

Primary Manufacturing Processes for Fiber Reinforced Composites: History, Development & Future Research Trends

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Abstract: Composite Materials are becoming more popular gradually replacing traditional material with extra strength, lighter weight and superior property. The world is exploring use of fiber reinforced composites in all application which includes air, land and water transport, construction industry, toys, instrumentation, medicine and the list is endless. Based on application and reinforcement used, there are many ways to manufacture parts with fiber reinforced composites. In this paper various manufacturing processes have been discussed at length, to make fiber reinforced composites components. The authors have endeavored to include all the processes available recently in composite industry. Paper first highlights history of fiber reinforced composites manufacturing, and then the comparison of different manufacturing process to build composites have been discussed, to give clear understanding on, which process should be selected, based on reinforcement, matrix and application. All though, there are several advantages to use such fiber reinforcement composites, still industries have not grown at par and there is a lot of scope to improve these industries. At last, where India stands today, what are the challenges in market has been highlighted and future market and research trend of exploring such composite industries have been discussed. This work is carried out as a part of research project sanctioned by GUJCOST, Gandhinagar.

1. Introduction:

There are more than 50,000 material exists. These materials have been classified to make them better understand on basis of their usage. Since long, composite material could solve technological issues, but since 1960s these material started capturing the attention of industry particularly in polymer based composites. Composite has replaced extensively steel and aluminum and many times shown enhanced performance. It was observed the weight reduction 60-80% with respect to steel and around 20-50% with respect to Aluminum offering same or better properties by use of composites. [1] Composite is a combination of two main element one is called matrix and the other is called reinforcement. Composite can be divided into mainly three category a. PMC (Polymer Matrix Composite), MMC (Metal Matrix Composite) and CMC (Ceramic Matrix Composite). When fibers are combined with resin or plastic they become fiber reinforcement plastic (FRP) composites. [2] The parts made with FRP composite materials have remarkable advantages over traditional materials such as light weight with high strength, good corrosion resistance, dimension stability, good impact resistance, durability, easy mould ability etc. This paper will help to compare different manufacturing process available and get a thought about which process is preferred for which kind of product application and why. The history shows how the different process were developed and grown over years. This paper gives an bird eye view of different primary manufacturing processes available in FRP industry and compares the process with other with respect to its



advantage, limitations, application, types of fibers, types of resin system, quality of part required, cost and production rate. There are several other decisive factors to find out the precise process, which includes size, shape, desired properties of component.[3] The authors have tried to highlight the future trends of composite industry. Why industry growth is limited, what are the actions needed and what is the future has been discussed at length. At last we have also discussed selection of VARTM process for research project sanctioned by GUJCOST.

2. History of Fiber Reinforced Composites:

Since ancient times we are using composites. If we observe back in 1500 BC., Egyptians and Mesopotamian settlers made a mixture of mud and straw to make huts. Afterwards in 1200 AD., Mongols discovered composite bow which was used for military dominance. [4] The use of composite increased after confinement of plastics in 1900s. The history of modern fiberglass is can be referred back to the 1930s. In 1907 the first plastic Bakelite was established after which plastic industry had grown and plastics such as vinyl, polyester, polystyrene were developed. In 1935, first glass fabric was introduced, and it was a start of FRP industry. World War II (1939-1945) brought the composite industry from laboratory to actual production. In 1941, Henry ford used FRP composites in automobile industry [5].

The father of Composite “Gold Worthy” made glass laminates in 1942-1944. The first boat hull was manufactured in 1946 with glass fiber. In 1960s to 1970s more research done on FRP composite. From 1960s the components of aircrafts like spoilers, fairings, and floor board were started developing with use of FRP Composites. In 1963 W.Watt, L.N. Phillips and W.John son introduced carbon fibers with high potential strength. [6] In 1970s the composite industry commenced to urbanized and matured. In 1972 Group Lotus Car Ltd. patented a vacuum moulding method for the production of Fiber Reinforced Composite.1973 due point introduced Aramid (Kevlar) fibers, who were having good impact strength.1978, Gotch demonstrated the use of vacuum impregnation with one solid tool with silicone rubber diaphragm bag. Again in 1980 and 1985 he performed experiments with silicone vacuum bag VARTM using vacuum pressure.Between1980s to 1990s, production of FRP composite was more to reduce manufacturing cost.In1980 Covington and Bavmgardner reported development of prototype fiber glass helicopter rotor blades using filament winding. In 1982 Pultrusion process was introduced by father of composite “Gold Worthy”. In 1982 the Indian institute of Composite material was put up [1]. In 1985, Resin transfer molding was introduced to manufacture motor car bodies, laser 28 deck and in 1986 boat hulls. In 1986, Hold has described the development of tape winding machine for the production of composite main motor blade parts. In 1987, Advance composite manufacturing center was set up to deliver course on composite for research and development consultancy. In 1988 – centrifugal casting was introduced to produce large diameter cylindrical pipes. In 1989 Boyce has used robots in the winding of resin impregnated fibers around pins to perform the reinforcement before compression molding. Since the concept on Fiber Reinforced Composite manufacturing started, composite industry has grown over years for different process. One may articulate four generations of composites: During 1940s, the first generation of composite started use of Glass fiber reinforced composites, During 1960s, the second generation started use of high performance composites, During 1970s to 1980s, in the third generation, search for fresh market and properties in composite world was in progress and after 1990s, the fourth generation used. Hybrid Materials, Nano-composites and Biomimetic Strategies [7].

3. Composite manufacturing Processes:

Various techniques are available depending on type of reinforcement used and application of the product. The classification of composite manufacturing process has been shown in figure 1.

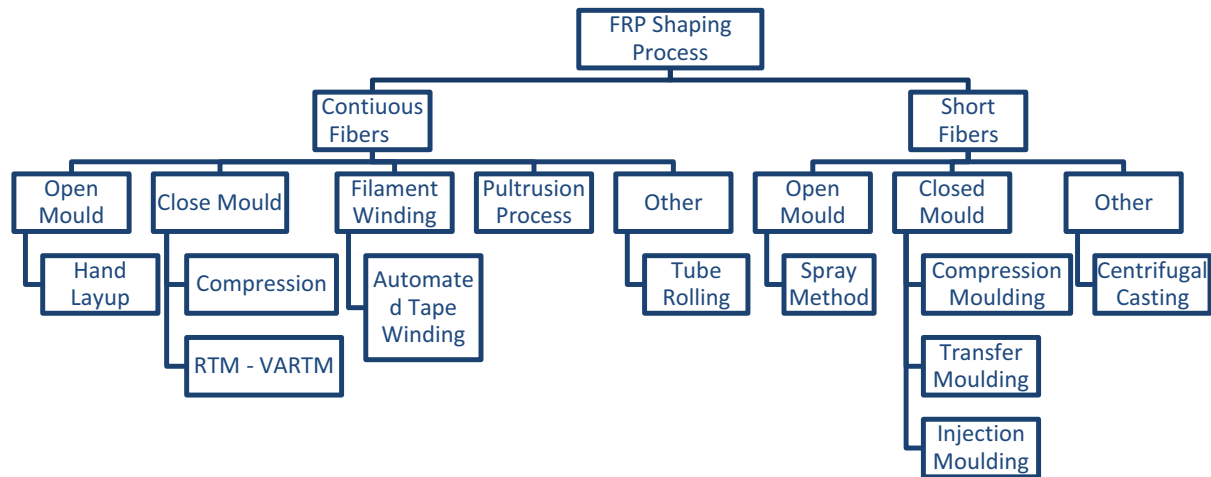


Figure 1: Composite manufacturing process classification [8]

There are various process adopted to manufacture fiber reinforced polymer composites. Refer Table 1 below which compares various manufacturing processes with respect to types of reinforcement, matrix system, application, cost of manufacturing, quality of product, and production rate.

Table 1: Comparison of various manufacturing processes.

Process Name	Process Details, Advantages & Limitations	Material System	Application	Cost/ Qly./ Prod. Rate
Hand Layup/ Wet layup Refer fig.2 [9,10]	In this process molding tool will be cleaned with acetone, normally 2-3 coats of mould release spray or wax will be applied with interval of 15m miniatures and then the reinforcement in the form of mats (UD, BD) will be laid in required orientation. Resin will be impregnated layers by layers with hand, brush and rollers. The number of layers depends on final laminate thickness required. The component can be cured at room temperature or elevated temperature based on resin system used. For getting better compaction pressure plate or vacuum bagging can apply. Process is less costly, less time consuming and easy but can achieve less fiber volume fraction	Woven, knitted, stitched or bonded fabrics Thermoset Epoxy, polyester	Wind-turbine blades, boats, architectural shapes, secondary structure in aerospace Composites, automobile parts, Dash board and deck.	Low, Low , Low

Spray Layup Refer fig.3 [10,11, 12,13]	Spray gun is used where mixture of chopped fibers with resin and catalyst is sprayed on the surface of mould. This is open mold and semi automatic process. Spray rollers are used to squeeze and remover air entrapped inside fibers. Part can be resin rich and very heavy, and it generates volatile organic compound and hazardous air pollution. Closed molding technique is used to get both side part finish. The main advantage of this process is shape complexity, used to make medium to large parts, faster production, low cost, versatility and easy application.	All type chopped fibers, flanks, particles Thermoset - Polyester	Enclosures, lightly loaded structural panels, e.g. caravan bodies, truck fairings, bathtubs, shower trays, small dinghies, Vent hoods, boats, shower unit.	Low, Low, Med
Prepreg layup [8,14]	The process use B stage cured pre-impregnated resin fabrics. This is faster process and provide good fiber volume ratio. Pre impregnated resin is laid on the tool and the component is cured at room or elevated temperature. The cost of process is little higher compared to hand layup. The storage and handling of Prepreg should be proper and the pot life of resin should be ensured before use.	Glass, Carbon. Boron (roving and chopped strand mats, woven roving-fabric) Thermoset-Epoxy Polyester	Aerospace, sports & Leisure, Automotive & Motorsports, Ballistic & Defense Marine	Med High, Med
Filament winding Refer fig.4 [10,11, 15,16]	Filaments or roving from bobbins are wrapped under tension on rotating mandrel in desired pattern to generate cylindrical parts. There are two main motions to lay fibers on mandrel, rotating motion of mandrel and reciprocating motion of carriage to ensure uniform part thickness and desired pattern of fibers on mandrel. Once the mandrel is wound with desired thickness and length, it will be allowed to cure at room temperature or elevated temperature depending upon resin system used. After curing the part can be extracted from the mandrel with hydraulic system. There are different winding patterns like polar winding, hoop winding, circumference winding and axial winding. The process is automated and high fiber volume fraction is possible. Initial cost is high and hence preferable for mass production.	Any fiber Thermoset-Epoxy, polyester, vinyl ester, phenolic	Pipe lines, tubing, pressure vessels, tanks, gas cylinders, fire-fighters breathing tanks, tube light poles, aircraft fuselages, wing sections, radomes, helicopter rotor shafts.	High, High, Med
Resin Transfer Molding (RTM)	The RTM is a closed injection molding process. In RTM process the resin is poured at high pressure to the closed mould, in which dry fabric has been previously positioned. The process is close mould process and product coming out of this is	Woven fabric, roving, chopped fiber mat Thermoset-	bath and Shower enclosures, cabinets, aircraft parts, automotive	High, High, Med

Refer fig.5 [1,10, 11]	well finished at both the sides. The production time and cost is little high as it requires special tooling and individual curing for each part. However the cost of autoclave reduces.	Epoxy, polyester, vinyl ester and phenolic	components, radomes and submarine sonar domes.	
Vacuum Assisted Resin transfer molding (VARTM) Refer fig.6 [10,14]	Instead of two parts male and female mould, VARTM offers one fixed and one flexible tool. A variant of RTM process The fabric is laid on mould, covered with peel ply, release film or distributor film, vacuum bag and sealed by sealant tape. The resin is supplied from resin tank to fabric with help of supply pipe, distribution media, vacuum pipe, resin trap and vacuum pump. The resin flows in to the system by pressure difference due to atmospheric pressure at outlet and vacuum pressure at inlet. One side of part is in contact with tool so only one smooth surface is possible. How to control part thickness variation in VARTM is area of research.	Woven fabric, roving, chopped fiber mat Thermoset resin- epoxy, polyester and vinyl ester.	bridge sections and rail carriages, Land-based and offshore utility-scale wind turbine blades	Less than RTM, Med Med
Pultrusion Refer fig.7 [11,17]	The continues roving from bobbins are guided to gather and merged in to resin tank after which these roving pass through pre heater where they get desire shape and pass through heating die for final curing. Unlike extrusion in this process pull of section performs by pulling mechanism provided in the system. At the end of the process there is cutting saw to get the desired shape of final product. The process is used for mass production, to make continuous cross sections and not economical for unit or batch production.	Continuous roving, fiber chopped strand mats, continuous filament mat Thermoset & thermoplastic epoxy, polyester, vinyl ester	Bar and rod, pipe, tubing, ladder rails and rungs, and supports of many kinds, Beams and girders used in roof structures, bridges, frameworks	MedH igh, High
Compression molding Refer fig 8 [13,14, 17,18, 19]	The main parameters in compression molding process are temperature, pressure and time and they depend upon size, shape thickness of parts and curing cycle requirement. Different process of compression molding includes, thick molding compound (TMC), Sheet molding compound (SMC), Bulk molding compound (BMC) and Wet layup molding compound. In wet molding the top mould will be moving and the bottom will be stationary. The load will be applied by hydraulic press. The temperature will be controlled with electrical circuit provided. It is necessary that there should be optimum pressure and temperature control between top mould and bottom mould to get best quality of products. Vary	Chopped strand mats, woven fabric (UD/BD), short fibers, chopped fibers Thermoset (epoxy, polyester, polyvinyl ester, phenolic), or thermo-plastic (polypro	Truck parts, aircraft window frames, automobile panels, toys, electrical and aero-plane parts.	High, High, High

	the temperature, pressure, with respect to time to get the desired property on the product. It has excellent part to part repeatability and less trimming and finishing cost required.	-pylene, polyethylene nylon, polyether ether ketonetc)		
Centrifugal casting [6]	In this process centrifugal force is used to generate cylindrical parts with resin and chopped fibers. This is continues process and for mass production. The part must be rotating to generate centrifugal action.	Chopped fibers Thermoset resin - epoxy, polyester	Large diameter cylindrical pipes, telegraph poles, cylindrical components	High, Low, High

Figures: Please refer below figures for all the process mentioned in above table.



Figure 2: Hand layup process

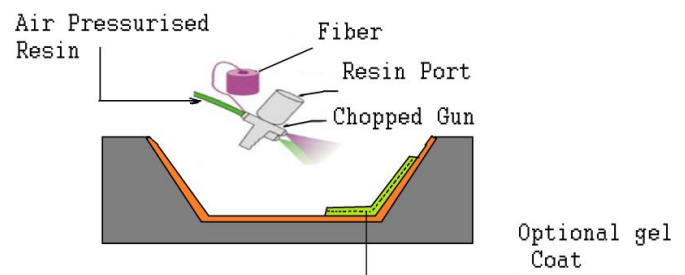


Figure 3: Spray layup process

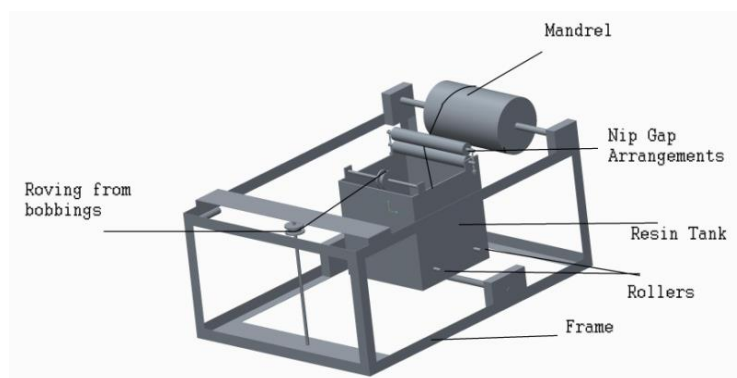


Figure 4: Filament winding process

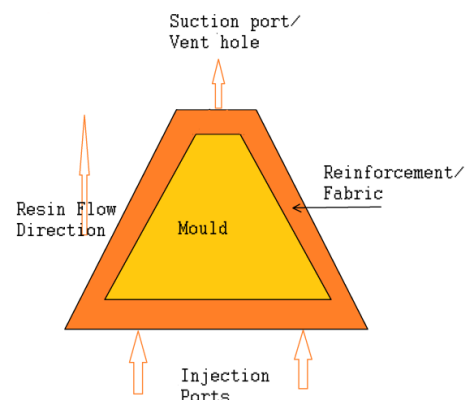


Figure 5: Resin transfer moulding



Figure 6: Vacuum Assisted Resin transfer moulding

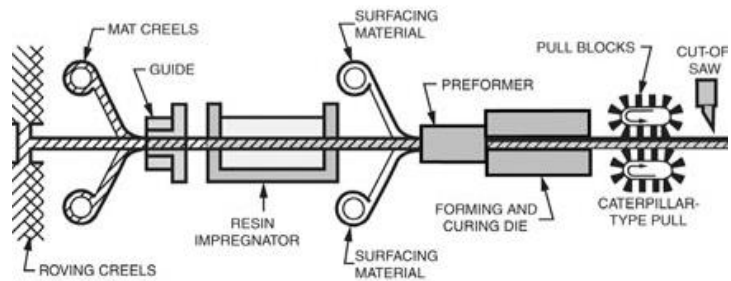


Figure 7: Pultrusion process

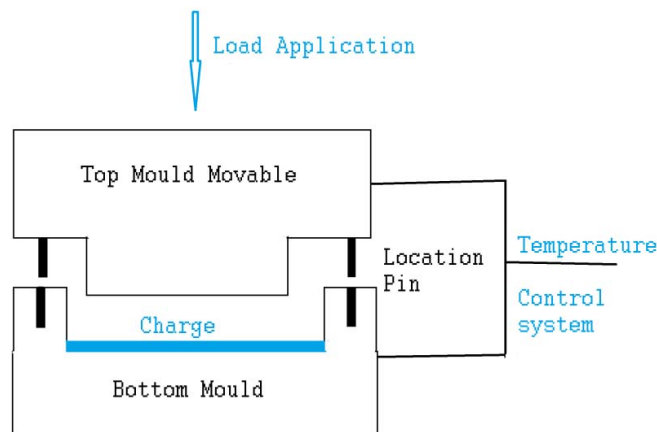


Figure 8: Compression moulding process

4. Composite Market and Research Trend:

Estimated growth opportunities in the Indian composites market by 2020 are going to be a huge requirement of fiberglass & resin. The Indian composites market is predicted to grow at a CAGR (compound annual growth rate) of 14.1% by value from 2016 to 2021. The future companies would be Aditya Birla, Arvind Advance Materials, Atul Pvt. Ltd., BrajBinani Group, Goa Glass fiber, Hindustan Technical Fabrics Limited, Huntsman, Kanoria Chemicals, Scott Bader, and TohoTenax etc will be leading in composite market. The requirement would be for Transportation, Automobile, Marine, Bicycles, Chemical Industry, Electrical & Electronics, Construction, Offshore Oil and Gas Industry, Consumer & Sports Goods etc.[16]

In Reinforcement, the glass fiber dominates the composite industry with market share of around 99% and among 25% of glass fibers are brought in India from other countries. The import of carbon fibers has risen from 30MT to 60MT in 2015. Carbon fibers covers only 0.05% market shares and, and Kevlar 0.092%.

On other side resin, unsaturated polymer resin (UPR) contributes market share of 85%, epoxy 13.978%, vinyl ester 3.6% and other 2.5% in year 2015.

There are major five industries where composite dominates, which includes, Mass transport with maximum of 20.2%, Building and construction 14.11%, Electrical & electronics 13.6%, wind 12.1% and infrastructure 11.2%. The remaining percentages are contribution of other industries like, medical, telecom, defense, and textile. In wind energy sector, the year 2015-16 was of great achievement. India added 3.46 MW energy capacity way ahead of its target value, 2200 MW and now government has recently increased target of installed wind capacity from current level of 24GW to 60 GW by 2022. To support manufacturing sector, government of India has stated that 30% of component should be locally outsource by the supplier in aerospace industry. In manufacturing process, 40% people prefer to use hand layup as a first choice to make laminate, filament winding comes next with 15%, injection molding 13%, compression 12%, pultrusion 9%, RTM/VARTM 8% and other 3%. [20]. A major advancement in composite manufacturing technology is not expected to happen in the near forecast future; presumably it is possible to have incremental developments in existing manufacturing technologies.

5. Challenges:

It is understandable that the enhancement in manufacturing technology alone is not enough to reduce the cost issue. It is important that there has to be an integrated effort in all discipline including design, material, process, tooling, manufacturing, quality assurance and even programme management for composite to become competitive with metal. With saying this shift from aircraft to other commercial use is becoming prominent in recent years. For composite to become competitive with metals, it is important to reduce cost along with required guaranteed durability, maintainability, and reliability. [21] Some major challenges with fiber reinforced composite are lack of knowledge and awareness, lack of standardization, non-biodegradability of synthetic fibers, high raw material price, little efforts in development of products and applications. [20] Sometimes, it has been observed that people don't share their knowledge for betterment to the society and try to keep their monopoly. This is the first step for research that the research should be ethical and should be betterment for the society. Manmade synthetic material available for composite is not bio-degradable and creates issues for environment. In India, importance of research is not that critical as other countries and hence development of composite technology is becoming very time consuming and costly process.

6. Conclusion: This paper deals with not only exploring different manufacturing process to produce fiber reinforced composites, but also it highlights history, recent developments and future market requirements.

It has been seen, there is enormous scope in manufacturing of fiber reinforced composite which includes defense, aerospace, wind, household, toys, transportation, wind, electrical parts and so on. It is high time to aware end product users about the scope of composite in market and requirement of mass production.

If we compare different manufacturing process, only 8% products are made with RTM & VARTM technology. VARTM has huge potential to manufacture critical parts with required properties at economical rate. We are working on the same concept under research project sanctioned by GUJCOST, Gandhinagar to make VARTM process more useful to manufacture high quality fiber reinforced composite parts.

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