FRP Composites Processing

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Introduction

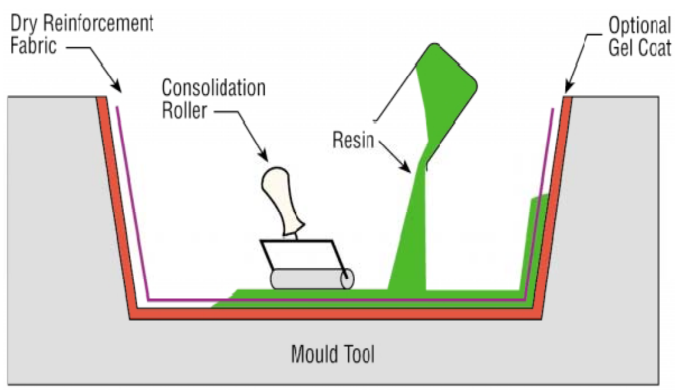
Considering composite materials as a whole, there are many different material options to choose from in the areas of resins, fibers and cores, all with their own unique set of properties such as strength, stiffness, toughness, heat resistance, cost, production rate etc. However, the end properties of a composite part produced from these different materials is not only a function of the individual properties of the resin matrix and fiber (and in sandwich structures, the core as well), but is also a function of the way in which the materials themselves are designed into the part and also the way in which they are processed. This section compares a few of the commonly used composite production methods and presents some of the factors to be borne in mind with each different process, including the influence of each process on materials selection.

Manufacturing Processes

1. Hand Lay-up

Description:

Matrixes/Resins are impregnated by hand into fibers which are in the form of chopped strand mat woven, knitted, stitched or bonded fabrics. This is usually accomplished by rollers or brushes, with an increasing use of nip-roller type impregnators for forcing resin into the fabrics by means of rotating rollers and a bath of resin. Laminates are left to cure under standard atmospheric conditions.



Materials Options:

Resins: Epoxy, polyester, vinyl ester, phenolic and any other resin.

Fibers: Glass, Carbon, Aramid and any other reinforcement, although heavy aramid fabrics can be difficult to wet-out by hand.

Cores: Any core materials can be used provided that should be compatible with resin system, i.e. polystyrene core cannot be used with polyester or vinylester resin system.

Main Advantages:

i) Low capital Investment.

ii) Simple principles to fabricate the part.

iii) Low cost tooling, if room-temperature cure resins are used.

iv) Wide choice of suppliers and material types.

Main Disadvantages:

i) Resin mixing, laminate resin contents, and laminate quality are very dependent on the skills of laminators. Low resin content laminates cannot usually be achieved without the incorporation of excessive quantities of voids.

ii) Health and safety considerations of resins. The lower is molecular weight of hand lay-up resins generally means that they have the potential to be more harmful than higher molecular weight products. The lower viscosity of the resins also means that they have an increased tendency to penetrate clothing etc.

iii) Limiting airborne styrene concentrations to legislated levels from polyesters and vinyl esters is becoming increasingly hard without expensive extraction systems.

iv) Resins need to be low in viscosity to be workable by hand. This generally compromises their mechanical/thermal properties due to the need for high diluents/styrene levels.

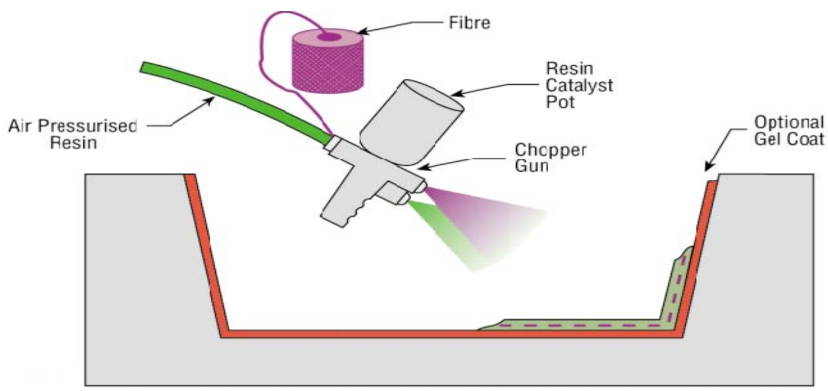
Typical Applications:

Standard wind-turbine blades, boats, architectural moldings, etc.

2. Spray Lay –up

Description

Fiber is chopped in a hand-held gun and fed into a spray of catalyzed resin directed at the mould. The deposited materials are left to cure under standard atmospheric conditions.



Materials Options:

Resins: Primarily polyester.

Fibers: Glass roving only.

Cores: None. These have to be incorporated separately.

Main Advantages:

i) Widely used for many years.

ii) Low cost way of quickly depositing fiber and resin.

iii) Low cost tooling.

Main Disadvantages:

i) Laminates tend to be very resin-rich and therefore excessively heavy.

ii) Only short fibers are incorporated which severely limits the mechanical properties of the laminate.

iii) Resins need to be low in viscosity to be sprayable. This generally compromises their mechanical/thermal properties.

iv) The high styrene contents of spray lay-up resins generally means that they have the potential to be more harmful and their lower viscosity means that they have an increased tendency to penetrate clothing etc.

v) Limiting airborne styrene concentrations to legislated levels is becoming increasingly difficult.

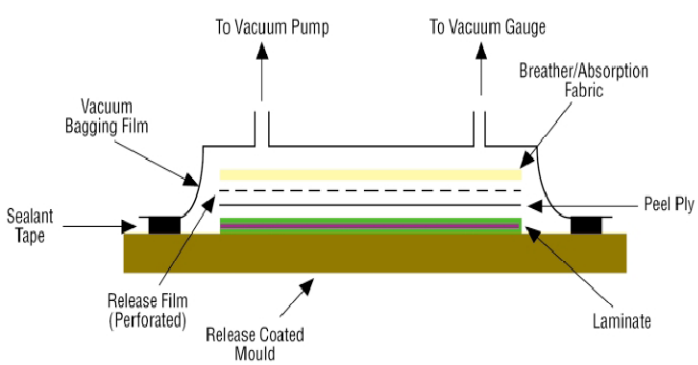
Typical Applications:

Simple enclosures, lightly loaded structural panels, e.g. caravan bodies, truck fairings, bathtubs, shower trays, some small dinghies.

3. Vacuum Bagging

Description

This is basically an extension of the wet lay-up process described above where pressure is applied to the laminate once laid-up in order to improve its consolidation. This is achieved by sealing a plastic film over the wet laid-up laminate and onto the tool. The air under the bag is extracted by a vacuum pump and thus up to one atmosphere of pressure can be applied to the laminate to consolidate it.



Materials Options:

Resins: Primarily epoxy and phenolic. Polyesters and vinyl esters may have problems in case of excessive extraction of styrene from the resin by the vacuum pump.

Fibers: The consolidation pressures mean that a variety of heavy fabrics can be wet-out.

Cores: Any.

Main Advantages:

i) Higher fiber content laminates can usually be achieved than with standard wet lay-up techniques.

ii) Lower void contents are achieved than with wet lay-up.

iii) Better fiber wet-out due to pressure and resin flow throughout structural fibers, with excess into bagging materials.

iv) Health and safety: The vacuum bag reduces the amount of volatiles emitted during cure.

Main Disadvantages:

i) The extra process adds cost both in labour and in disposable bagging materials.

ii) A higher level of skill is required by the operators.

iii) Mixing and control of resin content still largely determined by operator skill.

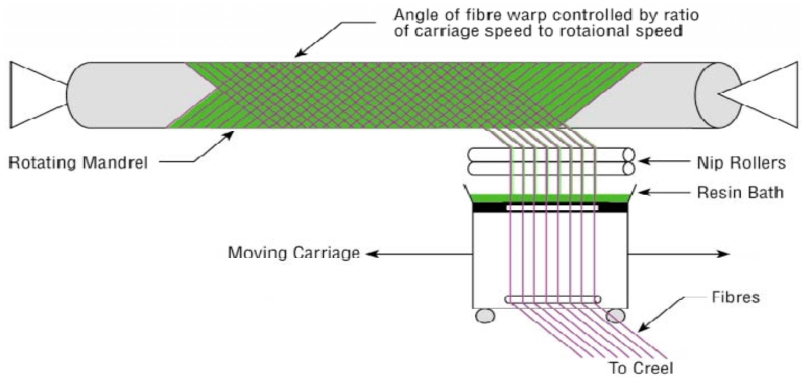
Typical Applications:

Large, one-off cruising boats, race car components, core-bonding in production boats.

4. Filament Winding

Description

This process is primarily used for hollow, generally circular or oval sectioned components, such as pipes and tanks. Fiber tows are passed through a resin bath before being wound onto a mandrel in a variety of orientations, controlled by the fiber feeding mechanism, and rate of rotation of the mandrel.



Materials Options:

Resins: Any, i.e. epoxy, polyester, vinyl ester and phenolic.

Fibers: Any. The fibers are used straight from a creel and not woven or stitched into a fabric form.

Cores: Any, although components are usually single skin.

Main Advantages:

i) This can be a very fast and therefore economic method of laying material down.

ii) Resin content can be controlled by metering the resin onto each fiber tow through nips or dies.

iv) Fiber cost is minimized since there is no secondary process to convert fiber into fabric prior to use.

1. Structural properties of laminates can be very good since straight fibers can be laid in a complex pattern to match the applied loads.

Main Disadvantages:

i) The process is limited to convex shaped components.

ii) Fiber cannot easily be laid exactly along the length of a component.

iii) Mandrel costs for large components can be high.

v) The external surface of the component is unmolded, and therefore cosmetically unattractive.

2. Low viscosity resins usually need to be used with their attendant lower mechanical and health and safety properties.

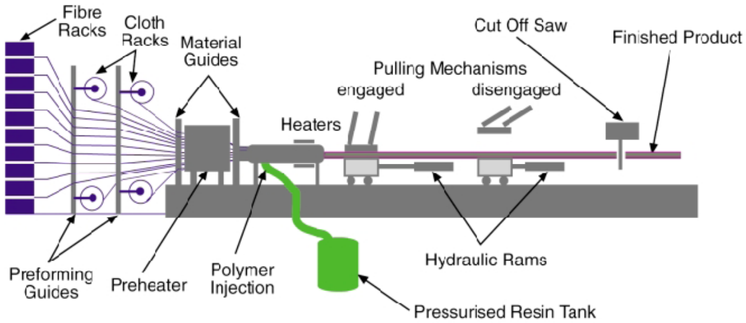
Typical Applications:

Chemical storage tanks and pipelines, gas cylinders, fire-fighters breathing tanks.

5. Pultrusion

Description

Fibers are pulled from a creel through a resin bath and then on through a heated die. The die completes the impregnation of the fiber, controls the resin content and cures the material into its final shape as it passes through the die. This cured profile is then automatically cut to length. Fabrics may also be introduced into the die to provide fiber direction other than at 0°. Although pultrusion is a continuous process, producing a profile of constant cross-section, a variant known as 'pulforming' allows for some variation to be introduced into the cross-section. The process pulls the materials through the die for impregnation, and then clamps them in a mould for curing. This makes the process non-continuous, but accommodating of small changes in cross-section.



Materials Options:

Resins: Generally epoxy, polyester, vinyl ester and phenolic.

Fibers: Any.

Cores: Generally not used.

Main Advantages:

i) This can be a very fast, and therefore economic, way of impregnating and curing materials.

ii) Resin content can be accurately controlled.

iii) Fiber cost is minimized since the majority is taken from a creel.

iv) Structural properties of laminates can be very good since the profiles have very straight fibers and high fiber volume fractions can be obtained.

vi) Resin impregnation area can be enclosed thus limiting volatile emissions.

Main Disadvantages:

i) Limited to constant or near constant cross-section components.

ii) Heated die costs can be high.

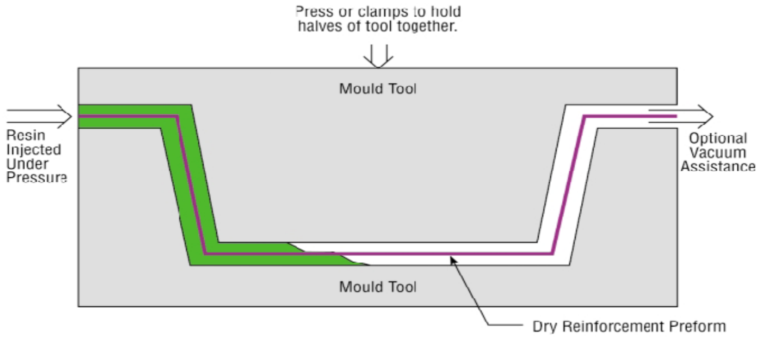
Typical Applications:

Beams and girders used in roof structures, bridges, ladders, frameworks.

6. Resin Transfer Molding (RTM)

Description

Fabrics are laid up as a dry stack of materials. These fabrics are sometimes pre-pressed to the mould shape, and held together by a binder. These "performs" are then more easily laid into the mould tool. A second mould tool is then clamped over the first, and resin is injected into the cavity. Vacuum can also be applied to the mould cavity to assist resin in being drawn into the fabrics. This is known as Vacuum Assisted Resin Injection (VARI). Once all the fabric is wet out, the resin inlets are closed, and the laminate is allowed to cure. Both injection and cure can take place at either ambient or elevated temperature.



Materials Options:

Resins: Generally epoxy, polyester, vinyl ester and phenolic, although high temperature resins such as bismaleimides can be used at elevated process temperatures.

Fibers: Any. Stitched materials work well in this process since the gaps allow rapid resin transport. Some specially developed fabrics can assist with resin flow.

Cores: Not honeycombs, since cells would fill with resin, and pressures involved can crush some foams.

Main Advantages:

i) High fiber volume laminates can be obtained with very low void contents.

ii) Good health and safety, and environmental control due to enclosure of resin.

iii) Possible labor reductions.

iv) Both sides of the component have a moulded surface.

Main Disadvantages:

i) Matched tooling is expensive and heavy in order to withstand pressures.

ii) Generally limited to smaller components.

iii) Un-impregnated areas can occur resulting in very expensive scrap parts.

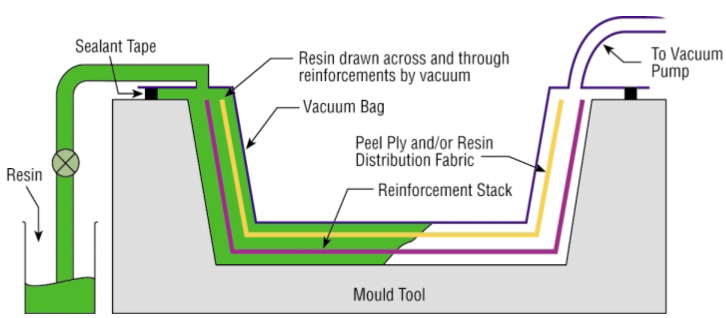
Typical Applications:

Small complex aircraft and automotive components, train seats, etc.

7. Other Infusion Processes - SCRIMP, RIFT, VARTM etc.

Description:

Fabrics are laid up as a dry stack of materials as in RTM. The fiber stack is then covered with peel ply and a knitted type of non-structural fabric. The whole dry stack is then vacuum bagged, and once bag leaks have been eliminated, resin is allowed to flow into the laminate. The resin distribution over the whole laminate is aided by resin flowing easily through the non-structural fabric, and wetting the fabric out from above.



Materials Options:

Resins: Generally epoxy, polyester and vinylester.

Fibers: Any conventional fabrics. Stitched materials work well in this process since the gaps allow rapid resin transport.

Cores: Any except honeycombs.

Main Advantages:

i) As RTM above, except only one side of the component has a molded finish.

ii) Much lower tooling cost due to one half of the tool being a vacuum bag, and less strength being required in the main tool.

iii) Large components can be fabricated.

iv) Standard wet lay-up tools may be able to be modified for this process.

v) Cored structures can be produced in one operation.

Main Disadvantages:

i) Relatively complex process to perform well.

ii) Resins must be very low in viscosity, thus comprising mechanical properties.

iii) Un-impregnated areas can occur resulting in very expensive scrap parts.

iv) Some elements of this process are covered by patents (SCRIMP).

Typical Applications:

Semi-production small yachts, train and truck body panels.

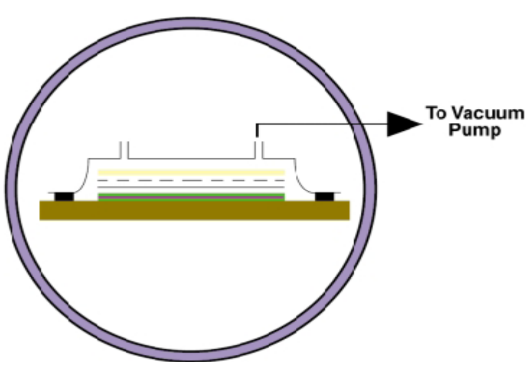
8. Prepregs

Description

Fabrics and fibers are pre-impregnated by the materials manufacturer, under heat and pressure or with solvent, with a pre-catalysed resin. The catalyst is largely latent at ambient temperatures giving the materials several weeks, or sometimes months, of useful life when defrosted. However to prolong storage life the materials are stored frozen.

The resin is usually a near-solid at ambient temperatures, and so the pre-impregnated materials (prepregs) have a light sticky feel to them, such as that of adhesive tape. Unidirectional materials take fiber direct from a creel, and are held together by the resin alone.

The prepregs are laid up by hand or machine onto a mould surface, vacuum bagged and then heated to typically 120-180°C. This allows the resin to initially reflow and eventually to cure. Additional pressure for the molding is usually provided by an autoclave (effectively a pressurised oven) which can apply up to 5 atmospheres to the laminate.



Materials Options:

Resins: Generally epoxy, polyester, phenolic and high temperature resins such as polyimides, cyanate esters and bismaleimides.

Fibers: Any. Used either direct from a creel or as any type of fabric.

Cores: Any, although special types of foam need to be used due to the elevated temperatures involved in the process.

Main Advantages:

i) Resin/catalyst levels and the resin content in the fiber are accurately set by the materials manufacturer. High fiber contents can be safely achieved.

ii) The materials have excellent health and safety characteristics and are clean to work with.

iii) Fiber cost is minimized in unidirectional tapes since there is no secondary process to convert fiber into fabric prior to use.

iv) Resin chemistry can be optimised for mechanical and thermal performance, with the high viscosity resins being impregnable due to the manufacturing process.

v) The extended working times (of up to several months at room temperatures) means that structurally optimized, complex lay-ups can be readily achieved.

v) Potential for automation and labor saving.

Main Disadvantages:

i) Materials cost is higher for pre-impregnated fabrics.

ii) Autoclaves are usually required to cure the component. These are expensive, slow to operate and limited in size.

iii) Tooling needs to be able to withstand the process temperatures involved.

iv) Core materials need to be able to withstand the process temperatures and pressures.

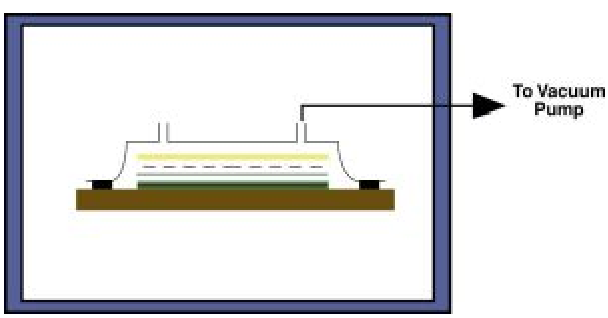
Typical Applications:

Aircraft structural components (e.g. wings and tail sections), F1 racing cars, sporting goods such as tennis racquets and skis.

8.1 Low Temperature \ Oven Curing Prepregs

Description

Low temperature curing prepregs are made exactly as conventional prepregs but have resin chemistries that allow cure to be achieved at temperatures from 60-100°C. The flow profiles of the resin systems allow for the use of vacuum bag pressures alone, avoiding the need for autoclaves.



Materials Options:

Resins: Generally only epoxy.

Fibers: Any, as for conventional prepregs.

Cores: Any, although standard PVC foam needs special care.

Main Advantages:

i) All of the advantages ((i)-(vi)) associated with the use of conventional prepregs are incorporated in low-temperature curing prepress.

ii) Cheaper tooling materials, such as wood, can be used due to the lower cure temperatures involved.

iii) Large structures can be readily made since only vacuum bag pressure is required, and heating to these lower temperatures can be achieved with simple hot-air circulated ovens, often built in-situ over the component.

iv) Conventional PVC foam core materials can be used, providing certain procedures are followed.

v) Lower energy cost.

Main Disadvantages:

i) Materials cost is still higher than for un-impregnated fabrics.

ii) An oven and vacuum bagging system is required to cure the component.

iii) Tooling needs to be able to withstand above-ambient temperatures involved (typically 60-100°C).

iv) Still an energy cost associated with above-ambient cure temperature.

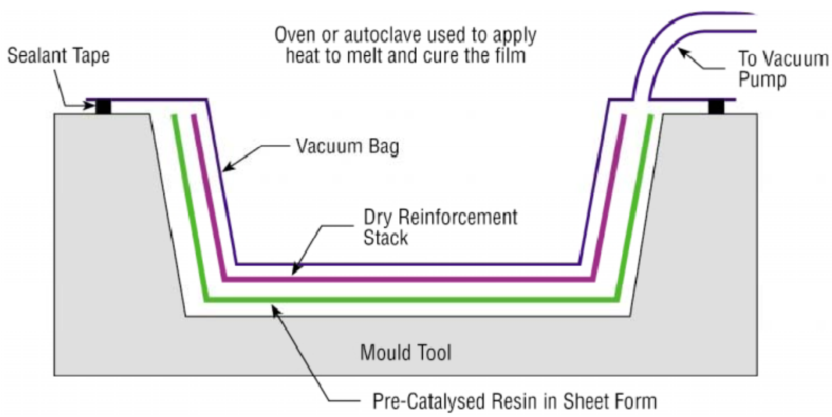
Typical Applications:

High-performance wind-turbine blades, large racing and cruising yachts, rescue craft, train components.

9. Resin Film Infusion (RFI)

Description:

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.



Materials Options:

Resins: Generally epoxy only.

Fibers: Any.

Cores: Most, although PVC foam needs special procedures due to the elevated temperatures involved in the process.

Main Advantages:

i) High fiber volumes can be accurately achieved with low void contents.

ii) Good health and safety and a clean lay-up, like prepreg.

iii) High resin mechanical properties due to solid state of initial polymer material and elevated temperature cure.

iv) Potentially lower cost than prepreg, with most of the advantages.

v) Less likelihood of dry areas than SCRIMP process due to resin travelling through fabric thickness only.

Main Disadvantages:

i) Not widely proven outside the aerospace industry.

ii) An oven and vacuum bagging system is required to cure the component as for prepreg, although the autoclave systems used by the aerospace industry are not always required.

iii) Tooling needs to be able to withstand the process temperatures of the resin film (which if using similar resin to those in low-temperature curing prepregs, is typically 60-100°C).

iv) Core materials need to be able to withstand the process temperatures and pressures.

Typical Applications:

Aircraft radomes and submarine sonar domes.