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"COMPOSITE MANUFACTURING METHOD SELECTION: A REVIEW"

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ABSTRACT :
These review paper focus on composite manufacturing methods which are useful for the manufacturing industries, The various aspect like production ,cost, surface finish, enhancement in properties, crack propagation, fatigue resistance, fiber-matrix bonding and time are necessary adaptable parameter for each composite manufacturing method are here discussed to make ease for use in various industries .
Keyword: Composite material, composite classification, composite manufacturing process, adaptability parameter

INTRODUCTION TO COMPOSITE MATERIALS:

Composite materials are engineered materials made from two or more distinct components with different physical or chemical properties. These components are combined to create a material with enhanced properties. The primary structure of a composite consists of a reinforcing phase (such as fibers or particles) and a matrix phase (a binder that holds the reinforcements together, transfers loads, and protects them).Composite materials have become an integral part of modern engineering and manufacturing, offering a unique combination of strength, lightweight characteristics, and adaptability. The use of composites has expanded into multiple industries, from aerospace to automotive, all of which require specific properties that traditional materials often cannot provide. To harness the full potential of composite materials, it's essential to understand the composite manufacturing processes involved. In this article, we will take a closer look at some of the key composite manufacturing processes, both traditional and advanced, as well as their applications and advantages. The production of composite materials involves several different manufacturing techniques, each suited to specific requirements and end-use applications. Here, we explore some of the most common composite manufacturing processes including hand lay-up, resin transfer molding, filament winding, and pultrusion, 3d printing for composites can be used to create components with customized mechanical. Selecting the right composite manufacturing processes depends on several factors, including the type of material, the desired properties of the end product, the production volume, and the cost constraints. [9][15][10]

CLASSIFICATION OF COMPOSITES:

By Matrix Type: (1) Organic Matrix Composites (OMCs): Composites with organic resins as the matrix. (2)Polymer Matrix Composites (PMCs): Use polymers like epoxy, polyester, or vinylester as the matrix. (3) Carbon-Carbon Composites: Made of carbon fibers in a carbon matrix, excellent for high-temperature applications. (4) Metal Matrix Composites (MMCs): Metal matrices reinforced with fibers or particles for enhanced mechanical properties. (5) Ceramic Matrix Composites (CMCs): Ceramic materials reinforced with fibers to improve toughness and reduce brittleness.

By Reinforcement Type: (1)Fiber-Reinforced Composites: Use fibers (e.g., glass, carbon) for high strength and stiffness.(2) Laminar Composites: Consist of multiple thin layers (laminates) bonded together. (3) Particulate Composites: Reinforced with particles instead of fibers, typically for specific mechanical properties.[5][6].

Advantages, Disadvantages and Application of composite material.[12][8]

Advantages: High Strength-to-Weight Ratio, Corrosion, Impact and Fatigue Resistance, Design Flexibility, Durability, Thermal and Electrical Insulation, Low Thermal Expansion, Customization

Disadvantages: High Cost, Manufacturing Complexity, Difficulty in Repair, Brittleness, Limited Recycling, Sensitive to UV Degradation, Difficult to Detect Defects

Application: Aerospace, Defence & Military, Marine, Automotive, Sports Equipment, Construction, Electronics, Medical Devices, Wind Energy

COMPOSITE MANUFACTURING METHOD:

composite manufacturing process are open mold like hand lay up, filament winding which is exposed to atmosphere and control over process is less, while closed mold like TM,VARTM, pultrusion, sheet moulding, compound,3d printing processes, autoclave molding, resin film infusion are close mold which is not direct contact to atmosphere or surrounding.the discussion for various process basic is necessary

RESIN TRANSFER MOLDING :-

Resin Transfer Molding (RTM) is a composite manufacturing process ideal for mass production of complex parts. It involves placing fiber or fabric in a two-part mold, followed by the injection of resin under low pressure.[41][42] The resin wets the fibers, and the mold is sealed to allow curing at room temperature. The process can be enhanced with Vacuum Assisted Resin Transfer Molding (VARTM), where resin is injected under vacuum pressure to ensure complete impregnation of the fibers. Though RTM is cost-efficient for intricate shapes, it requires expensive tooling and is typically limited to smaller components. [43]This method is commonly used for creating parts like motor casings and engine covers. The process results in high fiber volume, lower void content, and improved mechanical properties like tensile and flexural strength, though its tooling cost remains a challenge.[44][45]

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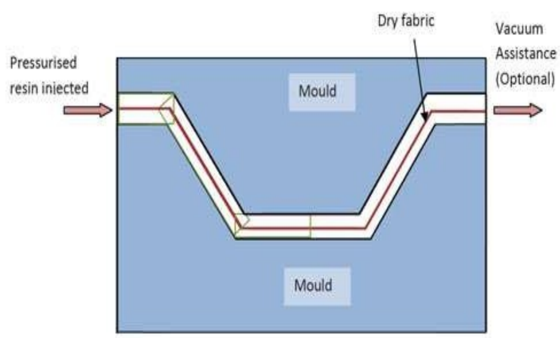

Resin transfer molding.

VACUUM ASSISTED RESIN TRANSFER MOLDING :

Vacuum Assisted Resin Transfer Molding (VARTM) is a low-pressure process developed as an alternative to traditional RTM, aimed at reducing costs and design challenges. In VARTM, the upper mold is replaced by a vacuum bag, and the laminate is placed over the mold, followed by a peel ply. The vacuum bag is sealed, and air is removed from the assembly. Resin is then introduced into the mold under atmospheric pressure, allowing it to impregnate the fibers and compact the preform. The process ensures minimal void content and excellent fiber wet-out. After the resin cures, typically at room temperature or with heat, the result is a high-quality composite part, commonly used in aerospace, automotive, and marine industries for large, complex components.[24][25]

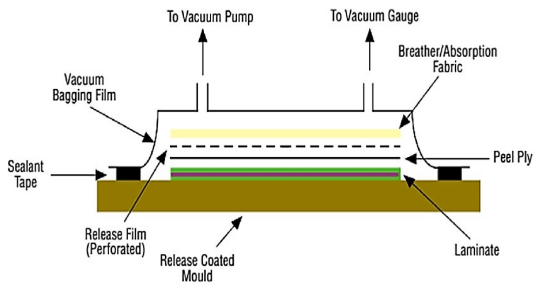

Fig.2 vacuum assisted resin transfer molding.

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 (sheat moulding compoung) 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.[3]

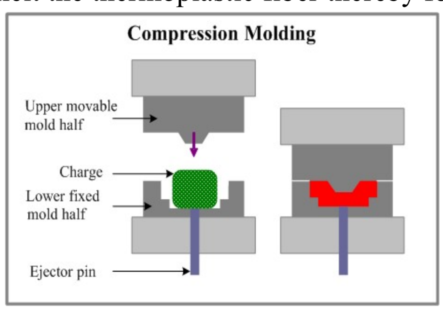

Fig.3 compression molding.

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 prepeg 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.[3]

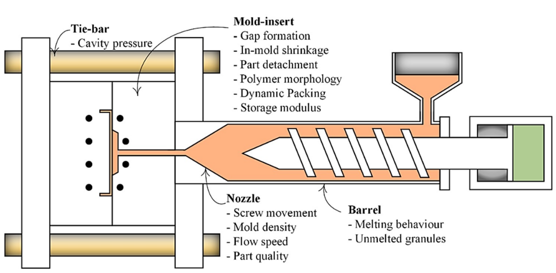

Fig.4 injection molding

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HAND LAY-UP :-

Hand lay-up is a manual composite fabrication process that is simple, flexible, and ideal for small to medium-sized production runs or custom components. The process starts with preparing the mold surface, cleaning it, and applying release agents. fiber reinforcements are manually placed on the mold, ensuring proper alignment, followed by resin application using brushes or rollers to fully impregnate the fibers. Air bubbles are removed using rollers or squeegees to ensure a strong bond. The part is then cured, either at room temperature or with controlled heat/pressure, and removed from the mold. This low-cost process allows for the use of various resin and fiber combinations and is particularly suited for parts like wind-turbine blades and boats. While versatile and simple, it requires skilled labor and is labor-intensive, making it more suitable for low-volume production. The quality of the finished part depends on the worker's skill and attention to detail.[22][29]

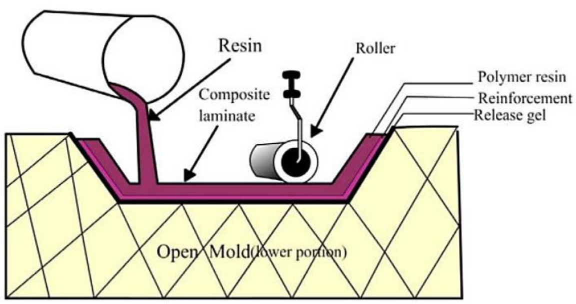

Fig.5 hand lay up method

PULTRUSION :-

Pultrusion is a continuous manufacturing process used to produce composite profiles with consistent quality and high production rates. In this process, fibers (such as basalt) are drawn through a resin bath to become fully impregnated. The resin-wetted fibers are then pulled through a heated die, which shapes the composite and initiates curing.[3][38] The cured material is continuously pulled from the die, cut to the desired length, and cooled if needed. This method is ideal for producing long, continuous profiles like beams, rods, and channels, and is widely used for large-scale production of structural components, such as pipes, gas tanks, and aerospace parts. While cost-effective in terms of fiber impregnation and curing, the process requires expensive heated dies and is limited to components with consistent cross-sections.[39][40]

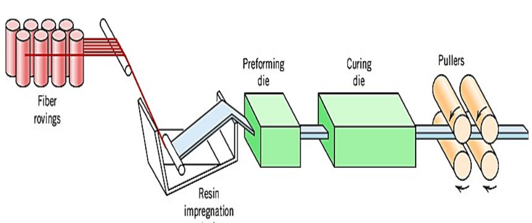

Fig.6 pultrusion

Sheet Moulding Compound (SMC) :

SMC is a key material for producing Glass Reinforced Plastic (GRP) parts. A significant portion of the world's thermoset production is in the form of Sheet Molding Compound (SMC), a flat, sheet-like material produced using a continuous moving belt process. SMC composites are made by sandwiching chopped multi-end roving strands between two layers of film, onto which a resin paste (including resin, shrink compensation, fillers, additives, and curing agents) is applied. The prepreg then passes through a compaction system, ensuring complete impregnation of the strands. The resulting sheet is wound into rolls and stored for pre-maturing, allowing the prepreg to thicken to a mouldable viscosity before it is used in molding applications.

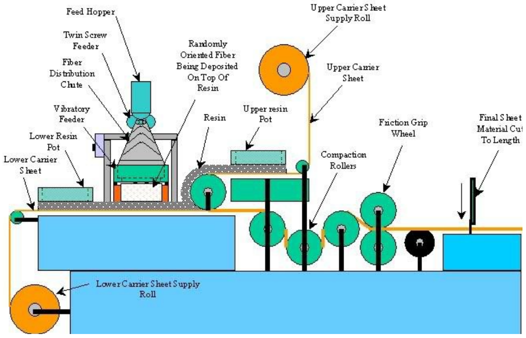

Fig.7Sheet Moulding Compound (SMC)

3D PRINTING PROCESS:

3D Printing or additive manufacturing is a process of making a three-dimensional solid object of virtually any shape from a digital model. Successive layers of material are laid down to construct a customized object. Each layer can be seen as a thinly sliced horizontal cross-section of the eventual object. The available materials also vary by process. Plastics are the most common, but metals, optically clear and rubber like objects can also be 3D printed. 3D Printing enables the production of complex shapes using less material than traditional subtractive manufacturing methods which involve cutting/ machining out the object from a larger block. The 3D Printer makes a three-dimensional solid object from a digital model. It consists of 3D printing apparatus attached to a multi-axis robotic arm. The arm consists of a nozzle that deposits

metal powder or wire on a surface; and an energy source (laser, electron beam or plasma arc) that melts it, forming a solid object. The first step of 3D printing is 3D scanning. 3D scanning is a process of collecting data on the shape and appearance of a real object, creating a digital model based on it. 3D printable models may be created with a computer-aided design (CAD) package, a 3D scanner or a plain digital

camera and photogrammetry software. 3D printed model created with CAD result in reduced errors and can be corrected, allowing verification in the design of the object before it is printed. Fused deposition modelling, selective laser sintering, streolithogrphy apparatus ,laminate object manufacturing, laser engineering net shaping are types of 3d printing.[17][21]

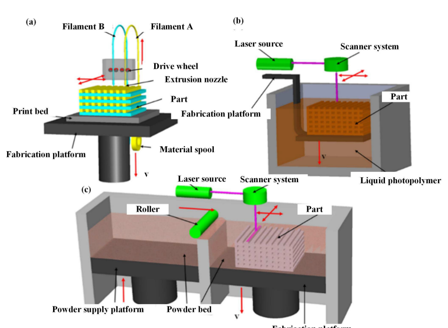

Figure 8 Schematic diagram of typical 3D printing [21]: (**a**) FDM; (**b**) SLA; (**c**) SLS.

Filament Winding:

Large cylinders (pipes) and spherical vessels (for chemical storage) are built with this process. Glass, carbon and aramid fibers used with epoxy, polyester and vinyl ester resins. Two types of filament winding process – Wet winding and Prepeg winding. [31][32] In Wet winding, low viscosity resin is applied to filaments during winding (e.g. polyesters or epoxies with viscosity less than 2000 centipoise. [33][34] In Prepeg winding, a hot melt or solvent dip process is used to pre-impregnate the fibers. (e.g. rigid amines, novolacs, polyamides, higher viscosity epoxy) In filament winding, probable void sites – roving crossover regions and regions between layers with different fiber orientations[23][35]

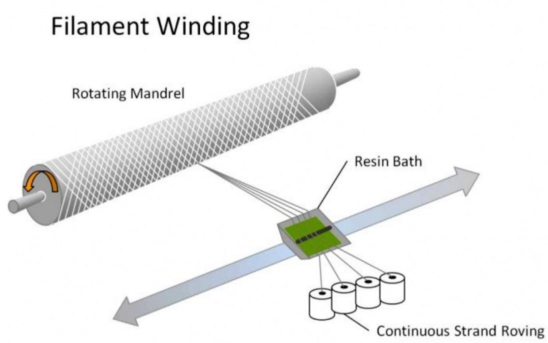

Fig.9 filament winding

AUTOCLAVE MOLDING:-

Autoclave molding technique is similar to vacuum bag and pressure bag molding method with some modifications. This method employs an autoclave to provide heat and pressure to the composite product during curing. In this method, prepregs (reinforcing fabrics pre- impregnated with resin) are stacked in a mold in a definite sequence and then spot welded to avoid any relative movement in between the prepreg sheets. After stacking the prepregs, the whole assembly is vacuum bagged to remove any air entrapped in between the layers. After a definite period of time when it is ensured that all air is removed, the entire assembly[27]

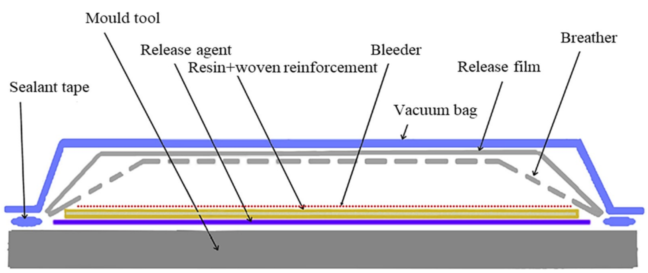

Fig.10 autoclave molding

RESIN FILM INFUSION (RFI):-

Dry fabrics are laid up interleaved with layers of semi-solid resin film supplied on a release paper. The lay-up is vacuum bagged to remove air through the dry fabrics, and then heated to allow the resin to first melt and flow into the air-free fabrics, and then after a certain time, to cure. Material used are Resins: Generally epoxy only, Fibres: Any Cores,: Most, although PVC foam needs special procedures due to the elevated temperatures involved in the process. Used in Aircraft radomes and submarine sonar domes. With these process High fibre volumes can be accurately achieved with low void contents. Good health and safety and a clean lay-up, like prepreg.. High resin mechanical properties due to solid state of initial polymer material and elevated temperature cure. Potentially lower cost than prepreg, with most of the advantages. Less likelihood of dry areas than SCRIMP process due to resin traveling through fabric thickness only. [2]

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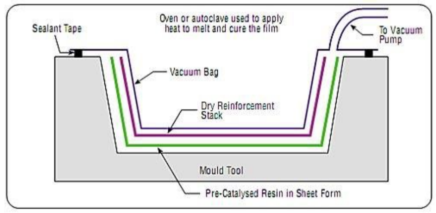

Fig.11 resin film infusion

The table from 1 to 11 shows parameter for selection or rejection after critically reviewed [2][46]

Table .1 [2][46]

1.Resin Transfer Molding (RTM)	Reviewed parameter
production	Medium-to-high production volume, complex shapes, and high-quality parts.
cost	Higher setup costs, but relatively cost-effective for moderate production volumes.
Surface finish	Excellent
Mechanical properties	Excellent
Crack propagation	Very Good
fatigue resistance	Excellent
Fiber and matrix bonding	good
Time	Moderate.

Table.2 [2][46]

2. Vacuum-Assisted Resin Transfer Molding (VARTM)	Reviewed parameter
production	Larger parts and low-to-medium production volume
cost	More cost-effective than RTM, especially for larger or less complex parts
Surface finish	Very Good
Mechanical properties	Very Good
Crack propagation	Good to Very Good
fatigue resistance	Good
Fiber and matrix bonding	good
Time	Moderate to Long

Table 3 [2][46]

3. Injection Molding	Reviewed parameter
production	High production rates of smaller parts.
cost	Very cost-effective for large-scale production, but only if the parts are simple
Surface finish	Excellent to Very Good
Mechanical properties	Good to Very Good
Crack propagation	Moderate
fatigue resistance	Moderate
Fiber and matrix bonding	it’s not always as strong as RTM or VARTM.
Time	Short.

Table 4 [2][46]

4. Compression Molding	Reviewed parameter
production	High-volume production of flat or simple shapes
cost	Moderate. Cost-effective for mid-range volumes but not as flexible as RTM or VARTM for more complex parts.
Surface finish	Good to Very Good
Mechanical properties	Good to Very Good
Crack propagation	Moderate to Good
fatigue resistance	Good
Fiber and matrix bonding	not achieve the same uniformity as RTM or VARTM,
Time	Moderate.

Table 5 [2][46]

5. Pultrusion	Reviewed parameter
production	Continuous production of long, constant cross-section parts (e.g., rods, beams).
cost	Very cost-effective for long production runs of simple, continuous profiles
Surface finish	Good (with limitations)
Mechanical properties	Excellent (for continuous profiles)
Crack propagation	Very Good
fatigue resistance	Excellent
Fiber and matrix bonding	good
Time	Short (Continuous Process)

Table 6 [2][46]

6. Sheet Molding Compound (SMC)	Reviewed parameter
production	High-volume production of large, complex parts with good mechanical properties.
cost	Cost-effective for high-volume production of large or moderately complex
Surface finish	Good to Very Good
Mechanical properties	Very Good
Crack propagation	Good
fatigue resistance	Good
Fiber and matrix bonding	very good
Time	Moderate.

Table 7 [2][46]

7. Hand Lay-Up	Reviewed parameter
production	Small production runs, prototypes, and complex parts with a high level of customization.
cost	Least cost-effective for large-scale production due

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	to high labour costs, but good for prototypes or low-volume custom jobs.
Surface finish	Fair to Good
Mechanical properties	Moderate
Crack propagation	Moderate
fatigue resistance	Moderate to Low
Fiber and matrix bonding	inconsistent
Time	Long.

Table 8 [2][46]

8 Filament Winding	Reviewed parameter
production	High for cylindrical and tabular parts
cost	high
Surface finish	Moderate to rough
Mechanical properties	excellent
Crack propagation	Moderate
fatigue resistance	Excellent
Fiber and matrix bonding	Strong
Time	Moderate

Table 9 [2][46]

9. Additive Manufacturing (3D Printing)	Reviewed parameter
production	Slower
cost	High
Surface finish	Rough Need high resolution setting
Mechanical properties	Moderate
Crack propagation	Low
fatigue resistance	Moderate to low
Fiber and matrix bonding	Moderate
Time	Slow

Table 10 [2][46]

10. Autoclave Processing	Reviewed parameter
production	Slower
cost	High
Surface finish	Excellent
Mechanical properties	Superior
Crack propagation	Low
fatigue resistance	Excellent
Fiber and matrix bonding	Excellent
Time	Long

Table 11 [2][46]

11. Resin Infusion	Reviewed parameter
production	Faster than hand lay up
cost	Low

Surface finish	High quality
Mechanical properties	Strong mechanical properties
Crack propagation	Very Good
fatigue resistance	Good
Fiber and matrix bonding	Good
Time	Moderate

CONCLUSION:

1 .each composite manufacturing technique has its own potential, merits and demerits.

2. Appropriate method of composite manufacturing technique depends upon parameter like part complexibility, production volume, material properties and cost.

3. The advancement of material can make better approach of these manufacturing technique

4. .More automated and economical manufacturing process needs to occupy.

5. Composite manufacturing sector grown up day by day hence demand should be satisfied with streamline process and reduced labour intensiveness.

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