COMPOSITE MATERIALS DESIGN

3 Manufacturing processes

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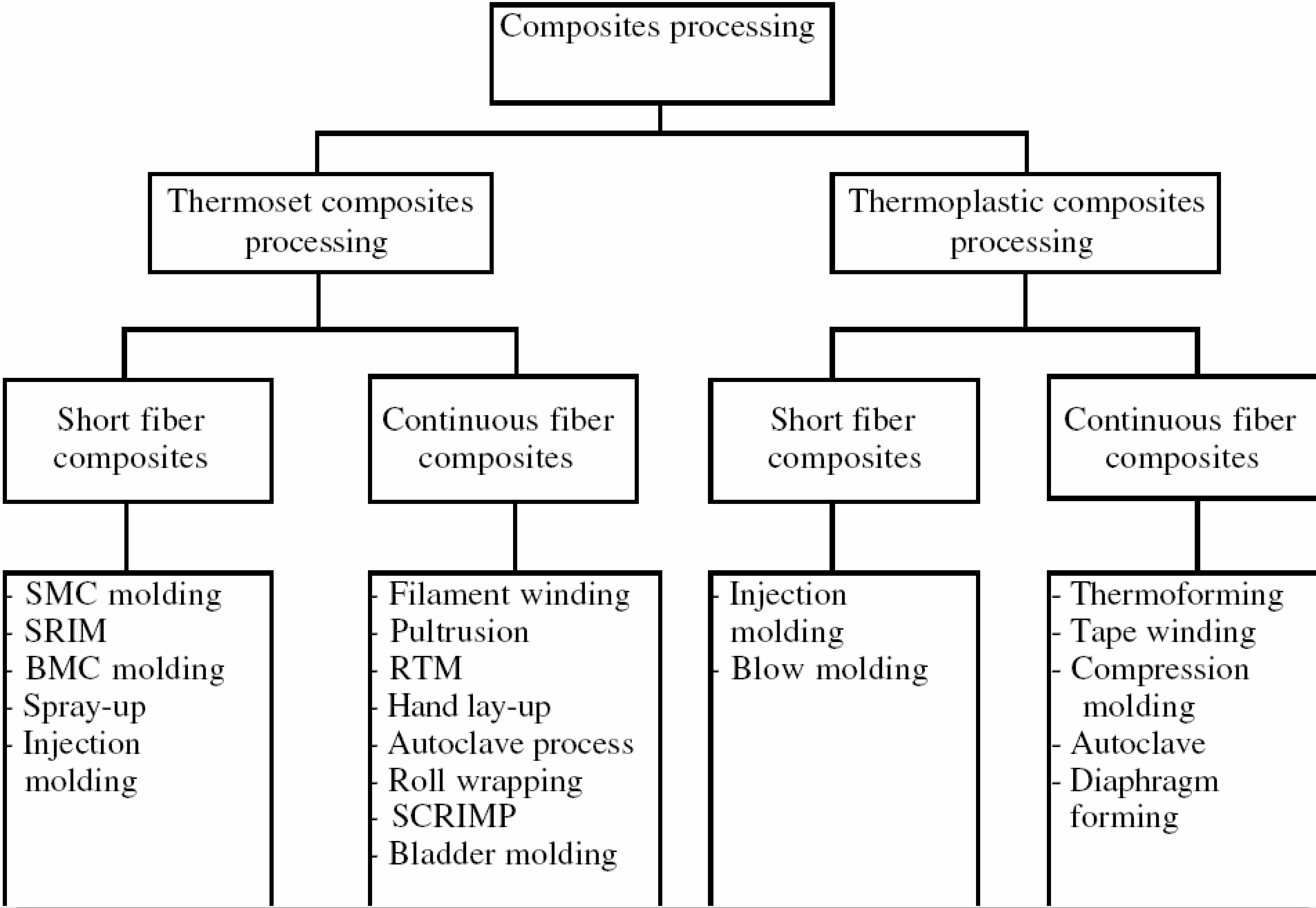
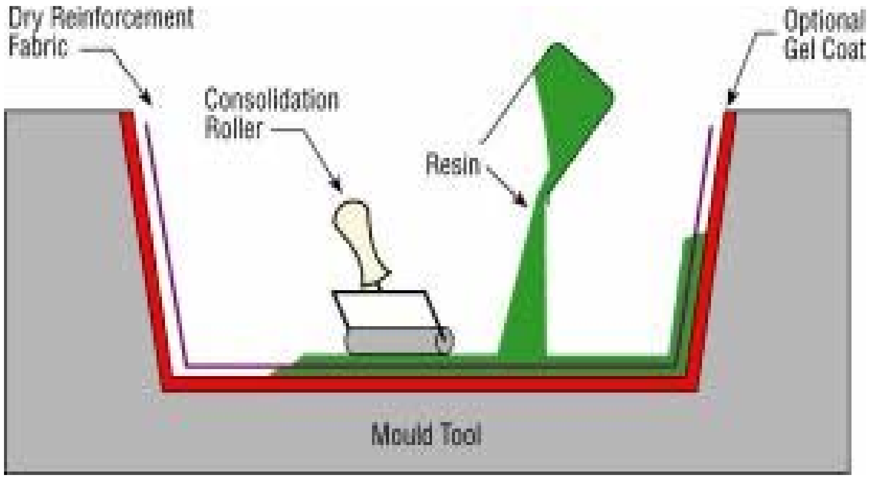

Composites processing
Thermoset composites processing
Thermoplastic composites processing
Short fiber composites
Continuous fiber composites
Short fiber composites
Continuous fiber composites
- SMC molding
- SRIM
- BMC molding
- Spray-up
- Injection molding
- Filament winding
- Pultrusion
- RTM
- Hand lay-up
- Autoclave process
- Roll wrapping
- SCRIMP
- Bladder molding
- Injection molding
- Blow molding
- Thermoforming
- Tape winding
- Compression molding
- Autoclave
- Diaphragm forming

Outline

- wet lay up – hand lay up
- spray lay up
- Vacuum Bagging
- Filament Winding
- Pultrusion
- Resin Transfer Moulding (RTM)
- Other Infusion Processes - SCRIMP, RIFT, VARTM
- Prepreg Moulding (SMC)
- Resin Film Infusion (RFI)

wet lay up – hand lay up



Resins are impregnated by hand into fibres which are in the form of 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.

wet lay up – hand lay up

- Advantages: i) Widely used for many years. ii) Simple principles to teach. iii) Low cost tooling, if room-temperature cure resins are used. iv) Wide choice of suppliers and material types. v) Higher fibre contents, and longer fibres than with spray lay-up.

- 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 molecular weights 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 vinylesters 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 diluent/styrene levels.

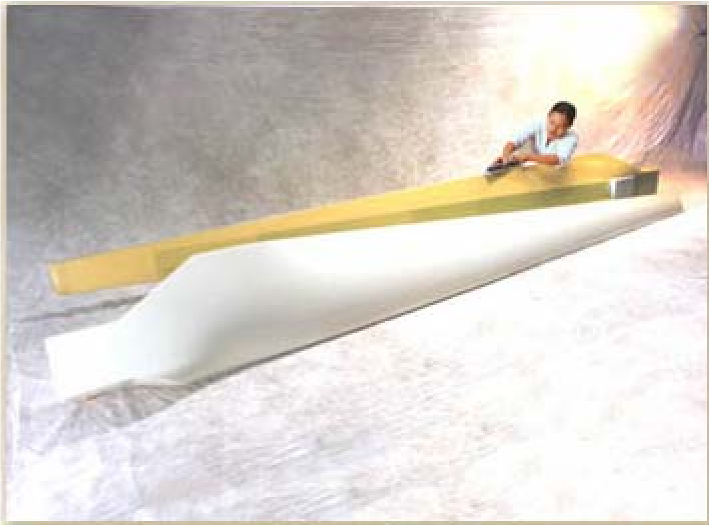
- Typical Applications: Standard wind-turbine blades, production boats, architectural mouldings.

wet lay up – hand lay up

Hand lay up to make the preformed racket

wet lay up – hand lay up

wind-turbine blades,



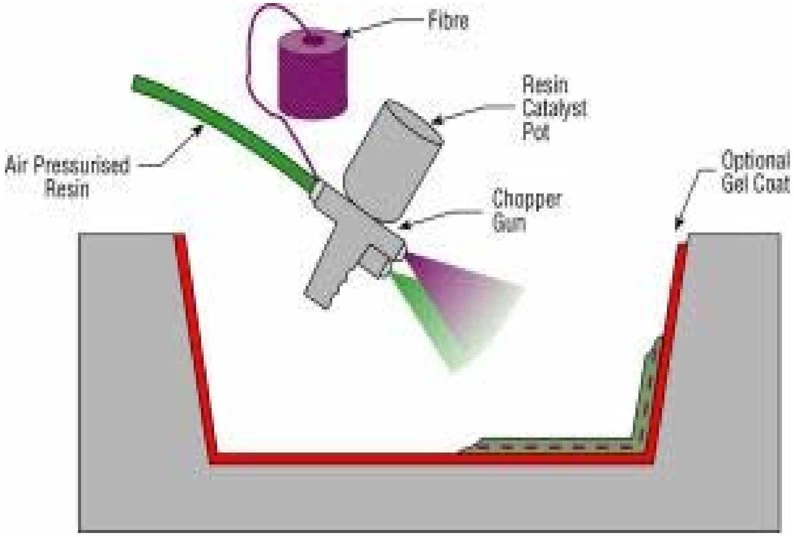
Flapwise fatigue tests of 3 blades running at the Sparkær Centre Blade Test Facilities.

wet lay up – hand lay up

manufa
proc

The "Automated Composite Layup & Spray-Up" program focuses on the various automated processes and equipment developed to manufacture composite products of high quality. The use of CNC gantry ply-cutters, robots, tape lamination machines and fiber placement machines are among the automated technologies detailed.

spray lay up

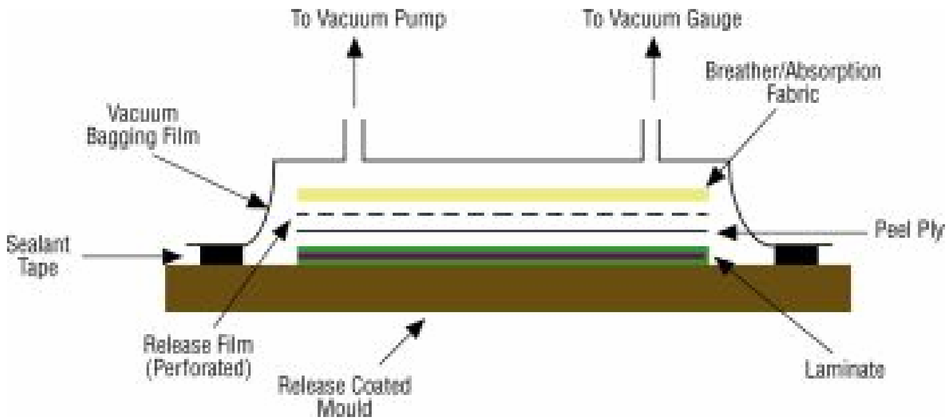


Fibre is chopped in a hand-held gun and fed into a spray of catalysed resin directed at the mould. The deposited materials are left to cure under standard atmospheric conditions.

spray lay up

- Advantages: Low cost way of quickly depositing fibre and resin. Low cost tooling. Widely used for many years.
- Disadvantages: i) Laminates tend to be very resin-rich and therefore excessively heavy. ii) Only short fibres 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, volatility.
- Typical Applications: sample enclosures, lightly loaded structural panels, e.g. caravan bodies, truck fairings, bathtubs, shower trays, some small dinghies.

Vacuum Bagging



This is basically an extension of the wet lay-up process 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.

Vacuum Bagging

- Materials Options: Resins: Primarily epoxy and phenolic. Polyesters and vinylesters may have problems due to excessive extraction of styrene from the resin by the vacuum pump.
  Fibres: The consolidation pressures mean that a variety of heavy fabrics can be wet-out.

- Advantages: i) Higher fibre 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 fibre wet-out due to pressure and resin flow throughout structural fibres, with excess into bagging materials. iv) Health and safety: The vacuum bag reduces the amount of volatiles emitted during cure.

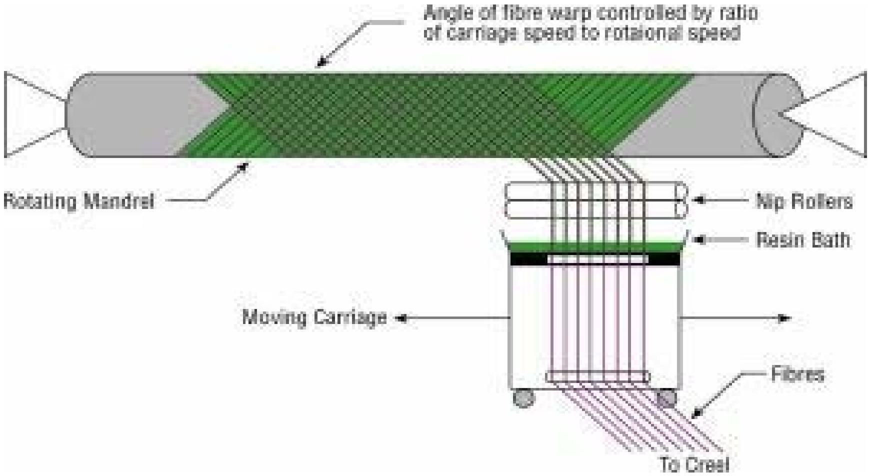
- Disadvantages: i) The extra process adds cost both in labour and in disposable bagging materials ii) A higher level of skill is required by the operators iii) Mixing and control of resin content still largely determined by operator skill

- Typical Applications: Large, one-off cruising boats, racecar components, core-bonding in production boats.

Vacuum Bagging

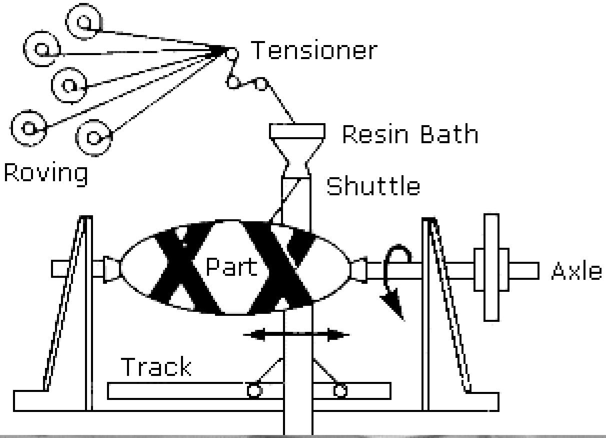
The "Liquid Molding" program encompasses several process variations of typically low-viscosity resin systems which are used in the production of detailed, high quality composite parts. Just a few of the liquid molding processes featured includes: resin transfer molding and vacuum infusion. The use of preformed reinforcement materials is also featured.

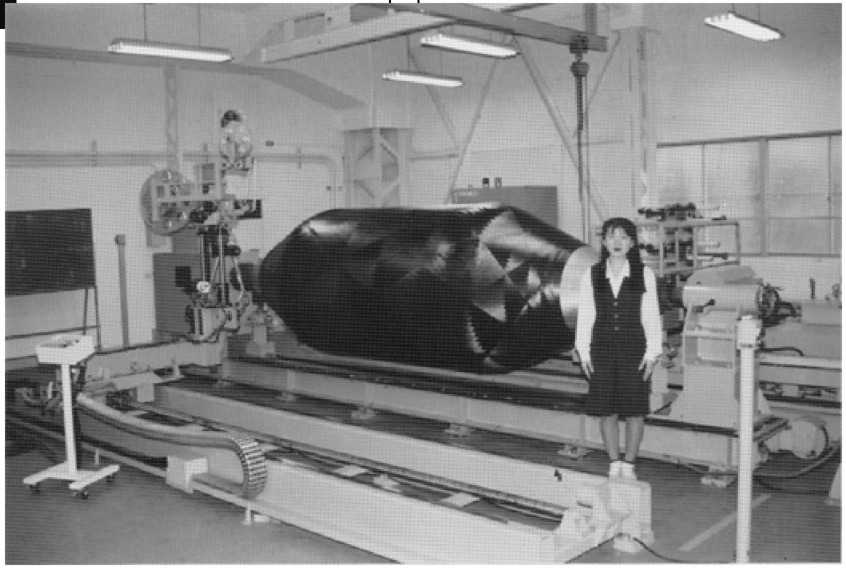
Filament Winding



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

Filament Winding





Filament Winding

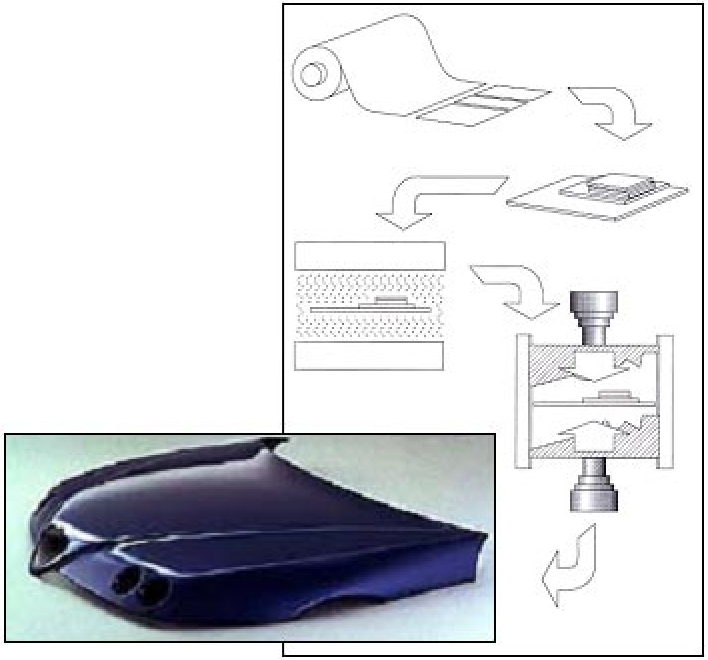


figure 2.13: Sheet moulding of a Alfa Romeo car hood

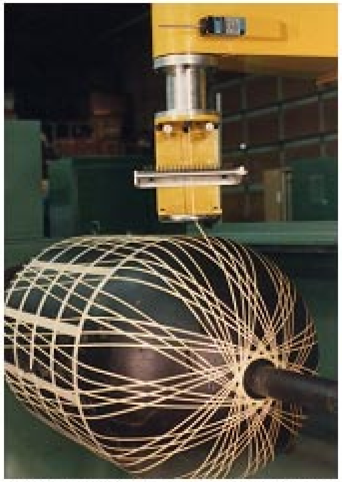


figure 2.14: Filament winding

figure 2.15: Composite LPG container vessel

Filament Winding

manufacturing processes

- Materials Options: Resins: Any, e.g. epoxy, polyester, vinylester, phenolic.
  Fibres: The fibres are used straight from a creel and not woven or stitched into a fabric form.

- 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 fibre tow through nips or dies. iii) Fibre cost is minimised since there is no secondary process to convert fibre into fabric prior to use. iv) Structural properties of laminates can be very good since straight fibres can be laid in a complex pattern to match the applied loads.

- Disadvantages: i) The process is limited to convex shaped components. ii) Fibre cannot easily be laid exactly along the length of a component. iii) Mandrel costs for large components can be high. iv) The external surface of the component is unmoulded, and therefore cosmetically unattractive. v) 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.

manufacturing processes

Filament Winding Applications

Hydraulic Accumulators and Pressure Vessels

advanced composite pressure vessels and hydraulic accumulators for a range of aerospace applications, meeting specific aerospace standards.

manufacturing processes

Filament Winding applications

Medical Imaging and Cryogenic Applications

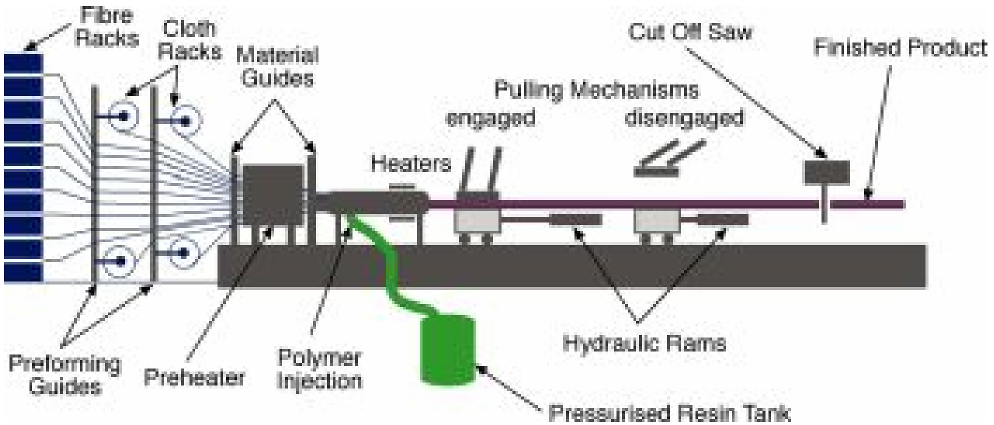
Computerized Axial Termography

High performance composite products to the medical imaging and cryogenic industries.

Filament winding

The "Filament Winding" program examines both the wet winding and dry winding processes. The primary types of filament winding methods are detailed including: hoop winding and helical winding. This program also features an in-depth look at the types and uses of filament winding mandrels.

Pultrusion



Fibres are pulled from a creel through a resin bath and then on through a heated die. The die completes the impregnation of the fibre, 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 fibre 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.

Pultrusion

manufacturing processes

- Materials Options: Resins: Generally epoxy, polyester, vinylester and phenolic.
  Fibres: any

- 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) Fibre cost is minimised since the majority is taken from a creel. iv) Structural properties of laminates can be very good since the profiles have very straight fibres and high fibre volume fractions can be obtained. v) Resin impregnation area can be enclosed thus limiting volatile emissions.

- Disadvantages: i) Limited to constant or near constant cross-section components, ii) Heated die costs can be high.

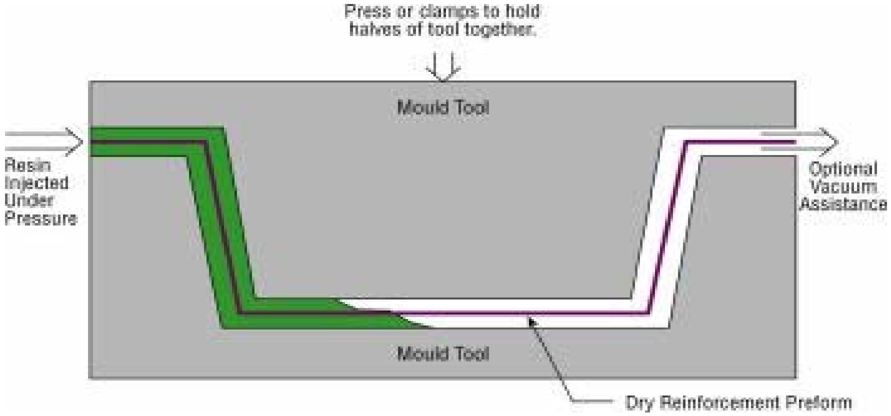
- Typical Applications: Beams and girders used in roof structures, bridges, ladders, frameworks.

Pultrusion

The "Pultrusion" program details the high-throughput, continuous pultrusion process. The reinforcement materials used to produce pultrusions are followed step by step through the process-- from resin saturation and impregnation, preforming, shaping, curing, and cut to length sawing.

Resin Transfer Moulding (RTM) - Vacuum Assisted Resin Injection (VARI)

manufacturing processes



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 'preforms' 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.

Resin Transfer Moulding (RTM)

- Materials Options: Resins: Generally epoxy, polyester, vinylester and phenolic, although high temperature resins such as bismaleimides can be used at elevated process temperatures. . Fibres: Stitched materials work well in this process since the gaps allow rapid resin transport. Some specially developed fabrics can assist with resin flow**.**

- Advantages: i) High fibre 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 labour reductions. iv) Both sides of the component have a moulded surface.

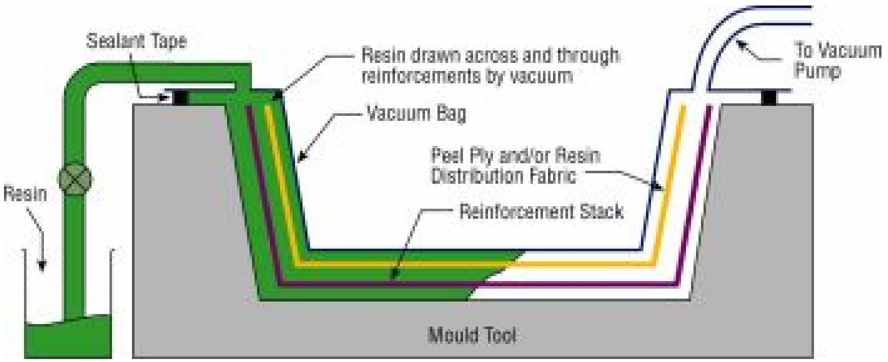
- Disadvantages: i) Matched tooling is expensive, and heavy in order to withstand pressures. ii) Generally limited to smaller components. iii) Unimpregnated areas can occur resulting in very expensive scrap parts.

- Typical Applications: Small complex aircraft and automotive components, train seats.

manufacturing processes

Other Infusion Processes –

SCRIMP (Seemann Composite Resin Infusion Molding Process),
RFI (Resin Film Infusion)
VARTM (Vacuum Assisted Resin Transfer Molding)



Fabrics are laid up as a dry stack of materials as in RTM. The fibre 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. .

Other Infusion Processes - SCRIMP, RIFT, VARTM

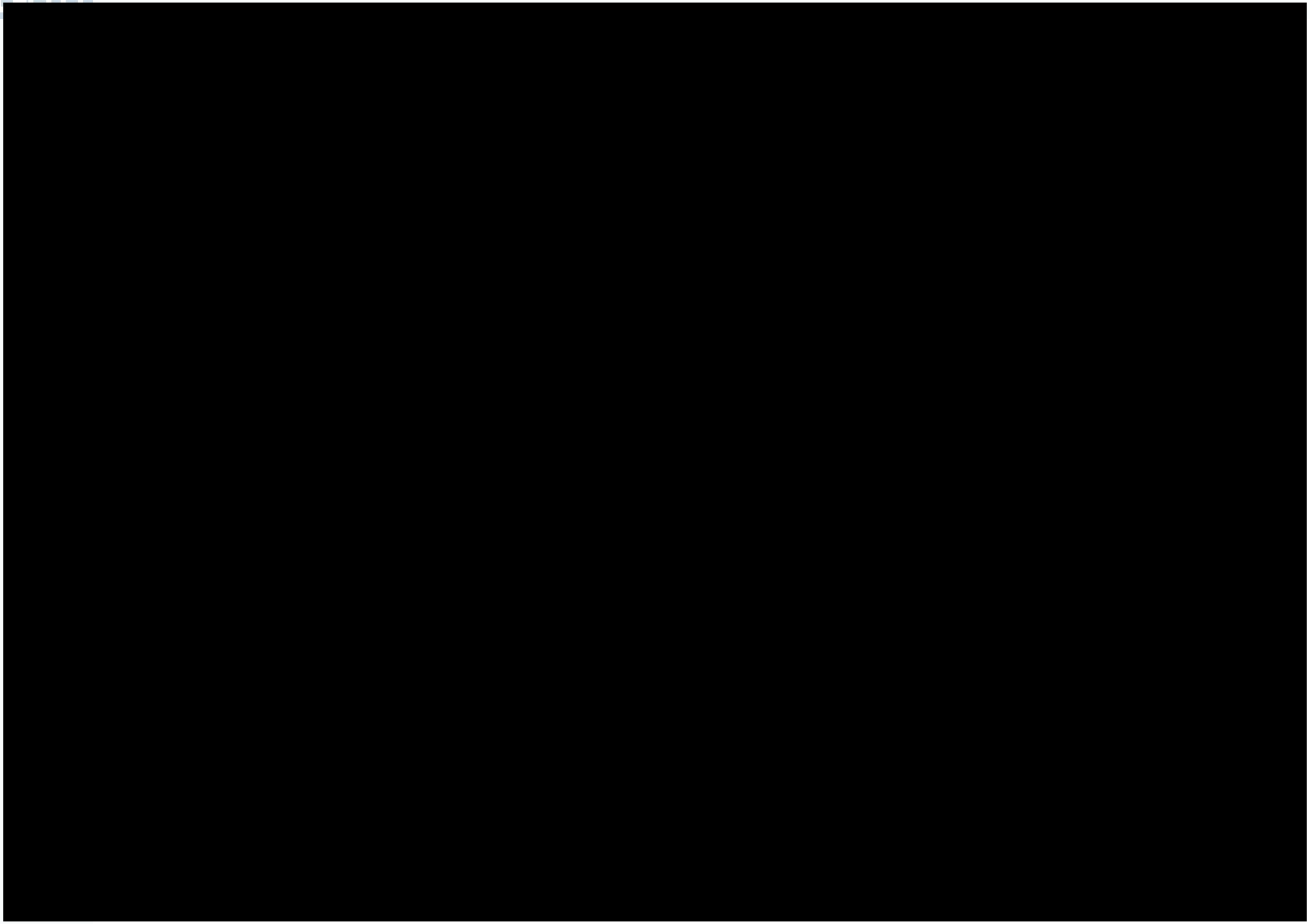
- Materials Options: Resins: Generally epoxy, polyester and vinylester.
  Fibres: Any conventional fabrics. Stitched materials work well in this process since the gaps allow rapid resin transport.

- Advantages: i) As RTM above, except only one side of the component has a moulded 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.

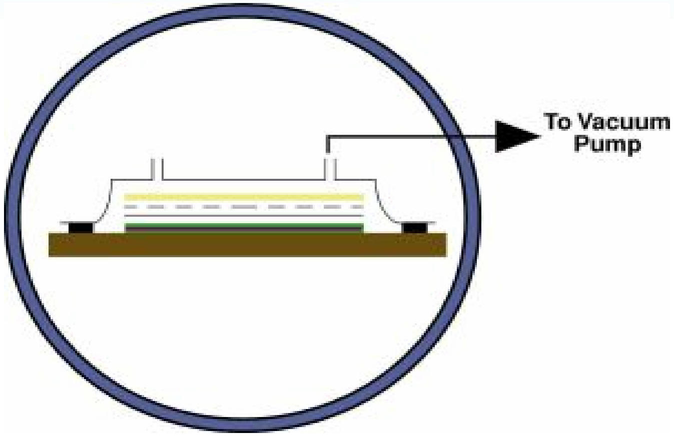
- Disadvantages: i) Relatively complex process to perform well. ii) Resins must be very low in viscosity, thus comprising mechanical properties. iii) Unimpregnated areas can occur resulting in very expensive scrap parts. iv) Some elements of this process are covered by patents (SCRIMP).

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

SCRIMP (Seemann Composite Resin Infusion Molding Process)



Prepreg Moulding (SMC)



Fabrics and fibres 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 fibre 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 moulding is usually provided by an autoclave (effectively a pressurised oven) which can apply up to 5 atmospheres to the laminate.

Prepreg Moulding

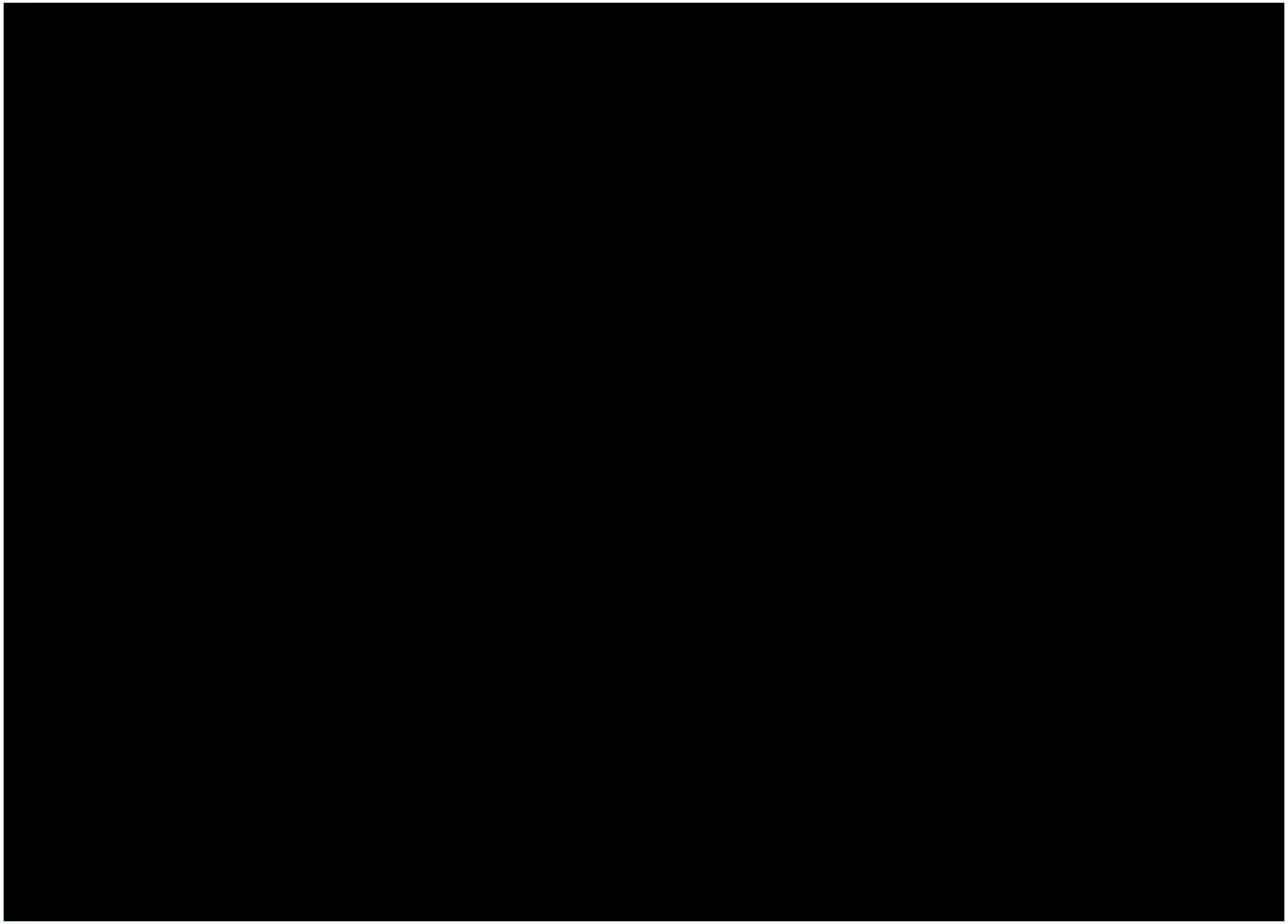
- Materials Options: Resins: Generally epoxy, polyester, phenolic and high temperature resins such as polyimides, cyanate esters and bismaleimides. .
  Fibres: Used either direct from a creel or as any type of fabric.

- Advantages: i) Resin/catalyst levels and the resin content in the fibre are accurately set by the materials manufacturer. High fibre contents can be safely achieved. ii) The materials have excellent health and safety characteristics and are clean to work with. iii) Fibre cost is minimised in unidirectional tapes since there is no secondary process to convert fibre 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 optimised, complex lay-ups can be readily achieved. vi) Potential for automation and labour saving.

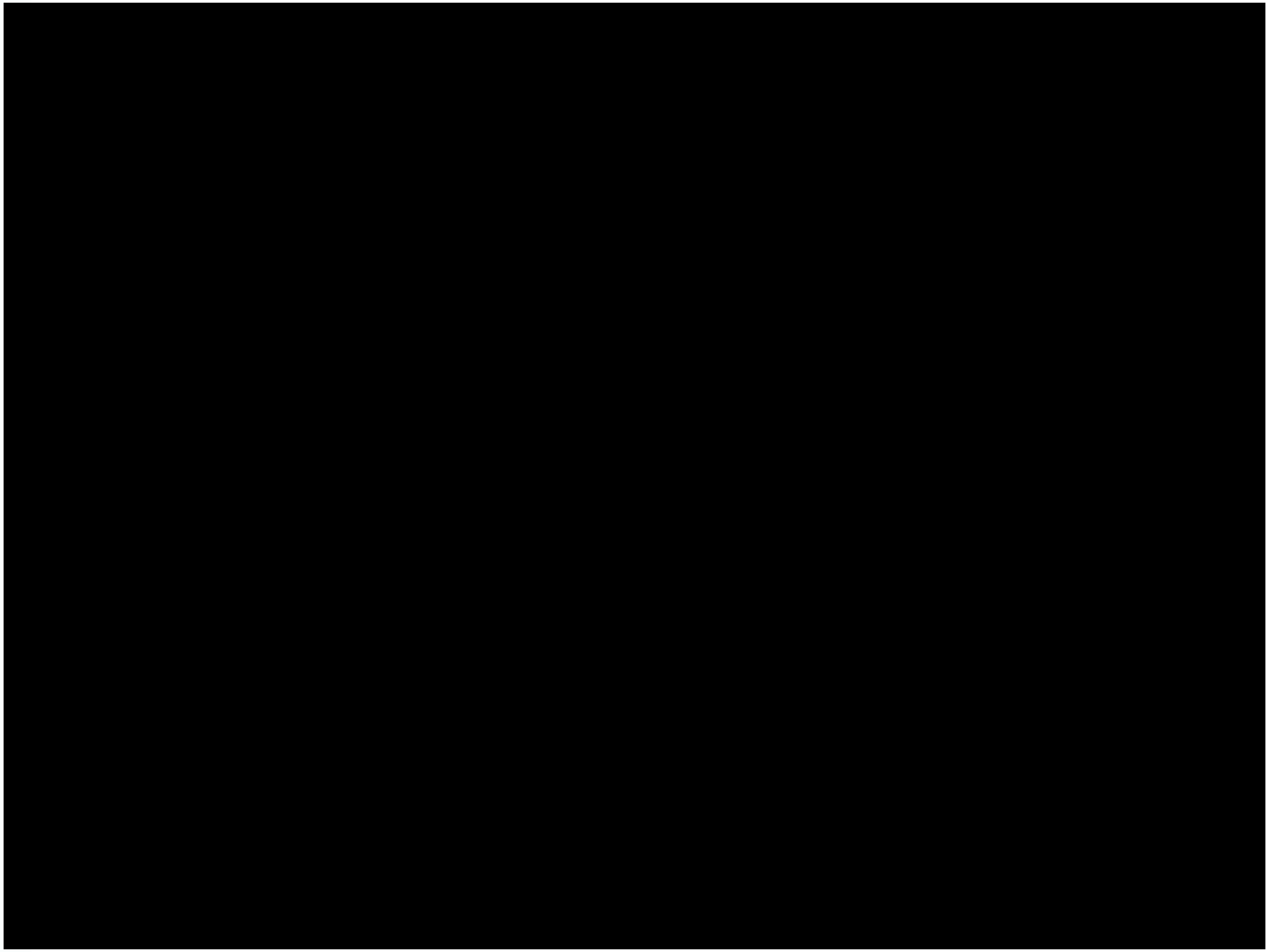
- Disadvantages: Materials cost is higher for preimpregnated fabrics. ii) Autoclaves are usually required to cure the component. These are expensive, slow to operate and limited in size. iii) Tooling needs to be able to withstand the process temperatures involved. iv) Core materials need to be able to 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.

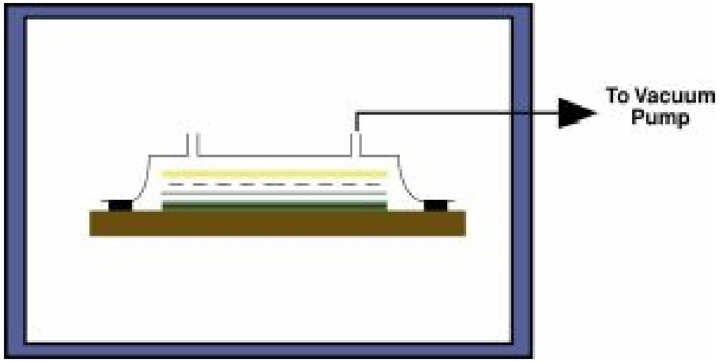
Sheet Molding Compound



Prepreg (SMC)



Low Temperature Prepreg Moulding (SMC)



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. At 60°C, the working life of the material may be limited to as little as a week, but above this working times can be as long as several months. The flow profiles of the resin systems allow for the use of vacuum bag pressures alone, avoiding the need for autoclaves.

Low Temperature Prepreg Moulding

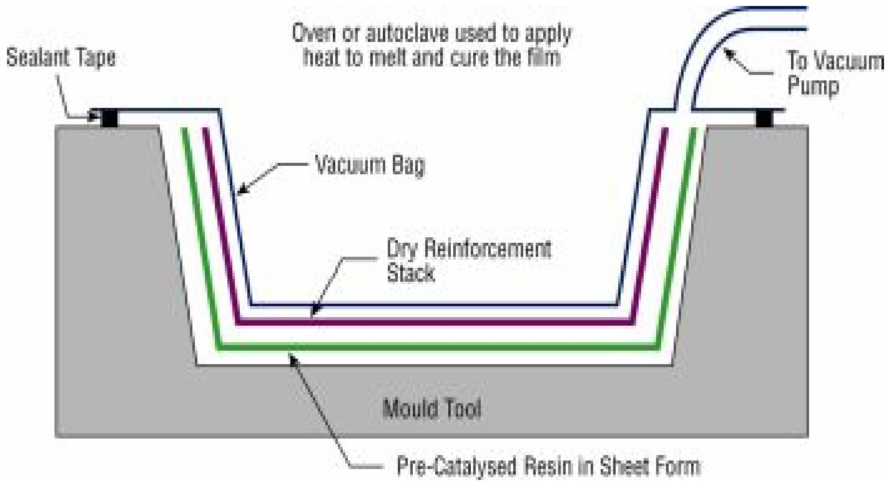
- Materials Options: Resins: Generally only epoxy.
  Fibres: As for conventional prepregs.

- Advantages: i) All of the advantages ((i)-(vi)) associated with the use of conventional prepregs are incorporated in low-temperature curing prepregs. i) Cheaper tooling materials, such as wood, can be used due to the lower cure temperatures involved. ii) 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.) Lower energy cost.

- Disadvantages:i) Materials cost is still higher than for non-preimpregnated 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.

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.

Resin Film Infusion (RFI)

- Materials Options: Resins: Generally epoxy only.
  Fibres: Any

- Advantages: i) High fibre 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.

- 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.

TABLE 6.1

Manufacturing Process Selection Criteria

Process	Production Speed	Cost	Strength	Size	Shape	Raw Material
Filament winding	Slow to fast	Low to high	High	Small to large	Cylindrical and axisymmetric	Continuous fibers with epoxy and polyester resins
Pultrusion	Fast	Low to medium	High (along longitudinal direction)	No restriction on length; small to medium size cross-section	Constant cross-section	Continuous fibers, usually with polyester and vinylester resins
Hand lay-up	Slow	High	High	Small to large	Simple to complex	Prepreg and fabric with epoxy resin
Wet lay-up	Slow	Medium	Medium to high	Medium to large	Simple to complex	Fabric/mat with polyester and epoxy resins
Spray-up	Medium to fast	Low	Low	Small to medium	Simple to complex	Short fiber with catalyzed resin
RTM	Medium	Low to medium	Medium	Small to medium	Simple to complex	Preform and fabric with vinylester and epoxy
SRIM	Fast	Low	Medium	Small to medium	Simple to complex	Fabric or preform with polyisocyanurate resin
Compression molding	Fast	Low	Medium	Small to medium	Simple to complex	Molded compound (e.g., SMC, BMC)
Stamping	Fast	Medium	Medium	Medium	Simple to contoured	Fabric impregnated with thermoplastic (tape)
Injection molding	Fast	Low	Low to medium	Small	Complex	Pallets (short fiber with thermoplastic)
Roll wrapping	Medium to fast	Low to medium	High	Small to medium	Tubular	Prepregs

COMPARATIVE STUDY

TECHNOLOGIES TO PRODUCE ADVANCED COMPOSITE STRUCTURES WITH THERMOSET MATRIX						
THERMOSET MATRIX & FIBER	**Pallet**	**Wet Impregnation**	**Long Fiber**	**Short Fiber 1 to 50 m/m**	**Pre-preg with Thermoset Resin**	**Sheet Transformation**
Hand Lay Up Autoclave		Yes	Yes	No	Yes	
Lay up Resin and Fiber by Projection		Yes	No	Yes	No	
Molding with Press		Yes	Yes	Yes	Yes	
Hand lay up with Oven		Yes	Yes	Yes	Yes	
Compression Molding BMC		No	No	Yes	Yes	
Compression Molding SMC		No	No	Yes	Yes	
Filament Winding		Yes	Yes	No	Yes	
RTM (Resin Transfer Molding)		Yes	Yes	No	No	
Pultrusion		Yes	Yes	No	Yes	
Rotomolding		Yes	Yes	Yes	No	
Braiding		Yes, After Braiding	Yes	No	Yes	
Continuous Lamination		Yes	Yes	No	Yes	Yes

Fet

COMPARATIVE STUDY

TECHNOLOGIES TO PRODUCE ADVANCED COMPOSITE STRUCTURES WITH THERMOPLASTIC MATRIX						
Thermoplastic Matrix & Fiber	**Pallet**	**Wet Impregnation**	**Long Fiber**	**Short Fiber**	**Pre-preg with Thermo-plastic Resin**	**Sheet Transformation**
Thermoplastic Injection	Yes	No	No	Yes	Yes	
Filament Winding		No	Yes		Yes	
Pultrusion		No	Yes		Yes	
Compression Molding	Yes	No	Yes	Yes	Yes	Sheet
Vacuum Forming		No	No	Yes	Yes	Sheet Only
Braiding		No	Yes	No	Yes	
Continuous Press Lamination		No	Yes	Yes	Yes	Yes
Extrusion	Yes	No	No	Yes	Yes	Sheet

The thermoplastic foam and thermoplastic matrix material, after being produced in a block, sheet or other shape, can be thermoformed again and again and are easy to recycle.

This is the main difference between the thermoplastic resin and the Thermoset resin. Thermoset resin, after curing, cannot be reshaped and is very hard to recycle.

Cutting Tool Materials

This video examines the wide variety of cutting tools and tool materials, from high speed steel and carbide to superhand materials. Whether you are using standard tools or tools designed and built for a special machining job, you'll learn about the selection criteria needed to help identify the first tool material to consider and when to consider superhard materials.