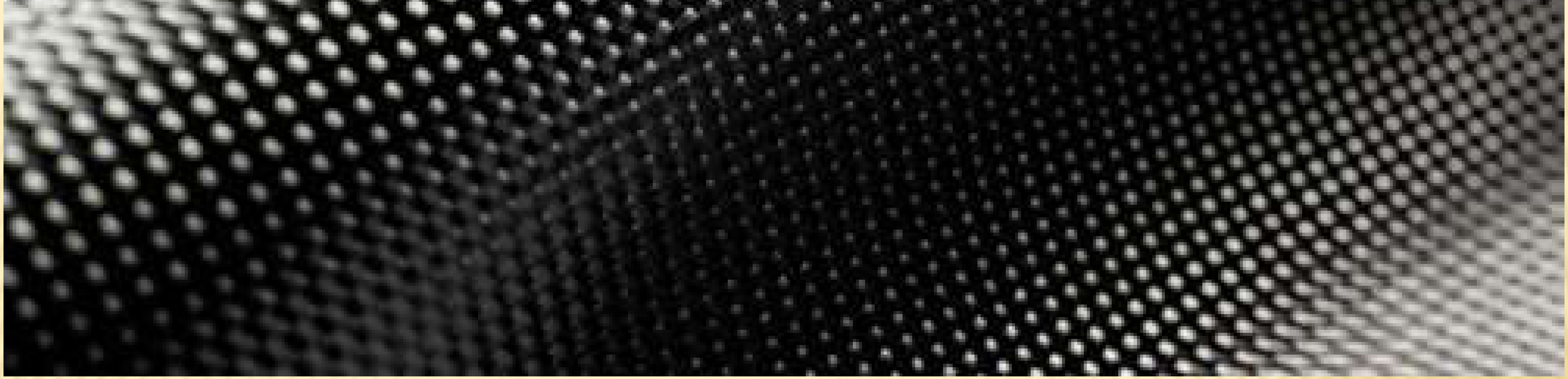


MANUFACTURE OF COMPOSITES

by-jyotiprakash das

MANUFACTURE OF COMPOSITES -

- ✓ **Hand lay up Technique**
- ✓ **Pressure bag and vacuum bag techni**
- ✓ **Pultrusion**
- ✓ **Resin – transfer Moulding**
- ✓ **Injection Moulding**

INTRODUCTION

- Composites consist of two distinct materials, which together improve product performance and lower production costs.
- Composite materials typically include plated, clad, or coated metals, however the term 'composites' has evolved to mean a material containing a matrix, or base substance, and a reinforcement material.
- The **matrix** acts as a binder for the reinforcement while controlling the physical shape and dimensions of the part. Its primary purpose however is to transfer the load, or stress, applied to the part to the reinforcement.
- The **matrix** also protects the reinforcement from adverse environmental effects.

INTRODUCTION

- The **reinforcement's** function is to enhance the mechanical properties of the composite and is typically the main load bearing element.
- **Reinforcements** are usually in the form of either fibers or particles.
- Matrix and reinforcement materials can be polymers, metals, ceramics, or carbon.
- The most widely used composite materials are fiber-reinforced thermosetting polymers.
- A composite can be defined as a combination of two or more materials that retain their macro-structure resulting in a material that can be designed to have improved properties than the constituents alone.

INTRODUCTION

- Advanced composite materials have been used to fabricate many structural parts in engineering applications.
- This is due to their many attractive characteristics such as light weight, high strength, high stiffness, good fatigue resistance and good corrosion resistance.
- Also, the ability to manufacture parts with complicated geometry using fewer components enables manufacturers to save cost as compared with the same parts made of conventional metallic materials.

The different stages of existence of composite constituents up to the final product :-

Stage a: *At this stage, the materials appear in raw basic form.* *For* fibers, these consist of fiber either in the form of filaments or fiber bundles. Fibers may also be woven into fabrics or braided into braided perform. For matrix, the material usually appears in liquid form for thermoset resin or in granular form in the case of thermoplastics.

Stage b: *At this stage, the fibers and matrix may be combined* into a single layer. For the case of thermoset matrix composite,the matrix may appear in a semi-liquid, semi-solid form so that the sheet can hold its shape. For the case of thermoplastic composite, the matrix is solidified. This form for thermoset matrix composites is called prepreg. For thermoplastic composites, it is called towpreg.

<u>Stage c:</u> *At this stage, the layers in stage b are stacked on top of* each other to make flat plate laminates. This intermediate step is important for the analysis where material properties are tested or calculated. However this step is usually bypassed in the manufacturing process of practical composite parts.

<u>Stage d:</u> *This is the final stage where the final product configuration* is formed.

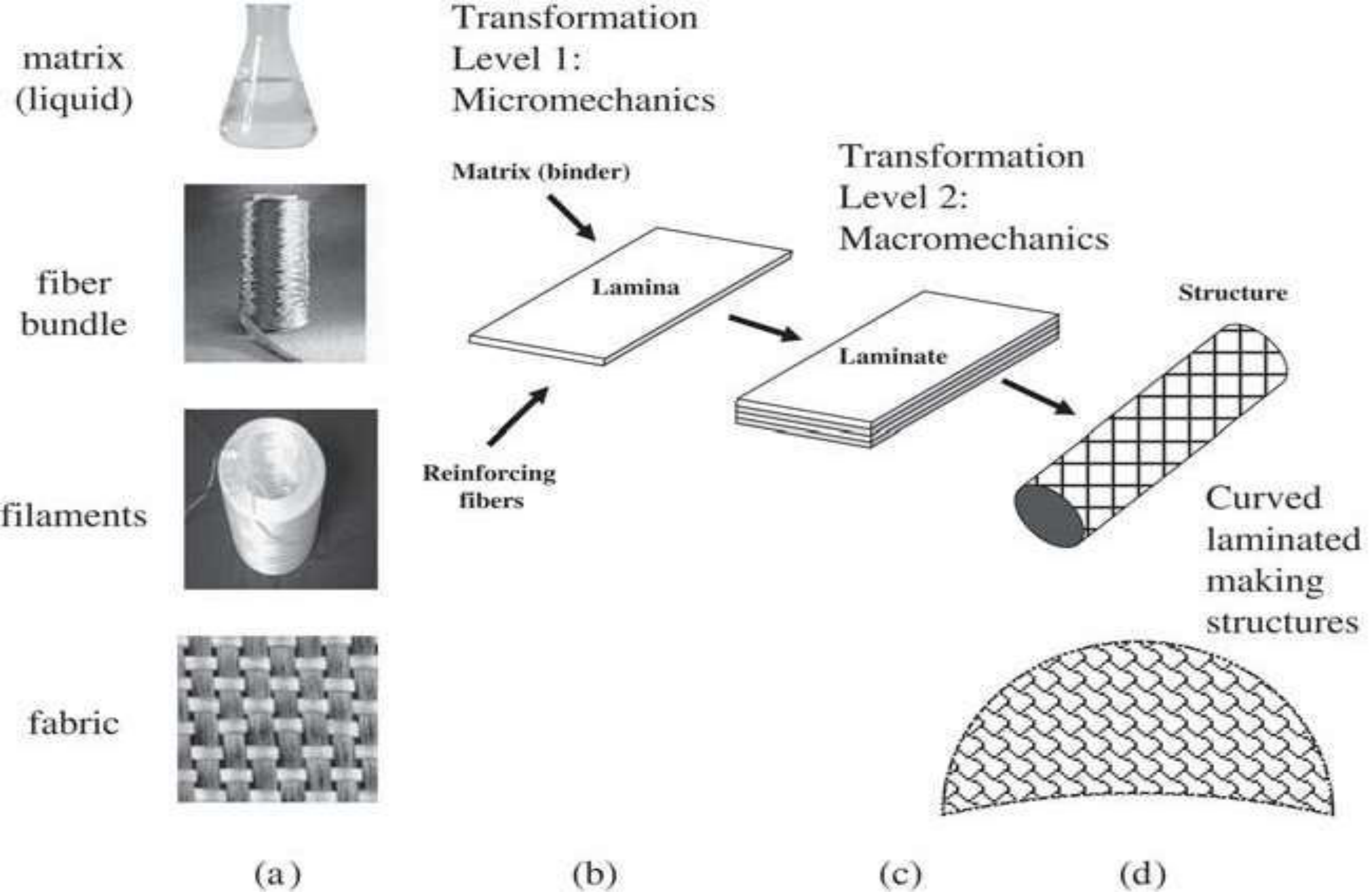


Figure : 1 Stages of existence of constituents in the manufacturing of composites

The involvement of these stages in the different manufacturing processes is as follows:

1. **Hand lay up Technique** :- Stages *a, b and d are* involved. Stage *c is bypassed.*

2. **Pultrusion** :- Stages *a and d are involved. Stages b and c are* bypassed.

<u>Theoretically, manufacturing of composites can be broken down into the following items :-</u>

• Aligning of fibers
• Single filaments
• Fabrics (mats, weaves, braids, knits)
• Bed consisting of many layers of fabrics
• Filling the interstices between filaments with liquid matrix •Wetting the fibers
• Curing the resin

❖ Filling interstices between the filaments with liquid resin can be done at the levels of single filaments, tows, fabrics, or a bed consisting of many layers of fabrics .

For making a composite part, a manufacturer can combine or alternate these steps, depending on the requirements
for quality and cost, as follows :-

For hand-lay-up in open mold for fiber glass/polyester, dry tows or dry fabrics are laid on a mold, liquid resin is then poured and spread onto the fiber beds. A few layers are wetted and left to cure in open air. After these layers are cured, more layers are added.

For pultrusion, the dry tows are run through a bath of resin to be wetted. These are then fed into a heated die. The fibers and resin are subjected to compaction and heating. When the assembly of fibers and resin exit the die, they are compacted and cured.

HAND-LAY-UP TECHNIQUE

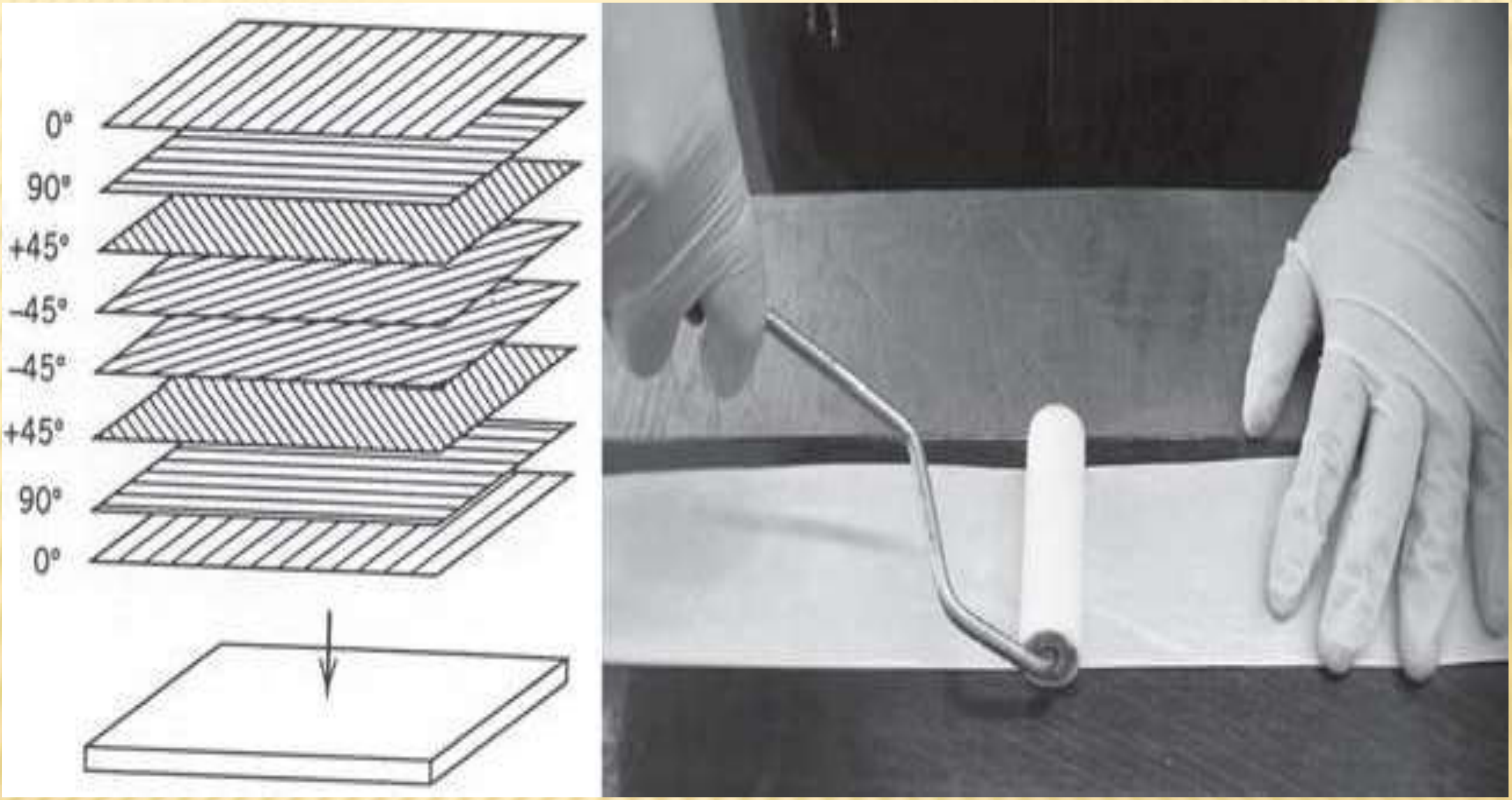


Figure : 2 hand-lay-up fabrication method and a representative lay-up sequence. Individual layers can be cut by hand or by a computerized machine cutter. The layers can be stacked one on top of the other by hand or by a robot.

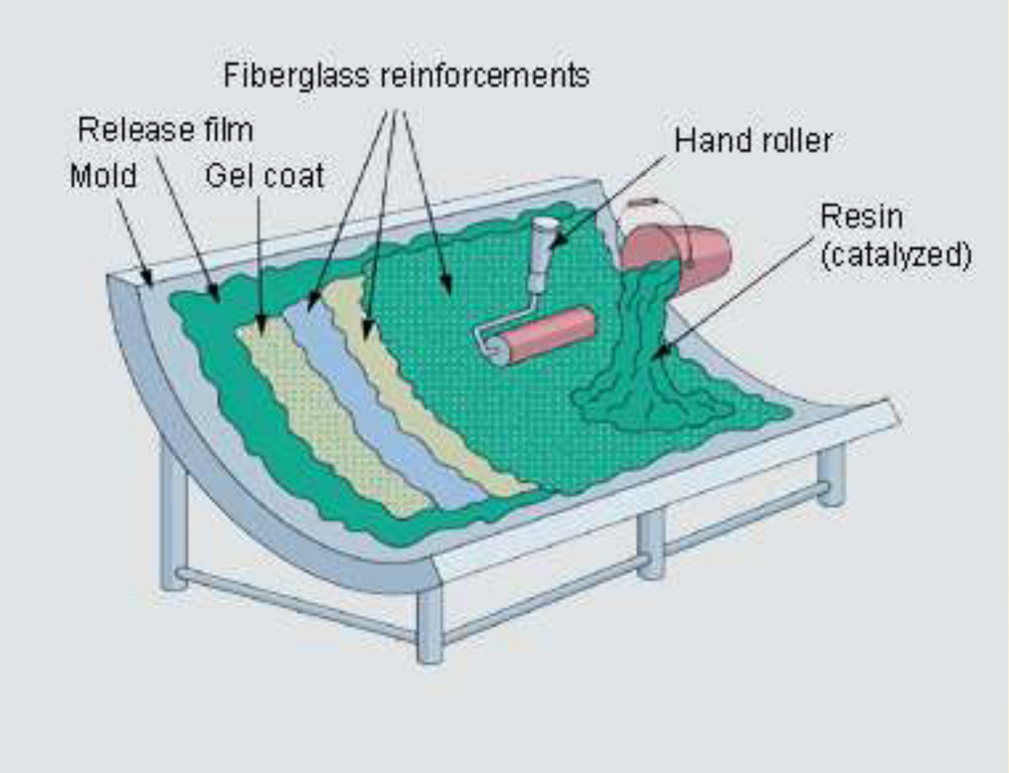
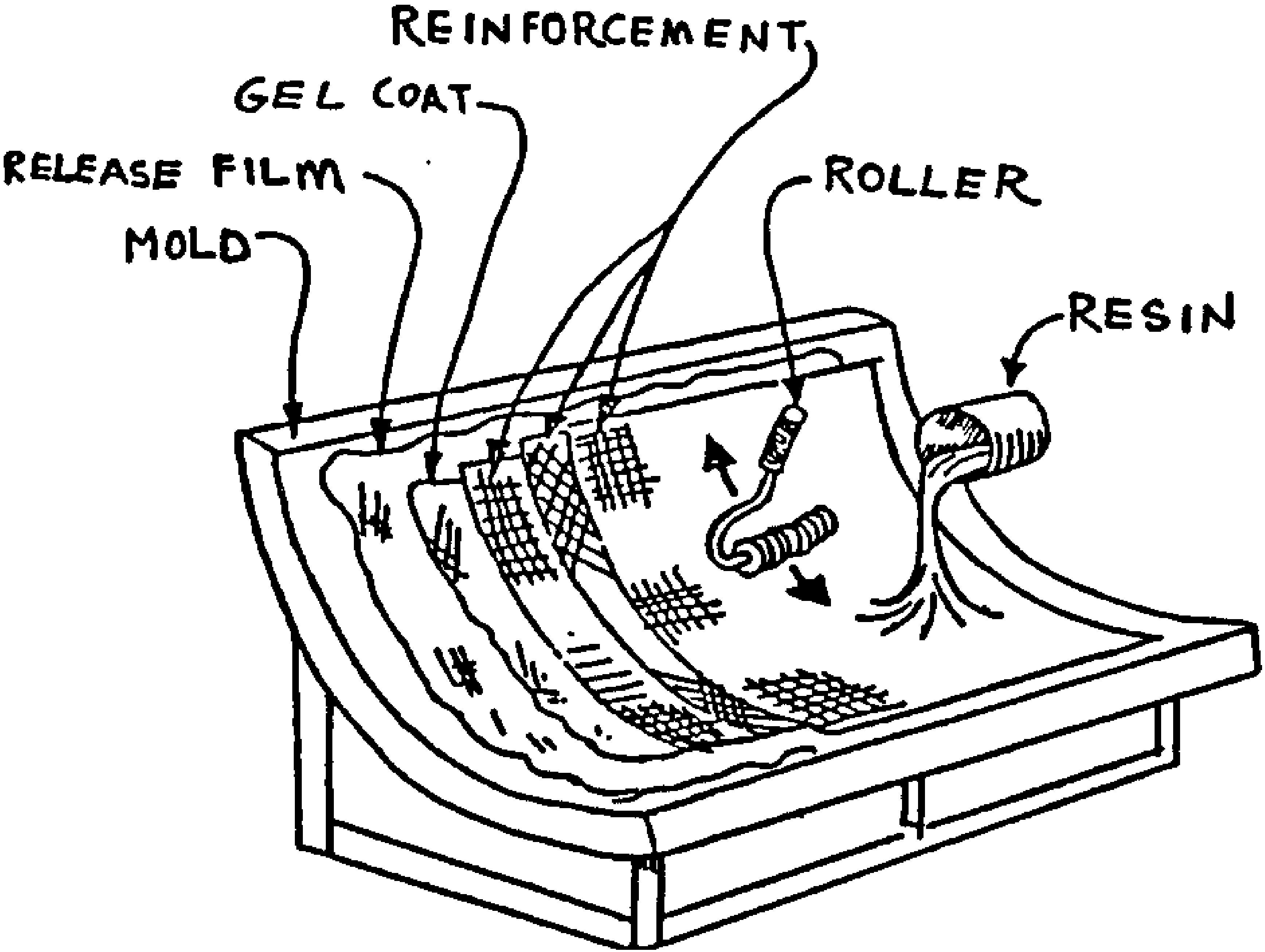


Figure 3 - Hand-Lay-Up Technique



MANUAL LAY UP PROCESS

- Manual lay-up involves cutting the reinforcement material to size using a variety of hand and power-operated devices.
- These cut pieces are then impregnated with wet matrix material, and laid over a mold surface that has been coated with a release agent and then typically a resin gel-coat.
- The impregnated reinforcement material is then hand-rolled to ensure uniform distribution and to remove trapped air. More reinforcement material is added until the required part thickness has been built-up.
- Manual lay-up can also be performed using pre impregnated reinforcement material, called 'prepreg'.
- The use of prepreg material eliminates separate handling of the reinforcement and resin, and can improve part quality by providing more consistent control of reinforcement and resin contents.
- Prepreg must be kept refrigerated prior to use, however, to prevent premature curing.

- The productivity of the manual lay-up can be automated using CNC machines.
- These machines are used for both prepreg tape-laying and prepreg fiber-placement primarily in the aerospace industry.
- There is virtually no limit to the size of the work that can be tape-rolled, but the shape has to be relatively flat to butt each successive row without gaps, overlaps or wrinkles.
- Automatic, multi axis fiber placement machines overcome this limitation by dispensing numerous, narrow individual tapes of material which are collimated as they are laid on the mold surface.

- Resins are impregnated by hand into fibers in the form of weaves and fabrics.
- Rollers or brushes are typically used.
- The composite is left to cure under standard atmospheric conditions.
- The major disadvantage is the lack of consistency;
- The quality of the product is highly dependent on the skill of the laminator.
- Resins need to be low in viscosity to be workable by hand.
- This generally compromises the mechanical and thermal properties of the composite and creates a health risk for the laminator.

Advantages:-

- low cost tools
- versatile: wide range of products

Disadvantages:-

- time consuming
- easy to form air bubbles
- disorientation of fibers
- inconsistency

APPLICATIONS

- ✓ Making of custom parts in low to medium volume quantities.
- ✓ Bathtubs,
- ✓ Swimming pools,
- ✓ Boat hulls,
- ✓ Storage tanks,
- ✓ Duct and air handling equipment,
- ✓ Furniture components

PULTRUSION

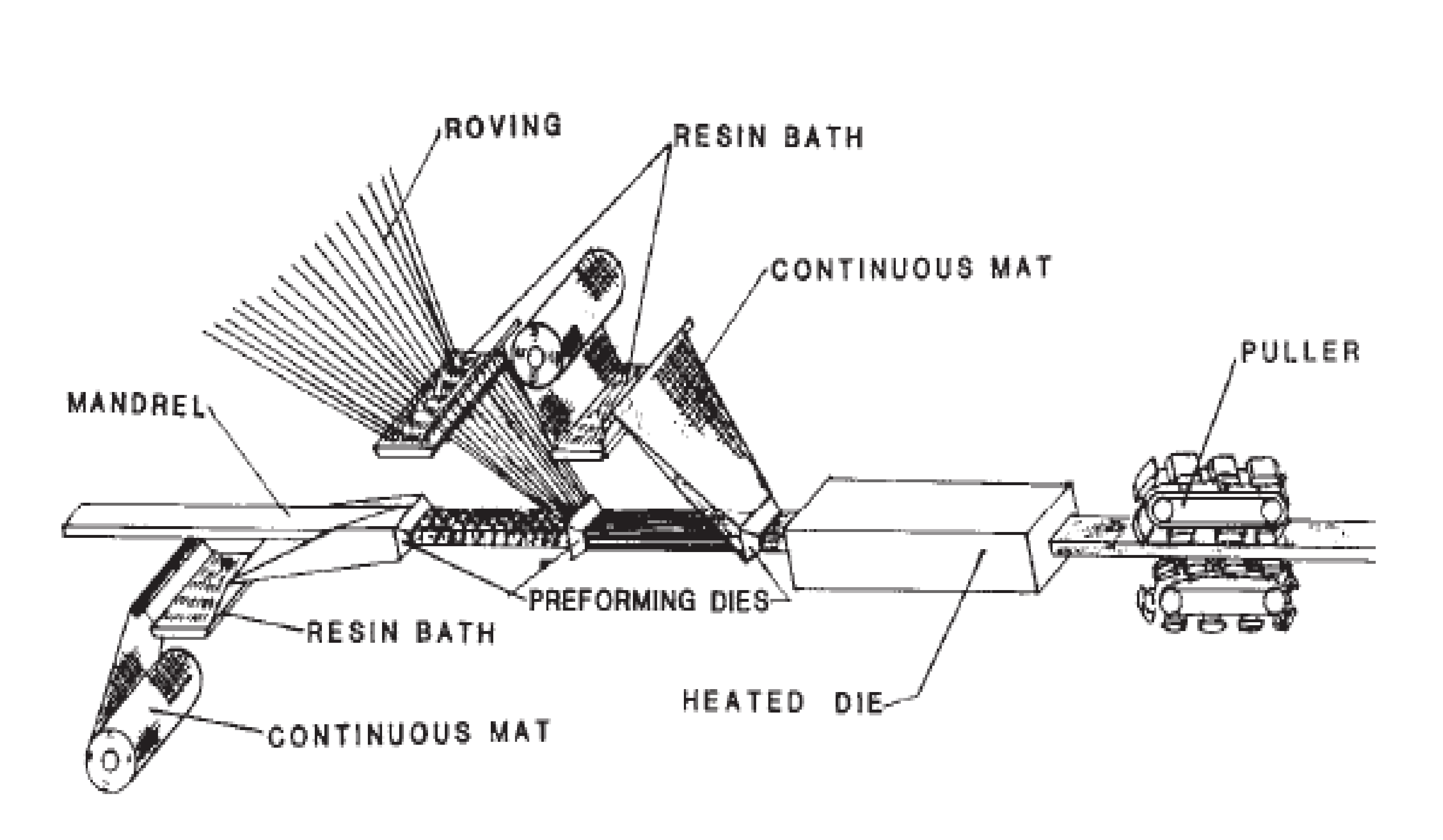


Figure : 4 Pultrusion Process

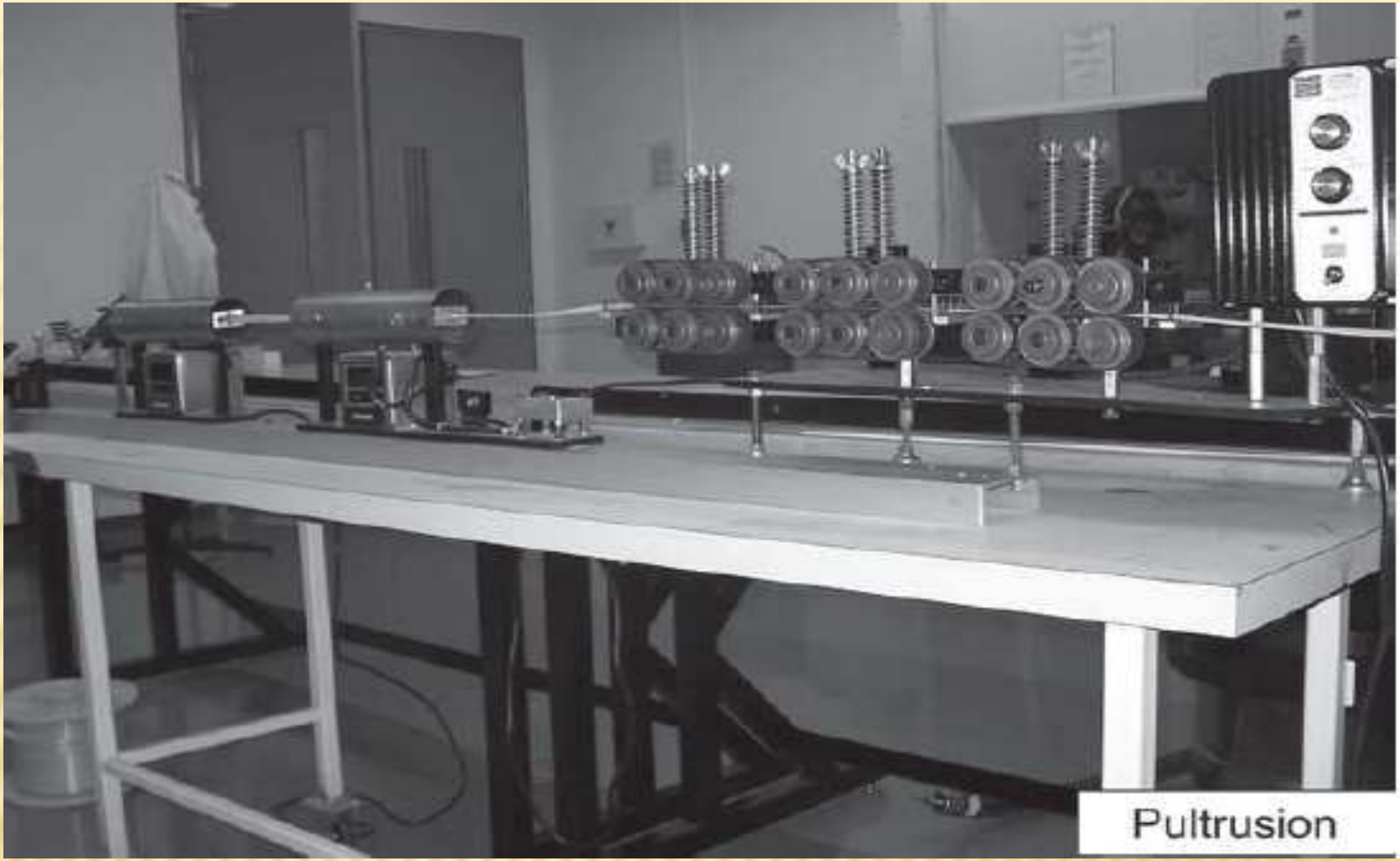


Figure : 5 A lab pultrusion machine

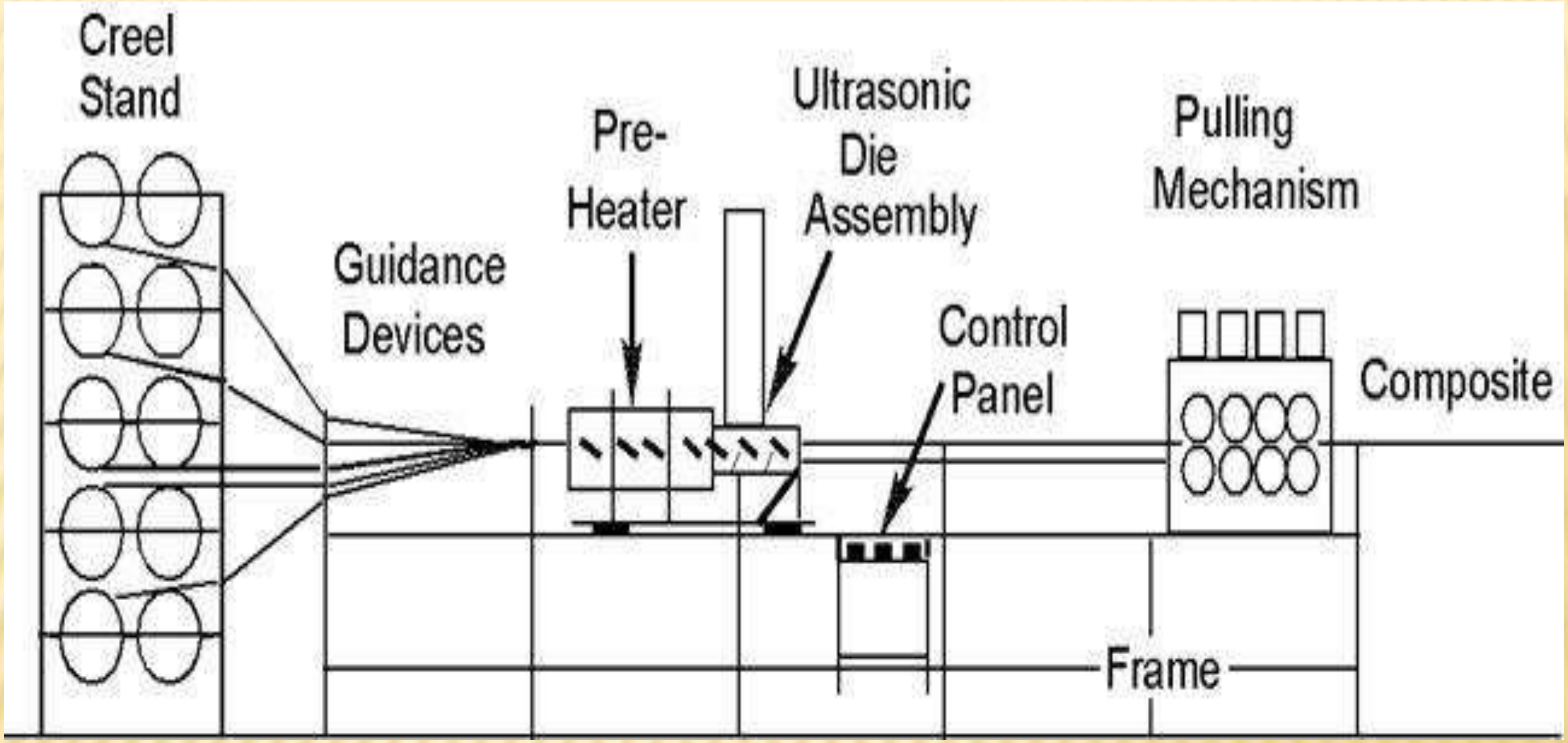
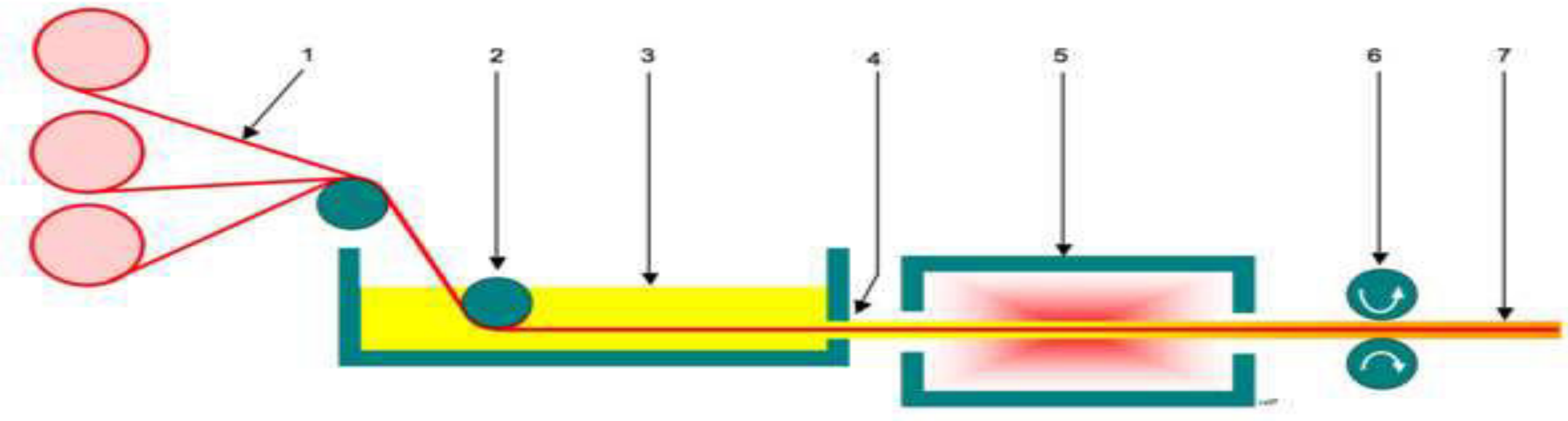


Figure : 6 Components of pultrusion machine



Process of pultrusion

1 - Continuous roll of reinforced fibers/woven fiber mat

2 - Tension roller

3 - Resin Impregnator

4 - Resin soaked fiber

5 - Die and heat source

6 - Pull mechanism

7 - Finished hardened fiber reinforced polymer

- Fibers are pulled from a creel through a resin bath and then on through a heated die.
- As the fiber passes through the die, the resin cures.
- This process is limited to components with constant, or near constant, cross-sections.
- Additionally, the cost of the heated die can be high.
- Pultrusion yields smooth finished parts that typically do not require post processing.
- A wide range of continuous, consistent, solid and hollow profiles are pultruded, and the process can be custom-tailored to fit specific applications such as the constant cross-section spar in some windmill

- Pultrusion is a continuous process used primarily to produce long, straight shapes of constant cross-section.
- Pultrusion is similar to extrusion except that the composite material is pulled, rather than pushed, through a die.
- Pultrusions are produced using continuous reinforcing fibers called 'roving' that provide longitudinal reinforcement, and transverse reinforcement in the form of mat or cloth materials.
- These reinforcements are resin impregnated by drawing through a resin wet-out station; and generally shaped within a guiding, or preforming, system.
- They are then subsequently shaped and cured through a preheated die or set of dies.
- Once cured, the pultrusion is saw-cut to length.
- Pultrusions can be hollow or solid, and applications include bar and rod, pipe, tubing, ladder rails and rungs, and supports of many kinds.

- **<u>Advantages:</u>** -
  - Automated processes.
  - High speed.
  - Versatile cross-sectional shape.
  - Continuous reinforcement.
- **<u>Disadvantages:</u>** -
  - Die can be easily messed up.
  - Expensive die.
  - Mainly thermoset matrix.

RESIN – TRANSFER MOULDING

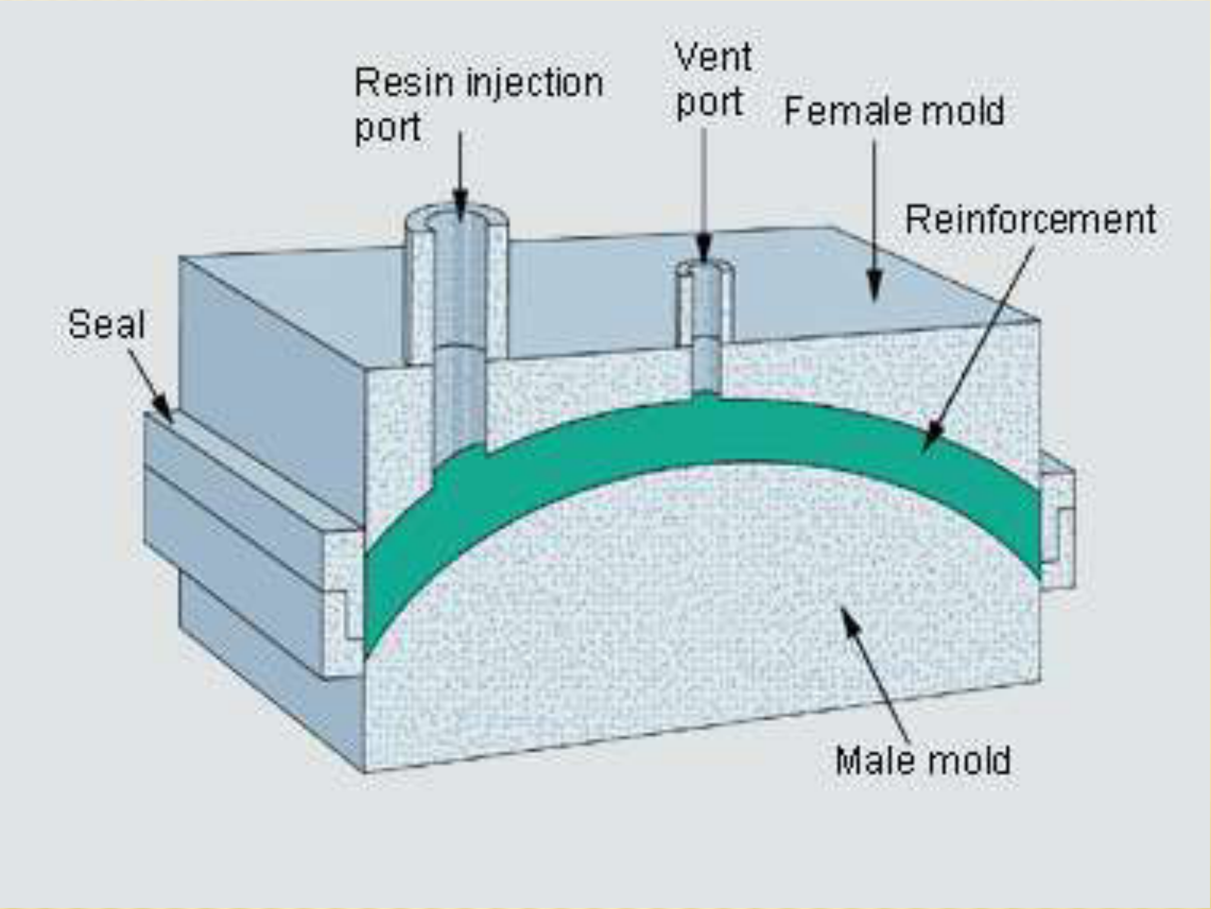
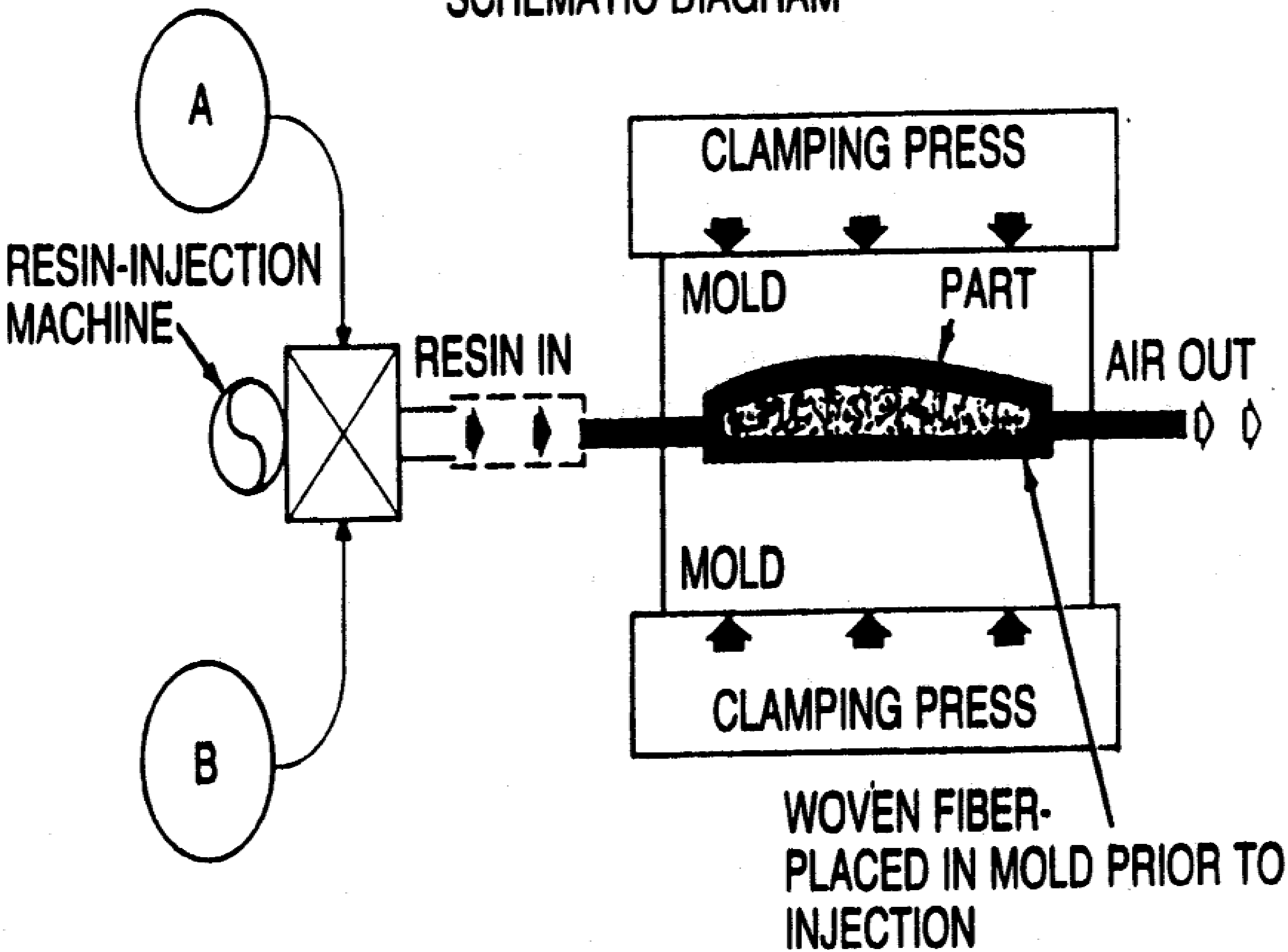


Figure 7 : Resin transfer moulding process

SCHEMATIC DIAGRAM



Introduction

- Resin transfer moulding (RTM) is an increasingly common form of moulding, using liquid composites.
- It is primarily used to mold components with large surface areas, complex shapes and smooth finishes.
- RTM is unlike reaction injection moulding and **structural reaction injection moulding processes (SRIM**), in which the chemical reaction is induced by the mixture of reactants.
- The chemical reaction for resins used in RTM are thermally activated from the fiber mat or preform and mold wall.
- The reaction speed of RTM is much slower than that in SRIM, allowing for a longer fill time at lower injection pressure.
- Final RTM products will be light in weight and high in strength. However, RTM uses heavy structured tooling to

Process

- Material held in a closed mold
- Resin injected

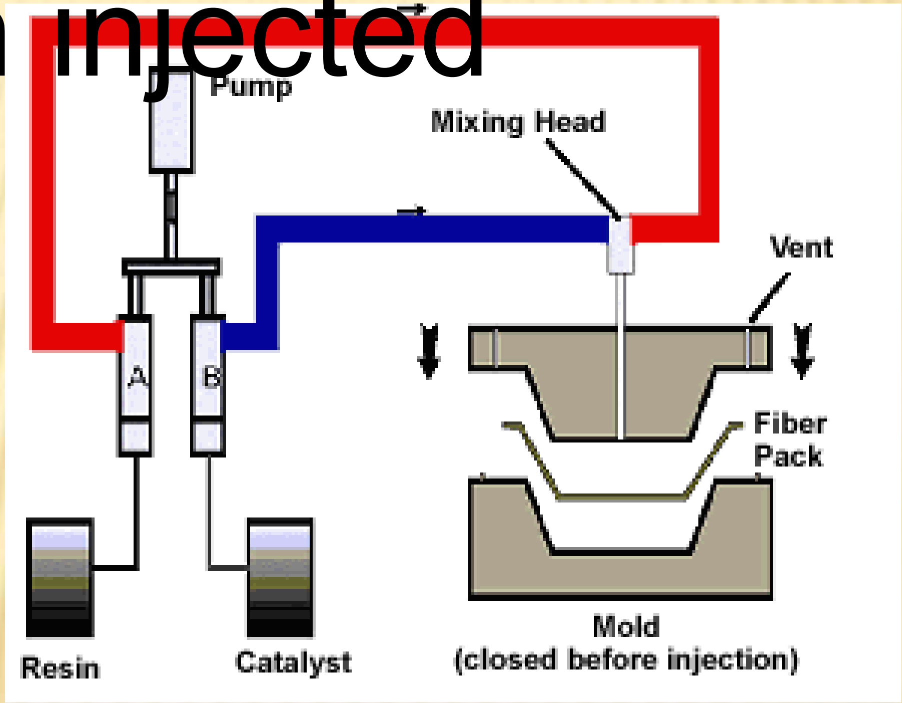


Figure 8 Resin Transfer moulding process

- RTM is a closed-mold, vacuum-assisted process that employs a flexible solid counter tool used for the B-side surface compression.
- This process yields excellent strength-to-weight characteristics, high glass-to-resin ratio and increased laminate compression.
- In this process, fiber preform or dry fiber reinforcement is packed into a mold cavity that has the shape of the desired part. The mold is then closed and clamped.
- Catalyzed, low viscosity resin is then pumped into the mold under pressure, displacing the air at the edges, until the mold is filled.
- After the fill cycle, the cure cycle starts during which the mold is heated, and the resin polymerizes to become rigid plastic.

- Gel coats may be used to provide a high-quality, durable finished product.
- This process is well-suited for mass production of 100 to 10,000 units/year of high-quality composite fiberglass or fiber-reinforced plastic parts.
- It is recommended for products that require high strength-to-weight requirements. Tooling used in this process can be made from various materials including aluminum, nickel shell, mild steel and polyester.
- The light RTM (LRTM) process, on the other hand, is similar to that of RTM, but differs in the method of closing the mould. The closure of the mould is done mechanically or by applying vacuum between two seals in the mould peripheral flange.

- **Advantages**
  - Components will have good surface finish on both sides
  - Selective reinforcement and accurate fiber management is achievable
  - Ability to build-in fiber volume fraction loadings up to 65%
  - Uniformity of thickness and fiber loading, uniform shrinkage
  - Inserts may be incorporated into moldings
  - Tooling costs comparatively low
  - Uses only low pressure injection
  - Low volatile emission during processing
  - Ability to produce near net shape moldings
  - Process can be automated, resulting in higher production rates
  - Ability to mould complex structural and hollow shapes
  - Low resultant voids
  - Ability to achieve from 0.5mm to 90mm laminate thickness

Disadvantages

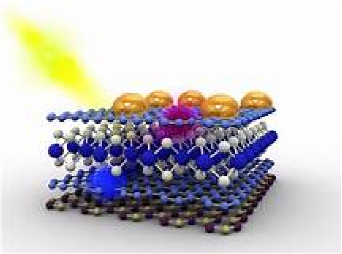
- waste some material (spill)
- curing time long
- hard for intricate parts
- high tooling cost

Applications

RTM is of major interest for various moulding applications as it promises performance improvements and cost savings over traditional methods. Some of the major applications of the RTM process include:-

- ✓ Truck panels
- ✓ Boat hulls
- ✓ Wind turbine blades
- ✓ Aerospace and automobile parts
- ✓ Medical composites
- ✓ Bathroom fixtures, car body, helmet, etc.

Nano Composite



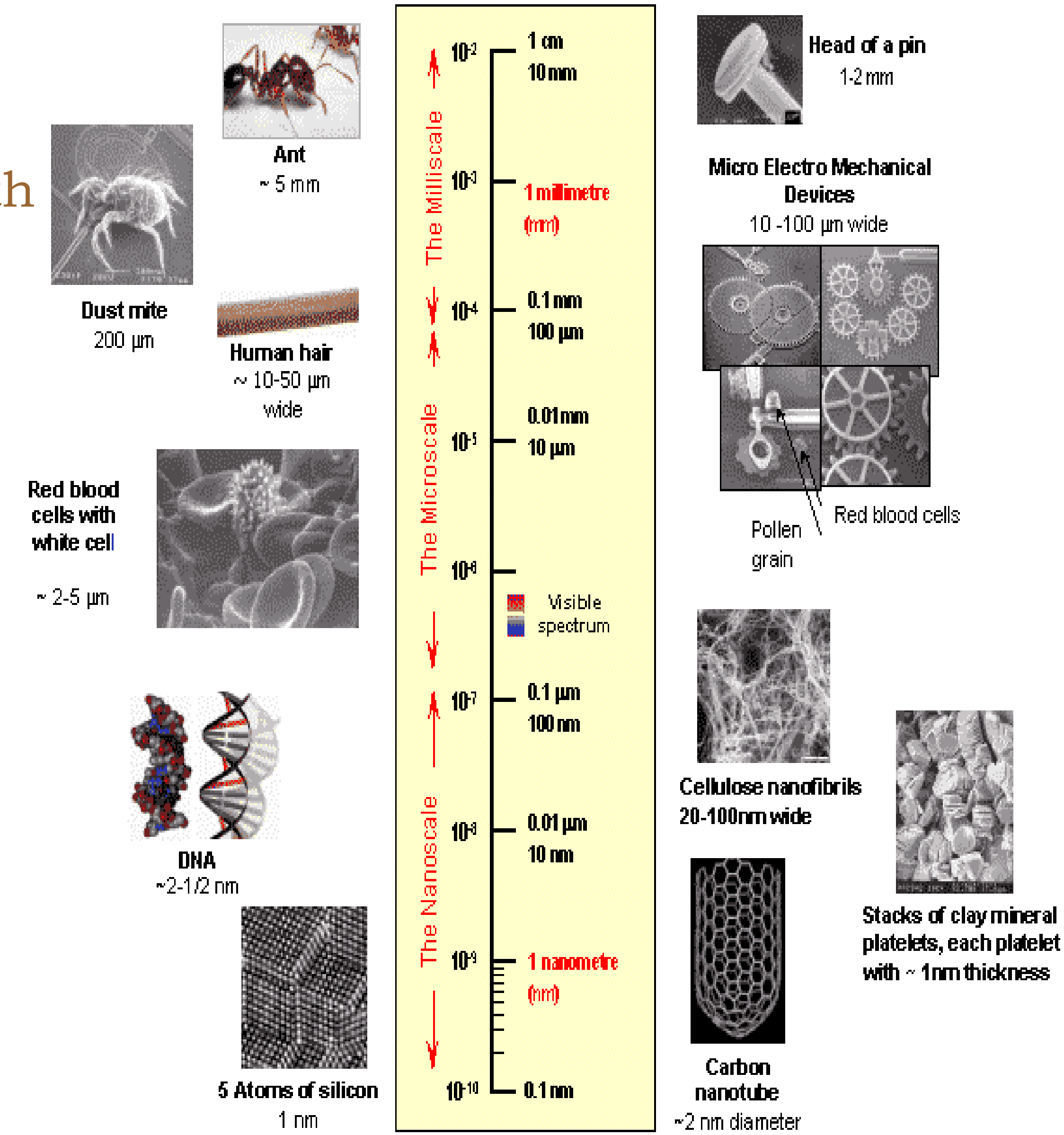
Outline

- Introduction
- Definitions
- Synthesis of nanomaterials
- Challenges
- Nanocomposites
- General features
- Advantages and Limitations
- Conclusion

Nanotechnology

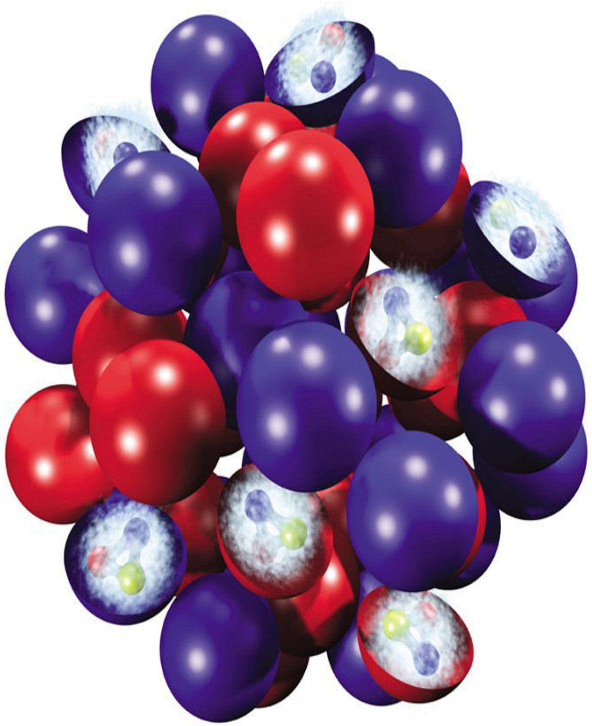
What is nanotechnology?

- Technology that deals with materials/particles in nano-size
- Nano = 10^{-9} m
- 1 nm = 1/1 000 000 m
  - Human hair 60-80 000 nm thickness
  - red blood corpuscle 2-500 nm in width



Contiued....

- Nano-size means atom level
- Percent surface area in propotion to total volume is changed compared to materials in bulk
- Use
  - Cars/motors, aircrafts, energy, electronic equipment, paint, cosmethics, medicine, packaging etc.



Different definitions for ‘ NANO’

Nanocluster
A collection of units (atoms or reactive molecules) of up to about 50 units

Nanocolloids
A stable liquid phase containing particles in the 1-1000 nm range. A colloid particle is one such 1-1000 nm particle.

Nanoparticle
A solid particle in the 1-100 nm range that could be noncrystalline, an aggregate of crystallites or a single crystallite

Nanocrystal
A solid particle that is a single crystal in the nanometer range

Some Nanotech inventions – Nano is not new!

- Nanowires of silicon, and other materials, have remarkable optical, electronic and magnetic properties.

- People use nanoparticles of soot in tires since 1900 to make them black, and nano bits of gold and silver have been added to color pigments in stained glass since the 10^{th} century! Color depends on the size of these particles.

- You can’t avoid nanoparticles-or you’d have to stop drinking milk, which is full of nano-sized particles of casein. The sugar molecule is about 1nm is diameter.

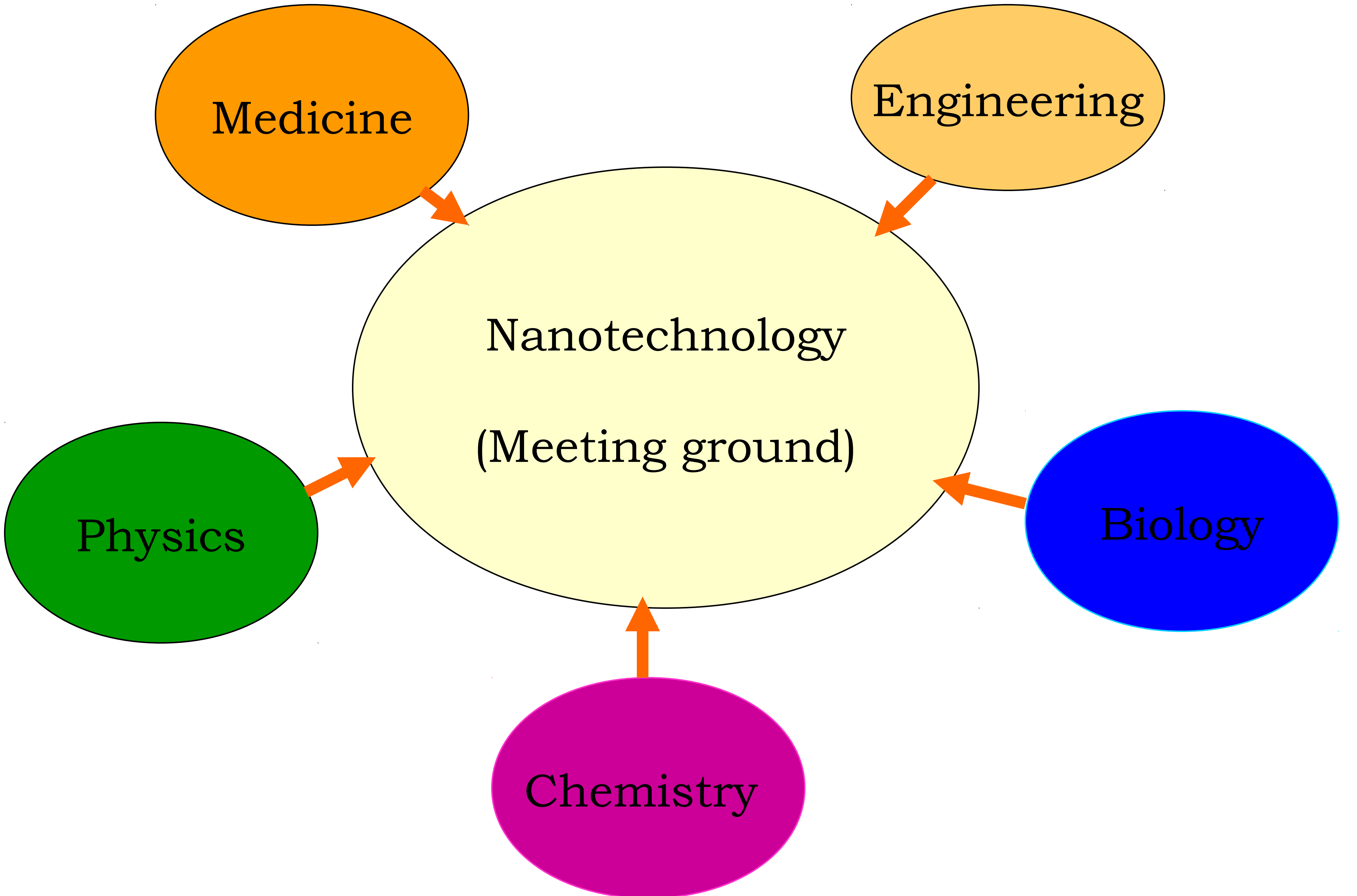
- Humans are living proof of Nanotechnology

Why nanoparticles are different from bulk materials?

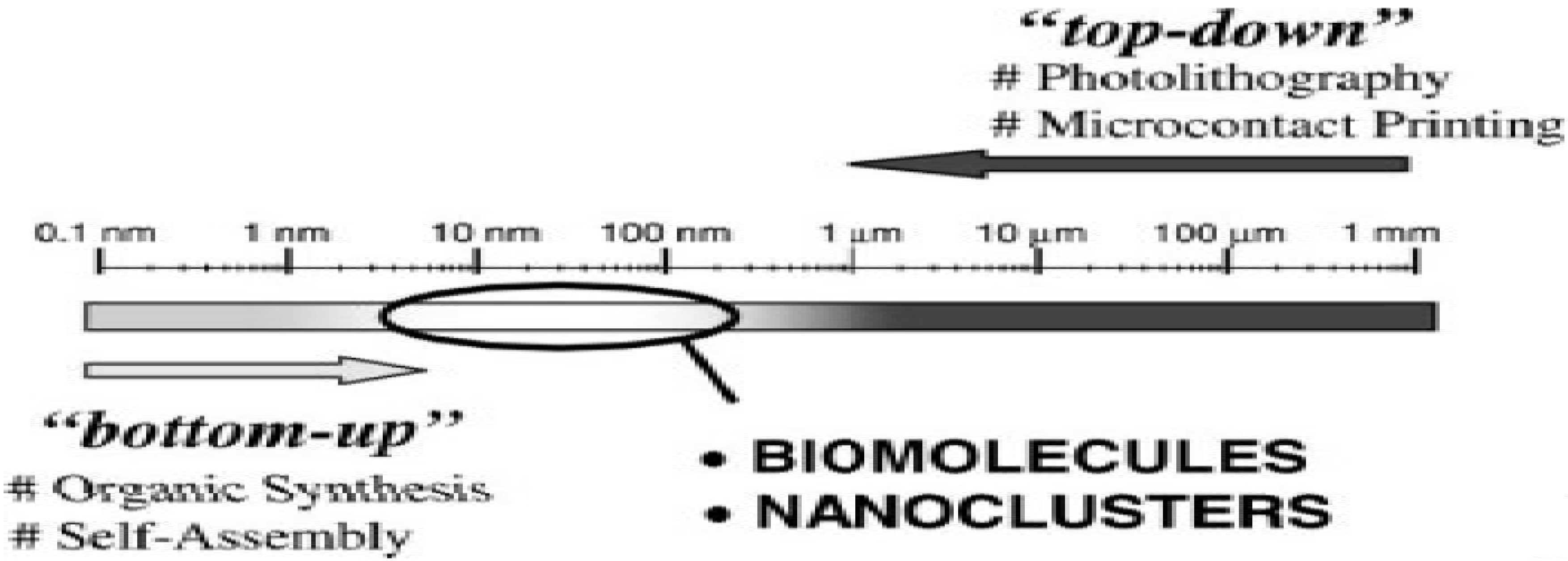
- Nanoparticles are different from bulk materials and isolated molecules because of their unique physical and chemical properties.

Properties	Examples
Catalytic	Better catalytic efficiency through higher surface-to-volume ratio
Electrical	Increased electrical conductivity in ceramics and magnetic nanocomposites, increased electric resistance in metals
Magnetic	Increased magnetic coercivity up to a critical grain size, superparamagnetic behaviour
Mechanical	Improved hardness and toughness of metals and alloys, ductility and superplasticity of ceramic
Optical	Spectral shift of optical absorbtion and fluorescence properties, increased quantum efficiency of semiconductor crystals
Sterical	Increased selectivity, hollow spheres for specific drug transportation and controlled release
Biological	Increased permeability through biological barriers (membranes, blood-brain barrier, etc.), improved biocom-patibility

Interdisciplinary technology



Two basic synthetic approaches



A gap currently exists in the engineering of small-scale devices. Whereas conventional top-down processes hardly allow the production of structures smaller than about 200 ±100 nm, the limits of regular bottom-up processes are in the range of about 2 ±5 nm.

Nanoparticles

- Nanoparticles are of different types viz.,
- Pure Metal Nanocolloids (Ag, Au, Cu, Fe, Ni, Co, etc.)
- Bimetallic Colloids (Pt –Ru, Pt –Ni, Co –Mo, Pd –Fe/Ru)
- Metal oxides (TiO_2, ZnO, Fe_2O_3, CrO_2 Meallates, etc.)
- Metal chalcogenides PbS, CdS, ZnS, ZnSe, CdSe, CdTe, HgS, CuInSe, etc.,
- Ferromagnetic Shape Memory Alloys
- Conducting Polymer –Metal Nanoparticles-Composites, etc.

Synthesis of Nanoparticles

- Chemical Reduction
- Reverse micellar synthesis
- Sol-gel process
- Aero-gel Process
- Microemulsion
- Co-precipitation
- Decomposition of Organometallic Compounds
- Hydrothermal routes•Solution evaporation process,
- Sonochemical Ultrasonication
- Encapsulation in hosts (Zeolites, clays, buseritesbuserites, etc.)
- γ- Ray irradiation in presence of redox mediators, etc.

Challenges in nanotechnology

For the fabrication and processing of nanomaterial and nanostructures, the following challenges must be met:

- Overcome the huge surface energy, a result of enormous surface area or large surface to volume ratio
- Ensure all nanomaterials with desired size, uniform size distribution,morphology, crystallinity, chemical composition and microstructure that altogether result in desired physical properties.
- Prevent nanomaterials and nanostructures from concerning through either Ostwald ripening or agglomeration
- Morphology control

Nanocomposites

Definitions:

- ✓ Nanocomposites are broad range of materials consisting of two or more components, with at least one component having dimensions in the nm regime (i.e. between 1 and 100 nm)

- ✓ Nanocomposites consist of two phases
  (i.e nanocrystalline phase + matrix phase)
  Phase may be
  inorganic-inorganic, inorganic-organic or organic-organic

- ✓ Nanocomposite means nanosized particles (i.e metals, semiconductors, dielectric materials, etc) embedded in different matrix materials (ceramics, glass, polymers, etc).

General features of nanocomposites

Nanocomposites differ from traditional composites in the smaller size of the particles in the matrix materials.

Small size may cause

a) Physical sensivity of bulk materials to physical or mechanical energy
b) Higher chemical reactivity of grain boundaries

<u>Physical sensitivity</u>

- ❑ Small size effect
- ❑ Quantum confinement effect

<u>Chemical reactivity</u>

- ❑ Higher gas absorption
- ❑ Increased nonstoichiometry
- ❑ Regrowth
- ❑ Rotation and orientation
- ❑ Sub graining
- ❑ Assembly

Physical sensitivity

Small size effect:

When the particle sizes in composite materials approach lengths of physical interaction with energy, such as light wave, electromagnetic waves, the periodic boundry conditions of coupling interaction with energy would behave different from its microscopic counterparts, which results in unusual properties

Quantum confinement effect:

When electrons are confined to a small domain, such as a nanoparticles, the electrons behave like “particles in a box” and their resulting new energy levels are determined by quantum confinement effect. These new energy levels give rise to the modification of optoelectronic properties such as “blue shift” light emitting diode

Chemical reactivity

Higher gas absorption:
large specific area of nanopartilces can easily absorb gaseous species

Increased nonstoichiometry phases:
Nanomaterials easily form chemically unsaturated bonds and nonstoichiometry compounds

Regrowth:
Nanomaterials are probably easier to recrystallise and regrow in processing and service conditions than traditional materials

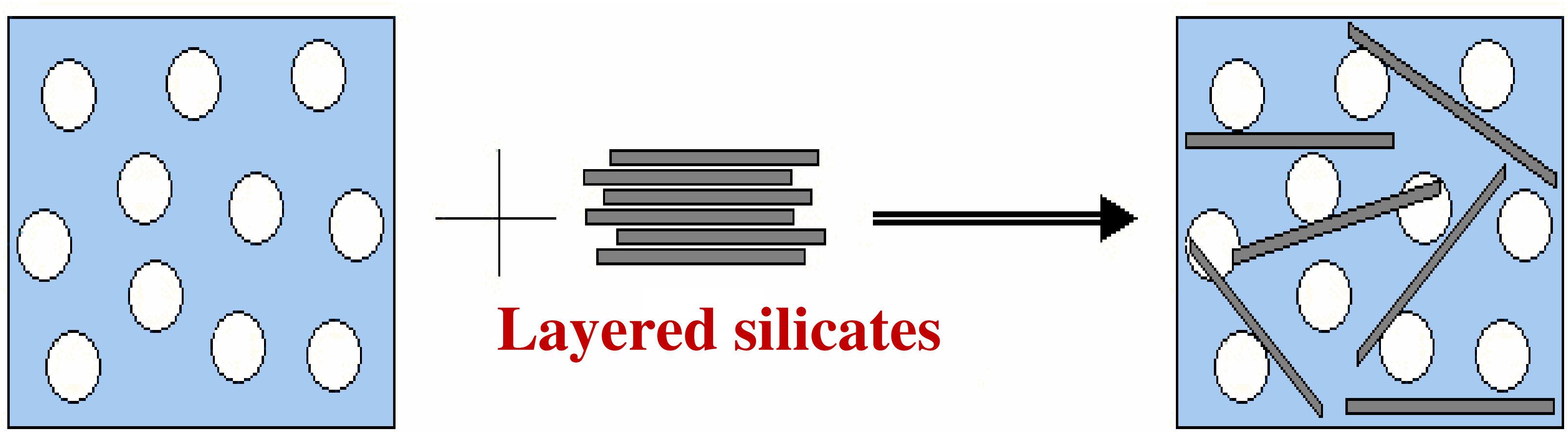
Rotation and orientation:
Crystallographic rotation and orientation of nanoparticles have been found in processing of nanocomposites

Sub-grain:
Nanoparticles enveloped into larger particles act as dispersed pinholes to divide the large particles into several parts.

Assembly
Nanoparticles are easy to aggregate and assemble in liquid or gaseous media

Nanocomposites materials

Nanocomposites can be formed by blending inorganic nanoclusters, fullerenes, clays, metals, oxides or semiconductors with numerous organic polymers or organic and organometallic compounds, biological molecules, enzymes, and sol-gel derived polymers



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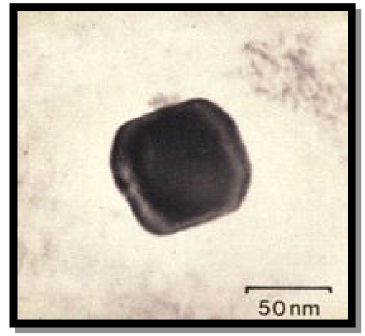
- Resulting nanocomposite may exhibit drastically different (often ***enhanced***) properties than the individual components
  - Electrical, magnetic, electrochemical, catalytic, optical, structural, and mechanical properties



Lycurgus Cup

Lycurgus Cup is made of glass. Roman ~400 AD, *Myth of King Lycurgus*

Appears green in reflected light and red in transmitted light

Classification of nanocomposites

Ceramic based nanocomposites

- Increase in the strength, hardness, and abression by refining particle size
- Enhance ductility, touchness, formability, superplasticity by nanophase
- Change electrical conduction and magnetic properties by increasing the disordered grain boundry interface

Metallic based nanocomposites

- Increased hardness, strength and superplasticity;
- Lowered melting point;
- Increased electrical resistivity due to increased disordered grain surfaces;
- Increased miscibility of the non-equilibrium components in alloying and solid solution;
- Improved magnetic properties such as coercivity, superparamagnetsation, saturation magnetization and magnetocolatic properties

Polymer based nanocomposites.

- electrical, optical, magnetic and catalytic properties arising from the inorganic materials, and enhanced thermal and mechanical stability originating from the polymeric matrix

Advantages and limitations of ceramic nanocomposite processing methods.

Methods	Advantages	Limitations
Powder process	Simple	Low formation rate, high temperature, agglomeration, poor phase dispersion, formation of secondary phases in the product.
Sol-Gel Process	Simple, low processing temperature; versatile; high chemical homogeneity; rigorous stoichiometry control; high purity products; formation of three dimensional polymers containing metal-oxygen bonds. Single or multiple matrices. Applicable specifically for the production of composite materials with liquids or with viscous fluids that are derived from alkoxides.	Greater shrinkage and lower amount of voids, compared to the mixing method
Polymer Precursor Process	Possibility of preparing finer particles; better reinforcement dispersion	Inhomogeneous and phase-segregated materials due to agglomeration and dispersion of ultra-fine particles

Advantages and limitations of processing methods for metal-based nanocomposites.

Methods	Advantages	Limitations
Spray Pyrolysis	Effective preparation of ultra fine, spherical and homogeneous powders in multicomponent systems, reproductive size and quality.	High cost associated with producing large quantities of uniform, nanosized particles.
Liquid Infiltration	Short contact times between matrix and reinforcements; moulding into different and near net shapes of different stiffness and enhanced wear resistance; rapid solidification; both lab scale and industrial scale production.	Use of high temperature; segregation of reinforcements; formation of undesired products during processing.
Rapid Solidification Process (RSP)	Simple; effective.	Only metal-metal nanocomposites; induced agglomeration and non-homogeneous distribution of fine particles.
RSP with ultrasonics	Good distribution without agglomeration, even with fine particles.	
High Energy Ball Milling	Homogeneous mixing and uniform distribution.	
Chemical Processes (Sol-Gel, Colloidal)	Simple; low processing temperature; versatile; high chemical homogeneity; rigorous stoichiometry control; high purity products.	Weak bonding, low wear-resistance, high permeability and difficult control of porosity.
CVD/PVD	Capability to produce highly dense and pure materials; uniform thick films; adhesion at high deposition rates; good reproducibility	Optimization of many parameters; cost; relative complexity.

Advantages and limitations of polymer-based nanocomposite processing methods

Methods	Advantages	Limitations
Intercalation / Prepolymer from Solution	Synthesis of intercalated nanocomposites based on polymers with low or even no polarity. Preparation of homogeneous dispersions of the filler.	Industrial use of large amounts of solvents.
In-situ Intercalative Polymerization	Easy procedure, based on the dispersion of the filler in the polymer precursors.	Difficult control of intragallery polymerization. Limited applications.
Melt Intercalation	Environmentally benign; use of polymers not suited for other processes; compatible with industrial polymer processes.	Limited applications to polyolefins, who represent the majority of used polymers.
Template Synthesis	Large scale production; easy procedure.	Limited applications; based mainly in water soluble polymers, contaminated by side products
Sol-Gel Process	Simple, low processing temperature; versatile; high chemical homogeneity; rigorous stoichiometry control; high purity products; formation of three dimensional polymers containing metal-oxygen bonds. Single or multiple matrices. Applicable specifically for the production of composite materials with liquids or with viscous fluids that are derived from alkoxides.	Greater shrinkage and lower amount of voids, compared to the mixing method

GREEN COMPOSITES

INTRODUCTION

- Ecological concerns have resulted in renewed interest in natural materials.
- Recyclability and environmental safety are becoming increasingly important to the introduction of materials and products.
- Petroleum based products such as resins in thermoset plastics, are toxic and non-biodegradable.

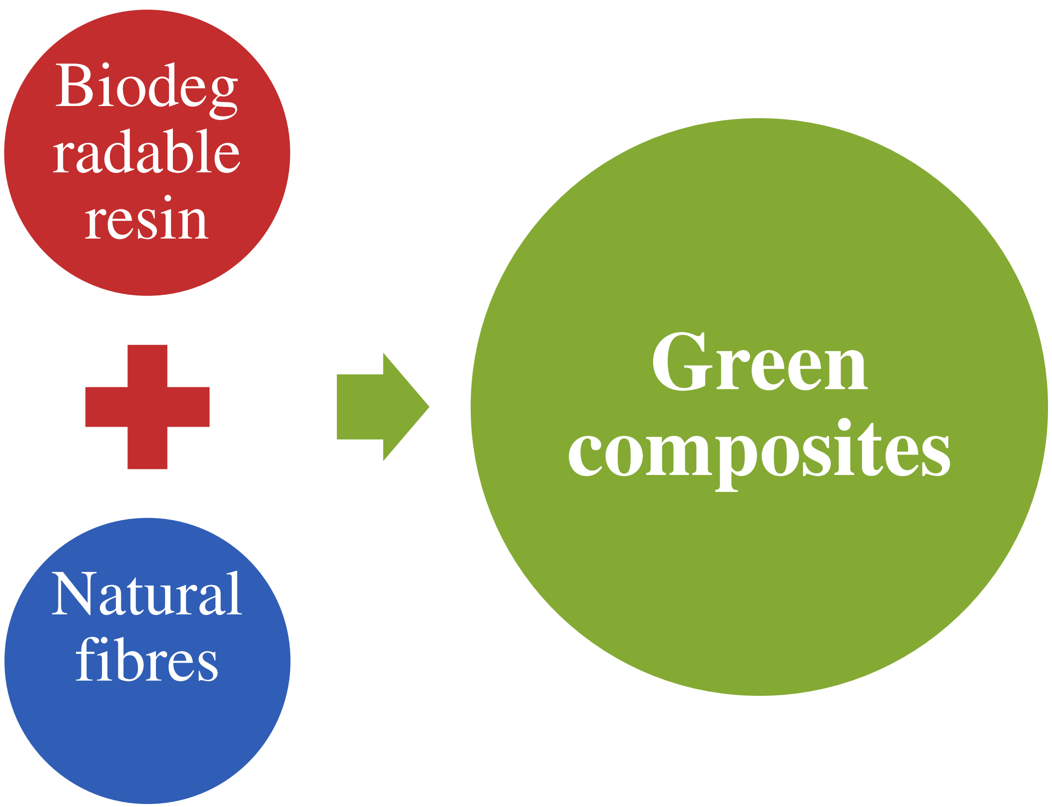
Why do we need green composites?

- The resins and fibres used in the green composites are biodegradable, when they dumped, decomposed by the action of microorganisms.

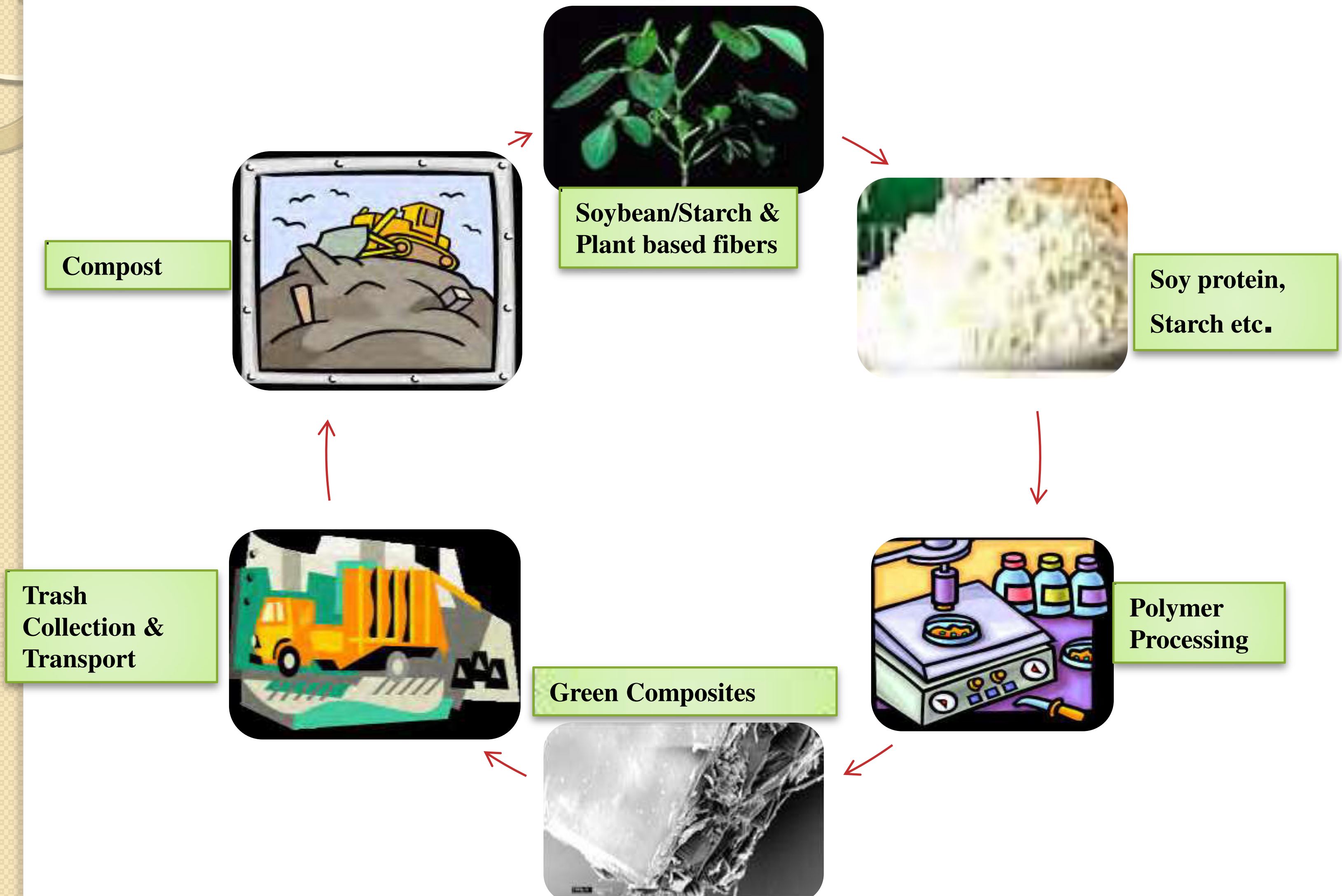
- They are converted into the form of H2O and CO2. These H2O and CO2 are absorbed into the plant systems.

GREEN COMPOSITES

- Green composite combines plant fibres with natural resins to create natural composite materials.



LIFE CYCLE OF
'Green' Composites



BIODEGRADABLE POLYMERS

✓ Natural -

- Polysaccharides – Starch , Cellulose, Chitin, Pullulan, Levan, Konjac, Elsinan
- Proteins - Collagen/Gelatin Casein, Albumin,
  Fibrogen, Silks, Elastins, Protein from grains
- Polyesters - Polyhydroxyalkanoates
- Other Polymers – Lignin Natural Rubber

BIODEGRADABLE POLYMERS

Synthetic –

1. Poly(amides)
2. Poly(anhydrides)
3. Poly(amide-enamines)
4. Poly(vinyl alcohol)
5. Poly(ethylene-co-vinyl alcohol)
6. Poly(vinyl acetate)

BIODEGRADABLE POLYMERS

Synthetic –

7. Polyesters - Poly(glycolic acid)
   Poly(lactic acid)
   Poly(caprolactone)
   Poly(ortho esters)

8. Poly(ethylene oxide)
9. Some Poly(urethanes)
10. Poly(phosphazines)
11. Poly(imino carbomates)
12. Some Poly(acrylates)

FIBRES USED IN GREEN COMPOSITES :

- Natural / biofibres may be classified in two broad categories:
  Non-wood fibres
  Wood fibres

- Natural fibres such as kenaf, flax, jute, hemp, and sisal have attracted renewed interest, especially as a E glass fibre substitute in the automotive industry.

- The other fibres used are Coir (Coconut), Bamboo , Pineapple , Ramie

General Objectives

- **To improve Mechanical properties**
- **To improve Moisture resistance**
- **To improve Thermal properties**
- **To improve Processability**

- To achieve these objectives without compromising the biodegradability
- To fabricate ‘Green’ Composites using the resin and various reinforcing agents

Methods of manufacturing composites

- Filament winding
- Lay up methods
- Resin transfer moulding
- Injection moulding
- Vacuum bonding
- Autoclave bonding

Methods Of Fabricating Soy Protien and Natural Fibre Composite

Resin process

Dissolving SPI powder (at room temperature)

↓

Control
pH-value

↓

Pre-curing + modification
(at around 75°C)
Cross-linker and other additives are added

Composite process

Fabric

↓

Resin impregnation

↓

Oven dry

↓

Hot press Curing at 120 C

↓

Green composite product

Tensile Properties of Ramie Fiber Reinforced SPC Unidirectional Composite (65% fiber content)

Test Direction	FracturStress (MPa)	Fracture Strain (%)	Young's Modulus (GPa)
Longitudinal	271.4 (8.6)*	9.2 (18.3)	4.9 (17.3)
Transverse	7.4 (27.5)	5.3 (22.5)	0.9 (30.3)

*Figures in parentheses are CV%

Tensile and Flexural Properties of Kevlar® and High Strength Cellulose Fiber based 'Advanced Green Composites'

Test Type	Composite	Fracture Stress MPa	Fracture Strain %	Young's (Chord) Modulus GPa
Tensile	Kevlar/ SPC based resin	1123	3.8	34.8
	Cellulose/ SPC based resin	618	8.3	12.8

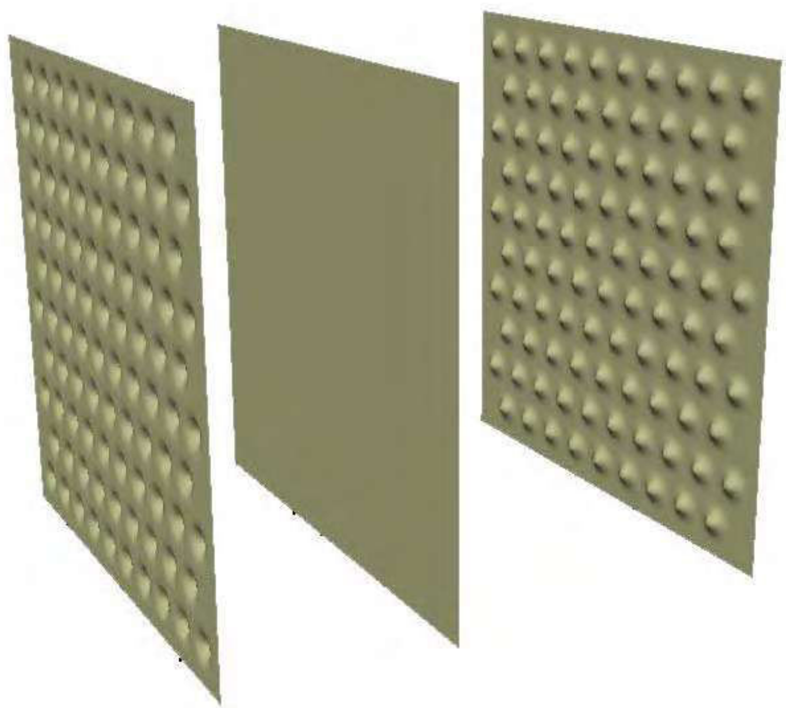
Note : Fiber content of all specimens is 44% by wt.

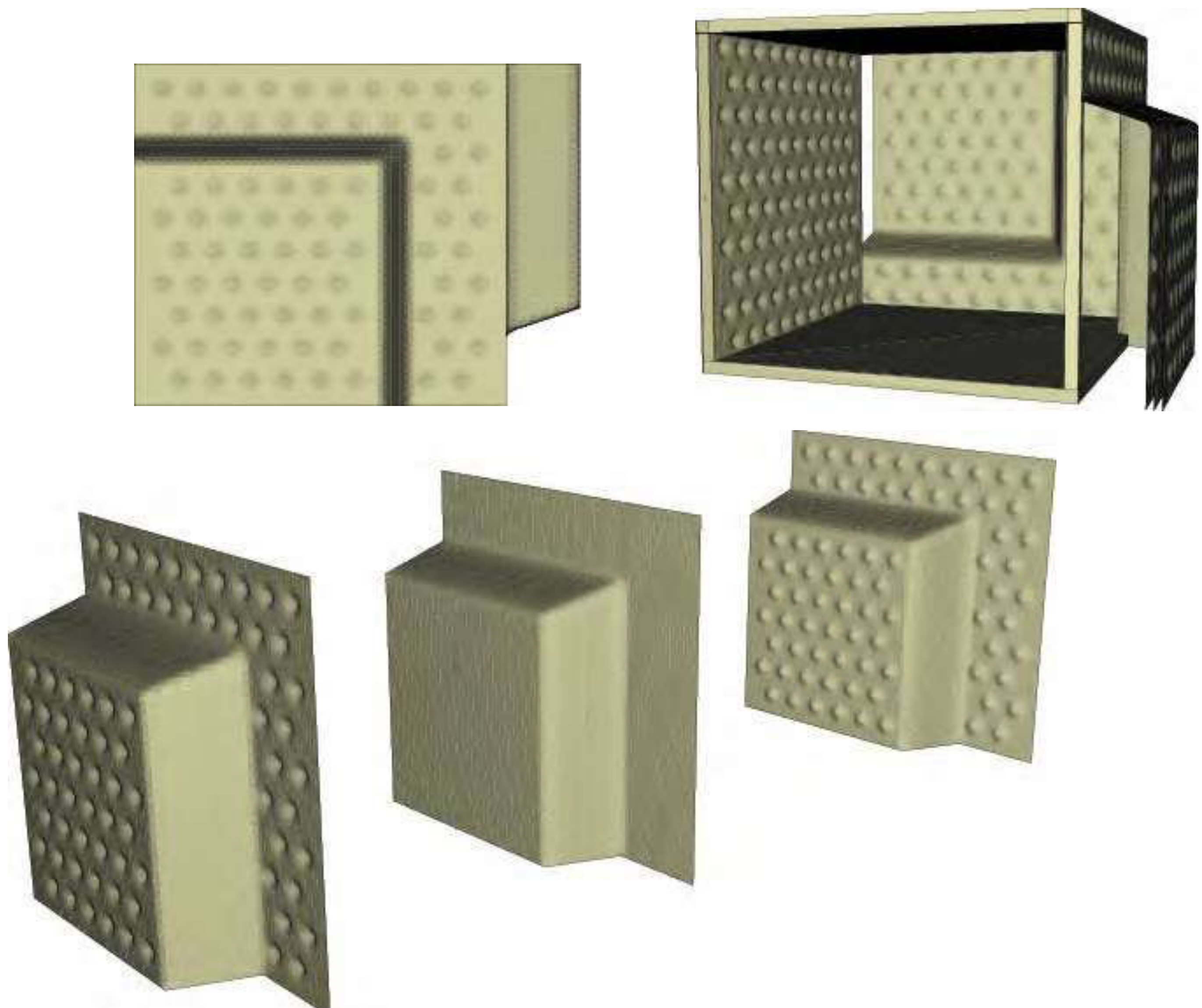
Advantages of green composites over traditional composites :

- Less expensive.
- Reduced weight.
- Increased flexibility.
- Renewable resource.
- Sound insulation.
- Thermal recycling is possible where glass poses problems.
- Friendly processing and no skin irritation.

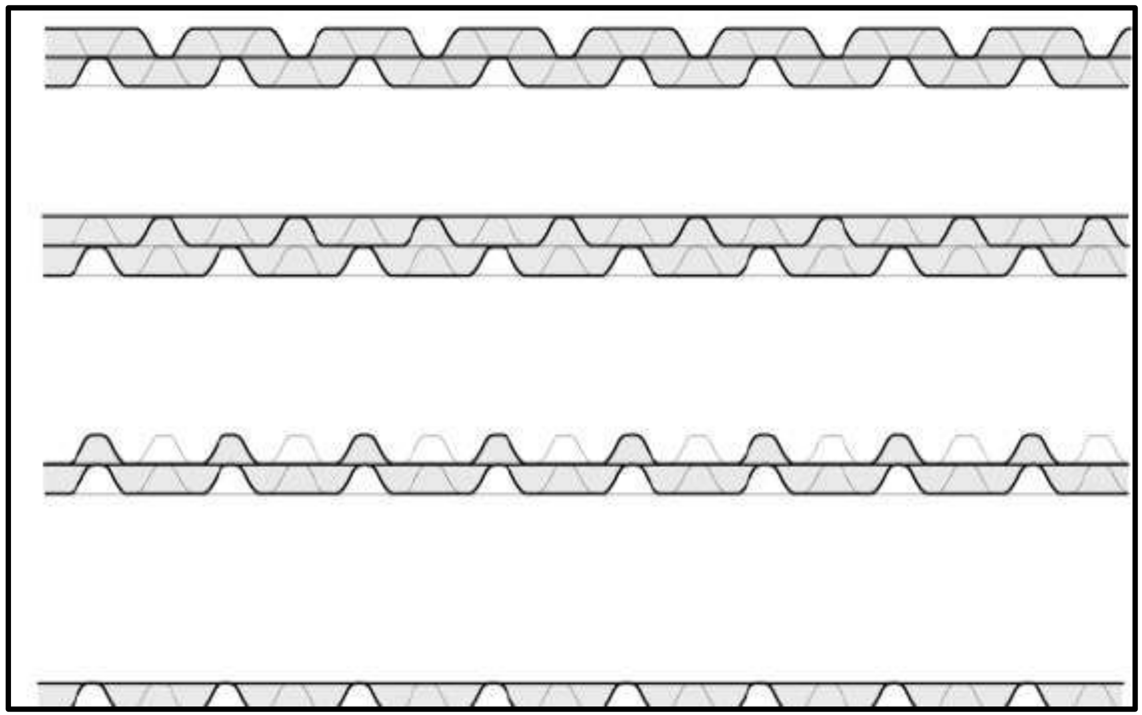
Application and end-uses

‘Green Composite’ Panels





Double-walled Panels Allow Combining With Insulation



Application and end-uses