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Dr. Priyanka Kesarwani
Lecturer in Ethelind School of
Home Science, SHIATS,
Allahabad, UP, India.

Dr. Shahnaz Jahan
Professor and Head,
Department of Clothing and
Textiles, G.B.P.U.A.T.,
Pantnagar, Uttrakhand, India

Kirti Kesarwani
Ph.D. Scholar, Department of
Family resource management,
G.B.P.U.A.T. Pantnagar,
Uttrakhand, India

Correspondence:
Dr. Priyanka Kesarwani
Lecturer in Ethelind School of
Home Science, SHIATS,
Allahabad, UP, India.

Composites: Classification and its manufacturing process

Priyanka Kesarwani, Shahnaz Jahan, Kirti Kesarwani

Abstract

Composites are the engineered materials made from two or more constituent materials, with significantly different physical and chemical properties and which remain distinct and separated at the microscopic level within the finished structure. These are becoming more and more important because of its increased utility. They have properties which could not be achieved by either of the constituent materials alone. Composites include a wide range of the products for different application ranging from construction, automobile components, furniture and insulation panel made from different fibers, particles and textiles (woven or non-woven textiles). Considerable growth has been seen in the production and use of composites made from natural fiber in the construction and automotive industry, but application in other sectors has been limited. The unconventional fibers and other bio-renewable resources offer an almost limitless supply of renewable and potentially sustainable raw materials for the production of composites. Also the introduction of new fibers, with different bioresins and additives may well result in an expansion in their use into more diverse, and technically demanding application areas.

Keywords: Composites, manufacturing, matrix, dispersed phase, process.

1. Introduction

Composites are the engineered materials made from two or more constituent materials, with significantly different physical and chemical properties and which remain distinct and separated at the microscopic level within the finished structure.

The production of composites is an attempt to copy nature. Wood is considered as the natural composites in which cellulose fibers are cemented together with lignin. Different components in composites can be physically identified because they do not dissolve completely into each other. Man-made materials such as metallic alloys have two or more constituents, but they are not classified as composites, because materials are combined in such a way that the individual components are indistinguishable.

The importance of composites

Composites are becoming more and more important because of its increased utility. They have properties which could not be achieved by either of the constituent materials alone. Composites are used in, automobiles, boats, pipelines, buildings, roads, bridges, and many other products. Efforts are being made to improve qualities of composites so that they may be more strong, lightweight, long-lived, and inexpensive to produce.

Origin of composites

Composites dates back to the middle age when our ancestors invented bricks by mixing straw and clay. The straw was used as the fiber reinforcement and the clay was used as matrix. But now the composites are produced by the selection of the right fibers with the right matrix depending on the end uses. Development and use of composite was started in the 1940.

Driving forces that led to the rapid development and use of composites:

- 1) Military vehicles, such as airplanes, helicopters, and rockets were made of the metallic components; the heavy weight of such components was a big problem, because higher the weight of the plane could carry less cargo. So the researches tried to developed new material i.e. Composites which was a light-weight material with a high strength.

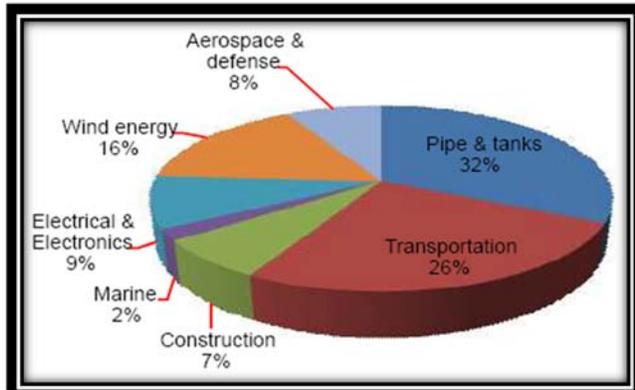
- 2) Polymer industries were quickly growing and tried to expand the market of plastics for variety of applications.
- 3) The extremely high strength glass fibers, was being discovered and the people thought that, this high-strength materials may solve the problems posed by the military's demands.

Production of composites in India

India has become one of the major producers of the composites. The Indian composites industry recorded 25% growth during 2004. The total production of composites was about 75,000 tons in 2004-2005 and has risen to 110,000 tons in 2005-2006. Glass fiber and the carbon fiber were generally used for the composites in the last decades. Various synthetic fibers and the natural fiber are now being used for the production of the composites.

The composites that uses the material obtained from the biological origin are called as the biocomposites. In biocomposites the plant fibers are combined with the resin to create natural composites. The materials used for the reinforcement of the biocomposites include plant fibers such as cotton, hemp, sisal soyabean etc. and even the by-product of the food crop. These fibers are combined with the resins or newer plant based resins (such as polyactic acid derived from corn starch), the matrix is derived from the vegetable oils and starch. Recycled thermoplastics such as polyethylene, polypropylene, polystyrene and polyvinyl chloride etc. are also used for the biocomposites. The selection of natural fibers used for making the biocomposites depend on the properties needed for the final product.

Application of the composites in India 2009



Composition of composite

- 1) Matrix phase: *Matrix is usually more ductile and less hard phase. It holds the dispersed phase and shares a load with it.*

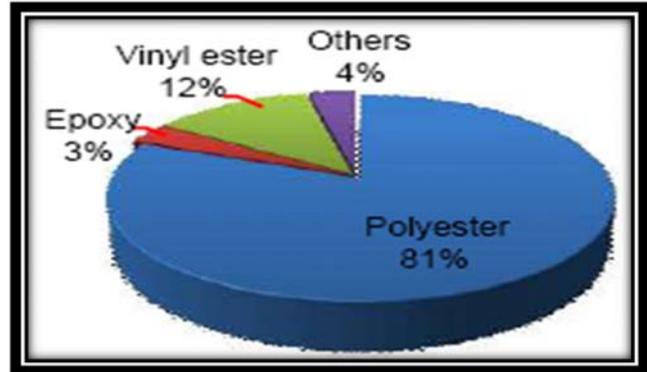
Essential properties of matrix

- ❖ Good mechanical properties
- ❖ Good adhesive properties
- ❖ Good toughness properties
- ❖ Good resistance to environmental degradation

Matrix phase used for the production of composites

- **Thermo set resins**
 - polyester
 - epoxy
 - Vinyl ester
 - Polyimide

- **Thermoplastics resins**
 - PPS (polyphenylene sulphide)
 - PEEK (polyetheretherketone)
- **Metals** (aluminum, titanium etc.)
- **Ceramics**



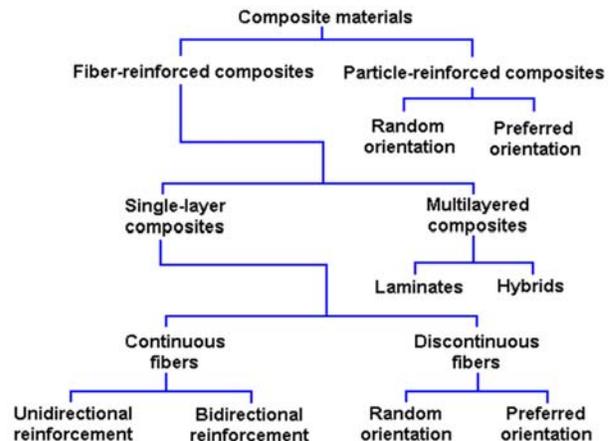
Thermo set resin used in the India for composites

- 2) **Dispersed (reinforcing) phase:** *It is embedded in the matrix A dispersed phase is usually stronger than the matrix, therefore it is also called as reinforcing phase.* eg.
 - Unconventional fibers (jute, ramie, hemp etc.)
 - Glass fiber
 - Organic fibers
 - Aramide (Kevlar) fibers
 - Polyethylene fiber
 - Carbon fiber
 - Ceramic fibers

Classification of Composites (based on matrix material)

1. **Metal Matrix Composites (MMC):** Metal Matrix Composites are composed of a metallic matrix (aluminum, magnesium, iron, cobalt, copper) and fibers as the dispersed phase
2. **Ceramic Matrix Composites (CMC):** Ceramic Matrix Composites are composed of a ceramic matrix and fibers as the dispersed phase.
3. **Polymer Matrix Composites (PMC):** Polymer Matrix Composites are composed of a matrix from thermoset (Polyester, Epoxy) or thermoplastic (Nylon, Polystyrene) polymer and fibers as the dispersed phase

Classification Of Composite (based on reinforcing material)



Factors influencing the performance of the composites

1) **Fiber architecture**

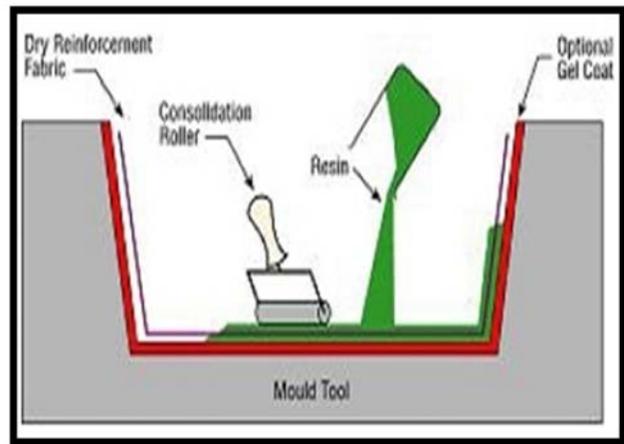
- a. **Fiber geometry:** the geometry of the fiber in composites is also important since fiber has the highest mechanical properties across the width, this leads to the highly anisotropic property of the composites. Aspect ratio is the ratio of the fiber length to diameter. Thus fibers with high aspect ratio are long and thin while fibers with low aspect ratio are shorter in length and broader in the transverse direction. It is advantageous to retain as much length as possible, since higher aspect ratio give rise to greater reinforcing efficiency.
 - b. **Fiber orientation:** the orientation of the fibers create highly direction specific properties in the composites this anisotropic features of the composites can be used to good advantage in designs with the majority of the fibers being placed along the orientation of the main load paths this minimizes the amount of the parasitic material that is put in orientations where there is little or no load.
 - c. **Packing arrangement and fiber diameter:** the more expensive smaller diameter fibers providing higher fiber surface areas spreading fiber or matrix interfacial loads. Small fiber diameter packs more closely to each other as compared to the smaller diameter fiber.
 - d. **Fiber volume fraction:** mechanical property increases with the increase in the mechanical properties up to a certain point. Fiber volume fraction is the ratio of the fiber to resin in the composites. The maximum volume fraction achievable is however, largely governed by the orientation and the packing arrangement of the fibers and this in turn, dictated the manufacturing process adopted.
- 2) **The fiber- matrices interface:** the interface between the fiber and the matrix is also crucial in terms of composite performance. Good bonding is essential between the fiber and the matrix

- Compression molding
- Pultrusion
- Injection molding

Open Mold Processes for Production of Composites

Wet Lay-Up Process

The mold cavity is coated with either polyvinyl alcohol or a non-silicon wax (eg simomize) to aid component release. Gel coat is applied to the mould using a spray gun then cured at room temperature. Gel- coat layer of approximately 0.3 - 0.4 mm thick Continuous strand of mat or fabrics such as woven knitted or stitched roving made from fiber is manually placed in the mold. Each ply is sprayed with catalyzed resin (1000-1500 cps). The resin is applied by pouring, brushing, or spraying. Rollers or squeegees are used to consolidate the laminate, wetting the reinforcement, and removing entrapped air.



Advantage

- It is a simple technique with no requirement for highly skilled labour.
- It requires low-cost tooling,
- A wide range of part sizes can be produced

Disadvantage

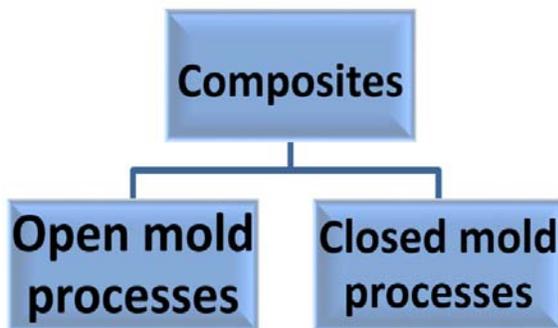
- Very complicated designs can't be produced.
- The resin content cannot be well controlled in this process.

Application: Composite made by this process is used for boats, tanks, bathing tubs, housings, etc

Spray-Up Process

The gel coat is applied to the mold, and then cured in a heated oven at 120°C. Continuous strand of fiber roving are fed into chopper gun and then the fibers along with catalyzed resin are fed through a chopper gun over the mould. Fibers are cut into lengths, varying from 20 to 60 mm. The laminate is then pressed with the roller, to remove the air bubbles from the laminate and to make it compact. Additional layers of chop laminate are added as required for thickness. Woven or knitted fabrics can be used in conjunction with the chopped laminates. It is then cured at the room temperature, cooled and removed from the reusable mold.

Manufacturing of the Composites



1. **Open molding process:** In this process the laminates are exposed to the atmosphere during the process.

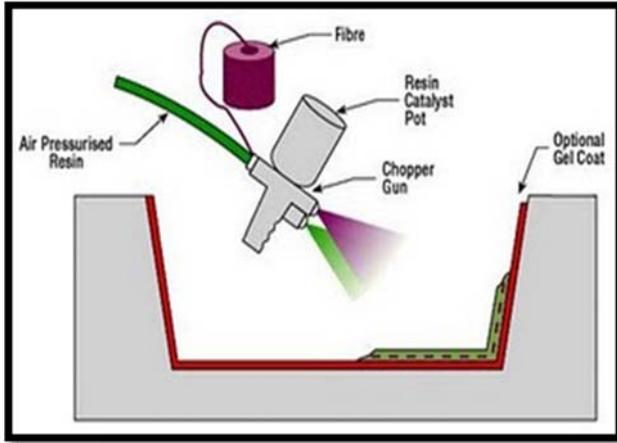
➤ **Types of open mold process**

- Wet lay-up process
- Spray-up process
- Filament Winding

2. **Close Mold Processes:** In this process, the composite is processed in a two-sided mold set, or within a vacuum bag.

➤ **Types of open mold process**

- Resin Transfer Molding (RTM)
- Vacuum assisted resin transfer Molding



- The production capacity of the spray up process is higher than the hand layup process.

Disadvantages

- It is difficult to achieve constant laminate thickness when compared to hand lay up process.

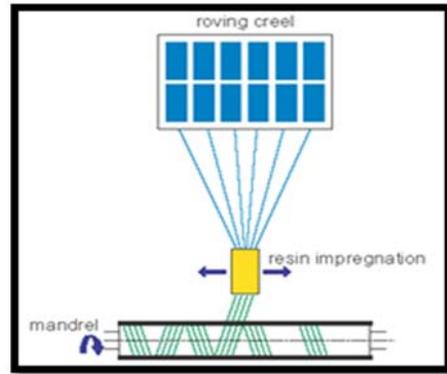
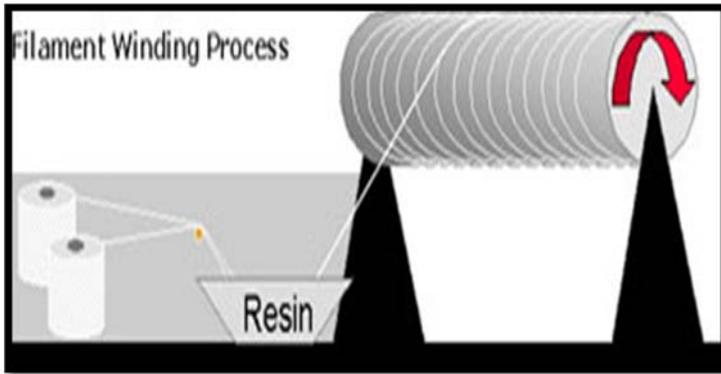
Application: Composite made by this process is used for boats, tanks, and tub in a large variety of shapes and sizes.

Advantages

- The process is simple.
- It requires low tooling cost than close mould process.
- portable equipment
- The process may be automated.

Filament Winding

Filament winding is an automated open molding process that uses a rotating mandrel as the mold. This process is used for the manufacturing of hollow, (generally cylindrical) products. Continuous strand roving is fed through a resin bath and wound onto a rotating mandrel. The roving feed runs on a trolley that traverses the length of the mandrel. All fibers are wound using the same tension. Machine has multi-spindle systems. When sufficient layers have been applied, the laminate is cured on the mandrel. Mandrels are collapsible to facilitate part removal.



Advantage

- Filament winding is automated
- The labor charges for filament winding is lower than other open molding processes.

Application

- Cylindrical products such as pipes, cylinders etc are produced.

Close Mold Process for Production of Composites

This process is used to produce intricate parts in industries.

Advantages of Closed Mold Processes

- Intricate parts, in less time, with less waste can be produced.
- Reduce labor costs.
- Reduce overall costs by making parts faster.
- Reduce post work.
- Closed mold process is cleaner process

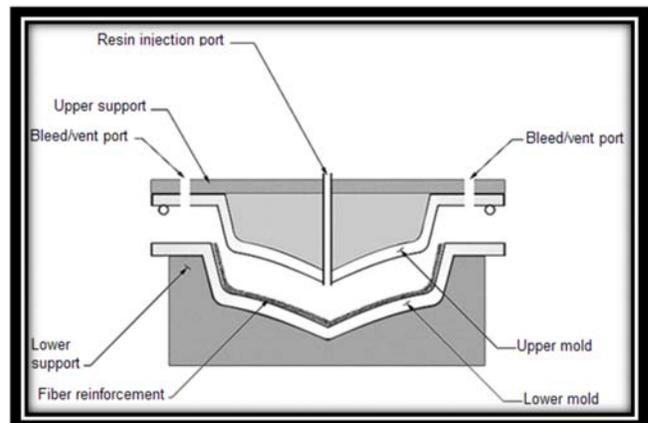
Disadvantage of Closed Mold Processes

- Initial cost for the construction of the mold is high.

Resin Transfer Molding

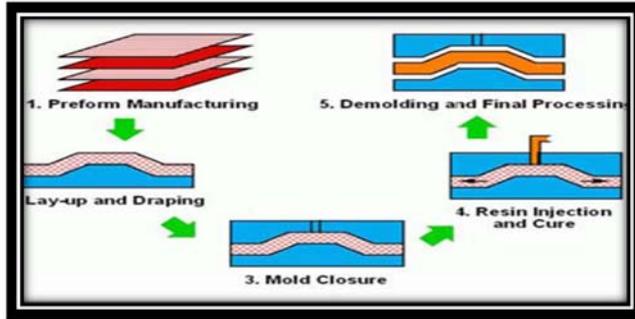
Resin transfer molding is excellent for mass production of composite parts. A two-part, matched-metal mold (or tool) is

prepared. The fibers / fabric is placed on the bottom half of the mold. Then the mold is closed and resin is then pumped under low pressure through injection ports into the mold, after all the fibers/fabric is wet out, the resin inlets are closed and the laminate is allowed to cure at the room temperature.



Advantage of resin transfer molding

- The process produces good finished sides of the composites.
- Process is less time taking



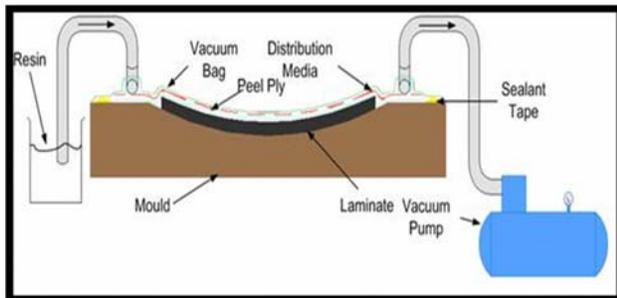
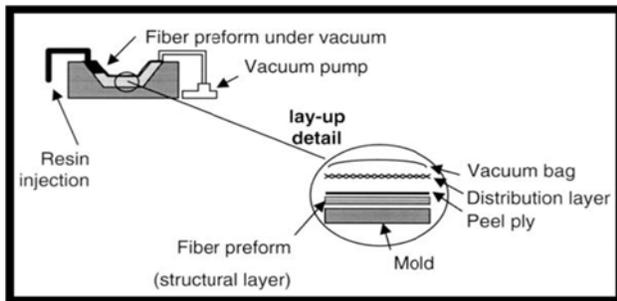
Disadvantage of resin transfer molding

- Initial cost for manufacturing the molds is high.

Application: Automotive parts, lower volume parts of the aerospace industry are produced by this method

Vacuum Assisted Resin Transfer Molding

This process is developed as a variant of the RTM process in order to reduce the cost and design difficulties associated with large metal molds. In this method there is no need for making a precise matched metal mold as in the conventional RTM process. In VARTM, the upper half of a conventional mold is replaced by a vacuum bag. The laminate is placed over the mold followed by the peel ply the vacuum bag is mounted over the entire assembly. Vacuum bag is then sealed with the sealant tape over the mold from all the sides. After that the vacuum pump is turned on to expel air from the preform assembly. When all air leaks have been eliminated, the resin is allowed to flow into the preform assembly. A pressure of 1 atm provides both the driving force for the resin to impregnate the reinforcement and force to compact the preform. Due to the low injection pressure (1 atm), of the resin, the resin easily fills the distribution medium, and then leaks downward and wets the perform. The vacuum is left on until the resin has completely gelled. Then it is cured at room temperature or in an oven.



Vacuum assisted resin transfer molding

Advantages

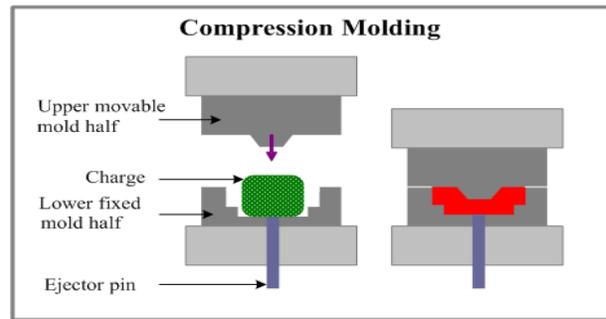
- Vacuum bag processing can produce laminates with a uniform degree of consolidation,
- Vacuum assisted wet lay helps to prevent the presence of voids, caused by air trapping,
- Low pressure removes the entrapped air, thus reducing the void content.
- Molds used in VARTM are similar to those used for conventional open-mold processes

Disadvantage

- It is a relatively complex process to perform well.
- Due to the complex nature of the VARTM process, the trial and error method is expensive for the process design and optimization.

Compression Molding

Compression molding is a high-pressure method suitable for molding high-strength glass fiber reinforcements. In this process the weighed charge is placed in the bottom half of the mold. The charge may be BMC (bulk molding compound) or SMC (sheet moulding compounding) these are mixture of chopped glass strands and resin. The two halves of the mold are closed and heated to 2500 to 4000 F. The pressure (60-100 bar) is applied to the charge. The heat and pressure are maintained until the molding material come in contact with all mold areas and is cured. Compression molding process is also used for producing composite from unconventional fibers Unconventional fibers like flax, hemp, sisal etc are comingled with the fiber of the thermoplastic polymer to form a nonwoven fleece. Then it is hot pressed in the mold to melt the thermoplastic fiber thereby forming the composites.



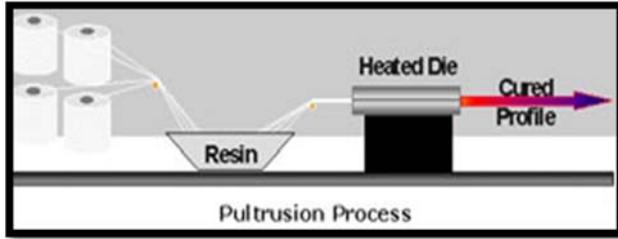
Advantages

- Compression molding is a fast molding process.
- The process is automated.
- Good surface finishes are obtainable, contributing to lower finishing cost.
- Labor costs are low.

Applications: automobile components, electrical components etc are produced by using BMC and SMC.

Pultrusion

Pultrusion is a continuous process for the manufacture of composites having a constant cross section. Many creels (balls of roving are positioned on a rack. The series of tensioning devices and roving guides direct the roving into the heated die. Continuous strand of fiber roving, is impregnated in a resin bath, then pulled (pul-trusion) through a steel die,



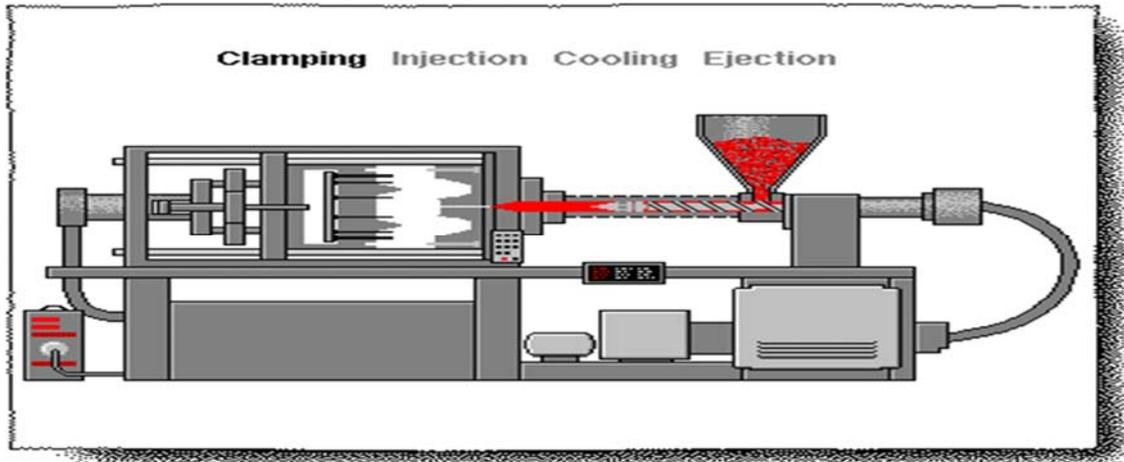
Application: products having a constant cross section, such as rods, beams, fishing rods, golf club shafts etc.

Injection Molding

The thermoplastic polymer or thermoset plastic polymer is heated by external heat source in the hopper. Wood fiber usually in the form of the flour or very short staple fibers is added to the polymer. The constituent is thoroughly mixed. The compound is ready to be extruded into the final product. The compound is transferred from the hopper to the extruder where it is injected in the mold cavity. The prepreg is cooled and hardened. The part is then ejected from the mold. Injection molding is a fast, process capable of producing up to 2000 small parts per hour.

Advantages

- The process is a continuous operation and it is automated.
- It is adaptable to both simple and complex cross-sectional shapes.



Advantages of injection molding

- Complex and fine designs are easily produced, because very high pressures are possible
- Cycle times are relatively low, and many parts can be made from a single mold, making extremely high volumes (millions per year) possible
- Injection molding is commonly automated. Many machines can be run by a single operator

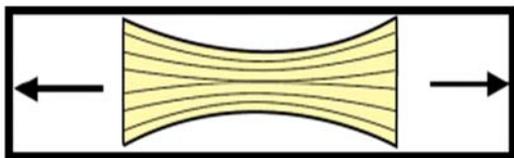
Disadvantages of injection molding

- Mold cost is high, so low part volumes are not recommended (usually less than 1000 parts is considered low).

Application: Injection molding is widely used for manufacturing a variety of parts, from the smallest component to entire body panels of cars, bathing tubs etc.

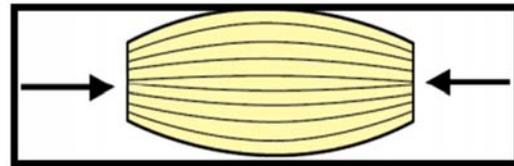
Composites has to be tested for following basic parameters for better performance

Tension: the response of the composites to the tensile load is very dependent on the strength properties of the reinforcement fiber.



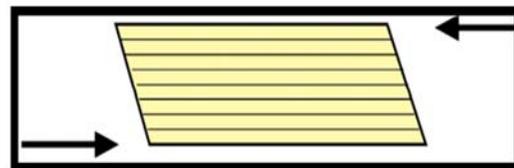
A tensile load applied to the composites

Compression: it is the role of the resin to maintain the fiber straight and to prevent them from bulking.



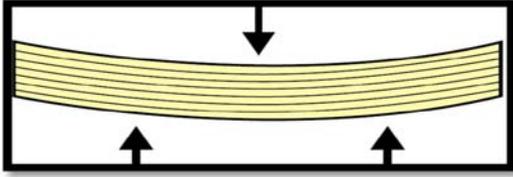
Composite under compressive load

Shear: this load is trying to slide the adjacent layer of the fibers over each other the resin play a major role in this condition. For the composite to perform good under the shear load the resin should not only have the good mechanical properties it should also have good adhesion properties.



Composite experiencing shear load

Flexure: it involves ability of the material to bend. When the upper face is put into tension the central portion of the laminate experience shear.



Composite experiencing flexure load

7. Dr. Shahnaz Jahan**Professor and Head, Deptt. of Clothing & Textiles, College of Home Science, G.B. Pant Univ. of Ag. & Tech, Pantnagar, Uttrakhand.
8. Ms. Kirti Kesarwani. Ph.D. Student in Department of Family Resource Management, G.B. Pant Univ. of Ag. & Tech, Pantnagar, Uttrakhand.

Need For Biocomposites

Regular polymer composites are non-biodegradable and pollute the environment. Using natural fibers with polymers based on renewable resources will allow many environmental issues to be solved. Natural fibers with renewable resource—such as cellulose plastics, polylactides, polyhydroxyalkanoates (bacterial polyesters); and soy-based plastics, could be the greener composites of the future.

Advantages of biocomposites

- They are lightweight as compared to glass fiber reinforced composites therefore it can be used in car components and in various other places to improve its performance.
- They are easy to process on the traditional textile machinery for making reinforcement elements, like yarn, mat or woven fabric.
- It provides better thermal and acoustic insulation properties, especially as an automotive interior or construction part, due to presence of lumen/void in the fiber.
- Less expensive.
- Renewable resource.

Conclusion

Composites include a wide range of the products for different application ranging from construction, automobile components, furniture and insulation panel made from different fibers, particles and textiles (woven or non woven textiles). Considerable growth has been seen in the production and use of composites made from natural fiber in the construction and automotive industry, but application in other sectors has been limited. The unconventional fibers and other bio-renewable resources offer an almost limitless supply of renewable and potentially sustainable raw materials for the production of composites. Also the introduction of new fibers, with different bioresins and additives may well result in an expansion in their use into more diverse, and technically demanding application areas

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6. Dr. Priyanka Kesarwani. Lecturer Department of Textiles and Apparel Desgning, S.H.I.A.T.S. Allahabad, U.P.