground storage tanks, scrubbers, piping, fume hoods, water treatment components, pressure vessels, and a host of other products.

Applications of Reinforced Plastics

Advanced Composites

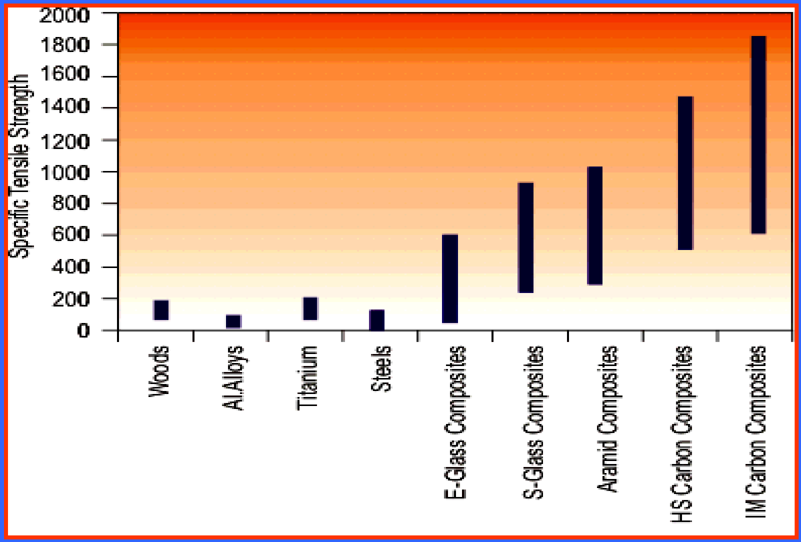
This sector of the composites industry is characterized by the use of expensive, high-performance resin systems and high strength, high stiffness fiber reinforcement. The aerospace industry, including military and commercial aircraft of all types, is the major customer for advanced composites.

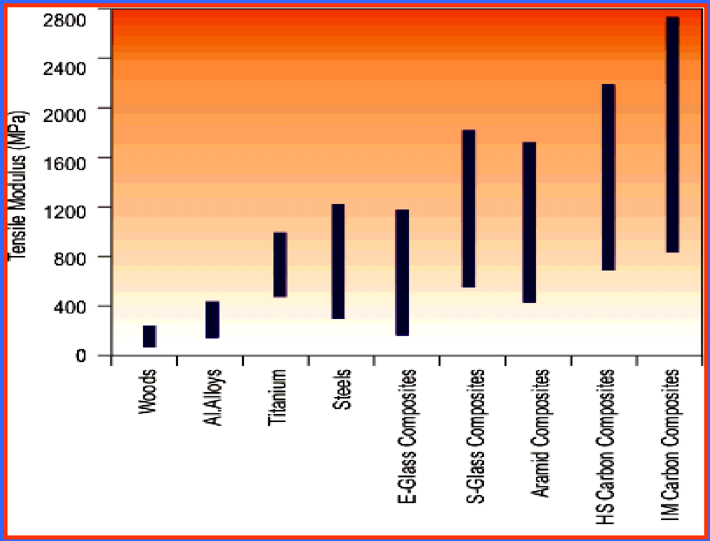
These materials have also been adopted for use in sporting goods, where high-performance equipment such as golf clubs, tennis rackets, fishing poles, and archery equipment, benefits from the light weight – high strength offered by advanced materials. There are a number of exotic resins and fibers used in advanced composites, however, epoxy resin and reinforcement fiber of aramid, carbon, or graphite dominates this segment of the market.

Advantages of Composites

Higher Specific Strength (strength-to-weight ratio)

Composites have a higher specific strength than many other materials. A distinct advantage of composites over other materials is the ability to use many combinations of resins and reinforcements, and therefore custom tailor the mechanical and physical properties of a structure.





The lowest properties for each material are associated with simple manufacturing processes and material forms (e.g. spray lay-up glass fibre), and the higher properties are associated with higher technology manufacture (e.g. autoclave moulding of unidirectional glass fibre), the aerospace industry.

Advantages of Composites

Design flexibility

Composites have an advantage over other materials because they can be molded into complex shapes at relatively low cost. This gives designers the freedom to create any shape or configuration. Boats are a good example of the success of composites.

Corrosion Resistance

Composites products provide long-term resistance to severe chemical and temperature environments. Composites are the material of choice for outdoor exposure, chemical handling applications, and severe environment service.

Advantages of Composites

Low Relative Investment

One reason the composites industry has been successful is because of the low relative investment in setting-up a composites manufacturing facility. This has resulted in many creative and innovative companies in the field.

Durability

Composite products and structures have an exceedingly long life span. Coupled with low maintenance requirements, the longevity of composites is a benefit in critical applications. In a half-century of composites development, well-designed composite structures have yet to wear out.

In 1947 the U.S. Coast Guard built a series of forty-foot patrol boats, using polyester resin and glass fiber. These boats were used until the early 1970s when they were taken out of service because the design was outdated. Extensive testing was done on the laminates after decommissioning, and it was found that only 2-3% of the original strength was lost after twenty-five years of hard service.