COMPOSITES MANUFACTURING PROCESSES

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Processes

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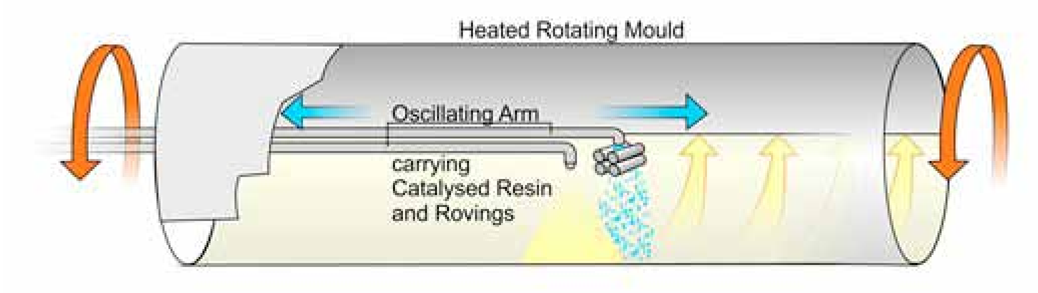
Centrifugal Moulding

Centrifugal casting is used for the manufacture of hollow tubes, usually pipes. The pipes made using this process have lower mechanical properties than those that are filament wound. The fibreglass laminate is laid inside the hollow cylindrical moulds, and the laminate is consolidated by centrifugal force.



Allnex Products Commonly Used:

- Customised multi-end roving
- Resin (UPE, vinyl ester or epoxy)
- Catalyst

Steps

1. The preheated cylindrical mould spins at a pre-determined rotational speed.

2. A horizontal boom holding feed lines and a chopper head oscillates back and forth along the length of the cylindrical mould, laying programmed quantities[1] of catalysed resin, chopped glass and sand.

3. Once the required layers of raw materials are in place, the speed of rotation is increased to compact the laminate. Heating is then applied as required to complete the cure of the laminate.

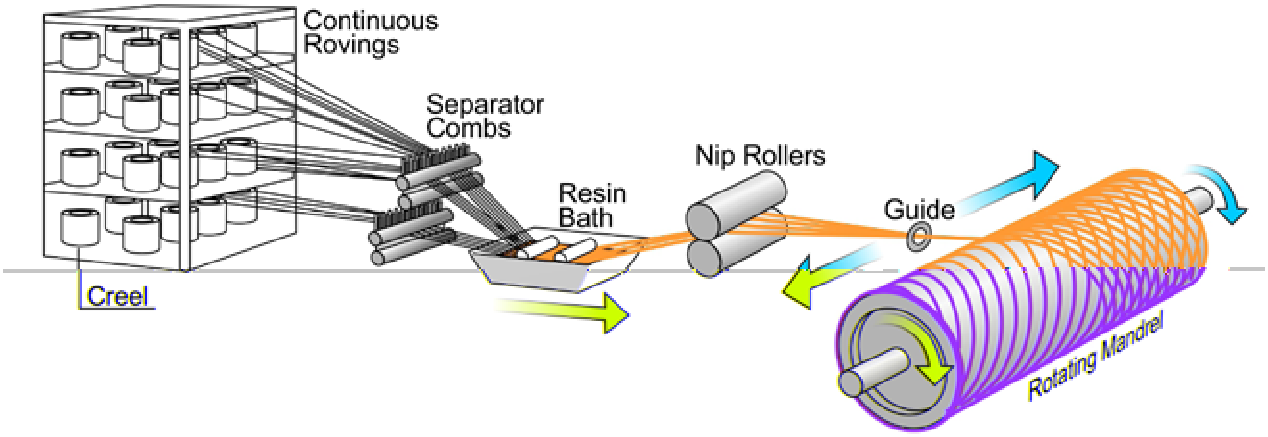
4. The finished tube is then removed from the mould.

Notes

[1] The portion of resin, glass and sand determines the overall hoop and burst strength of the pipe. The portions may vary for each layer. Common finished products are low pressure and jacking pipes.

Filament Winding

Filament winding is a fabrication technique involving wrapping pre-tensioned, resin saturated continuous reinforcements around a mandrel (male mould). The mandrel is usually circular in cross-section; however, other cross sections are achievable with the correct programming.



Specific mechanical properties are achieved through reinforcement and resin selection, careful fibre orientation and thickness. Suitability to operating environment is primarily determined by the resin matrix and internal lining. However reinforcement selection should also be carefully considered. Programs can adjust settings such as wind angle throughout the laminate build to optimise the properties.

Filament winding with a fixed mandrel restricts the overall length of the finished part by the length of the mandrel. Manufacturing is best described as a batch process. Continuous filament winding utilises a steel band wrapped to form the mandrel. The band collapses on itself at the end of its travel, and relocating back to the beginning to form the mandrel again. This process is for larger diameter parts, but the length of the part is restricted by machinery constraints.

Allnex Products Commonly Used:

- Resin (UPE, vinyl ester or epoxy)
- Catalyst
- Single end rovings surface veil
- Mould release

Steps

1. A release film can be wound around the mandrel to prevent stick-ups.

2. If required for added corrosion resistance or surface smoothness, a surface veil[1] is wound around the mandrel.

3. The doffs/cheeses of continuous strand roving are set on creels[2] (Bobbins in the case of carbon).

4. The selected number of ends of continuous strand roving is fed from creels then gathered and tensioned[3].

5. The strands are pulled through a bath of catalysed resin, then through a squeegee or nip-rollers to remove excess resin.

6. The saturated strands pass through a guide-eye that is mounted on a traversing mechanism which travels along the length of the rotating mandrel.[4]

7. When the required number of layers are deposited the feed of strands is discontinued and the part can be cured on the rotating mandrel.[5] Curing may occur at room temperature or at elevated temperatures (if a heating mechanism is installed).

Notes

[1] For pipes or tanks surface veil selection is critical to the corrosive resistance of the finished part. C-glass or synthetic surface veils are standard.

[2] Some reinforcement suppliers are capable of supplying pre-spliced doffs/cheeses which enable high volumes of reinforcement to be run directly from the pallets.

[3] The tension will influence the glass:resin ratio and finished thickness of each layer.

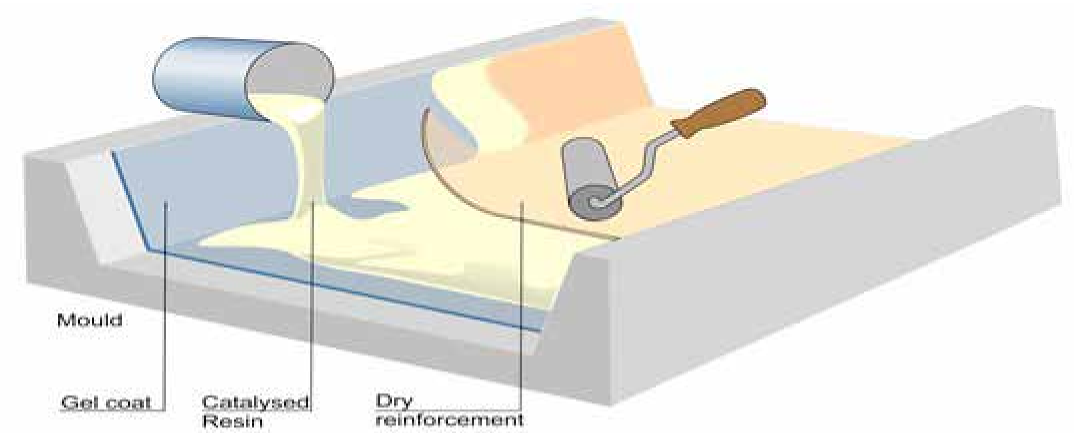
[4] The ratio of traverse speed vs mandrel rpm determines the angle of the strands, while the shape of the guide-eye and number of strands influences the band width. In some cases the resin bath can also traverse alongside the mandrel.

Hints & Comments

1. Filament winding is a medium paced manufacturing technique. Equipment set up cost can be high, but production itself is economical. Careful consideration should be given to mandrel specifications.
2. Filament winding can be an adaptable process for producing a variety of products.
3. Where parts with a polypropylene, PVC or liner of other material are required, the prefabricated liner can take the place of the mandrel.
4. Polyester, vinyl ester and epoxy resins can all be used giving scope to a variety of environmental suitability.
5. Sand can be included in between layers to bulk up the laminate.
6. Reinforcement selection and placement, resin type, compatibility of resin and reinforcement, all have an impact on mechanicals such as burst strength, hoop and compression strength. Stiffness is determined by fibre angle, wall thickness and stiffening ribs can also be built in in-situ.
7. Parts can be tapered. A finished inner surface is produced and the outside surface is flowcoated. This process produces parts with high fibre content in a controlled orientation resulting in good mechanical properties. Parts have very uniform thickness and resin to glass ratio.
8. Products currently being produced using this technique range from pipes, masts and spars, golf clubs, power and transmission poles, pressure vessels to missile casings, aircraft fuselages and lamp posts.

Hand Lay-Up

Hand lay-up is the simplest method of fabricating. The tooling and equipment is low cost and design changes can be readily made. This method is good for low to medium volume parts. Hand lay-up gives a finished/gelcoated surface on one side of the product only (the mould face). This is the most labour intensive method of fabricating. Skilled fabricators ensure consistent quality. Hand lay-up is also called open moulding or contact moulding.



Allnex Products Commonly Used:

- Resin (UPE, vinyl ester or epoxy)
- Fillers & putties
- Catalyst, promoters, inhibitors
- Mould preparations
- Gelcoats & flowcoats
- Accessories (brushes, rollers, bags, peel ply)
- Reinforcements (chopped strand mat, fabrics, tissues, speciality fabrics)

Steps

1. The mould surface must be well prepared with a release agent.
2. Gelcoat is firstly applied to the waxed mould surface either with a brush or with a spray gun and allowed to cure.
3. The resin is catalysed[1] and then applied by: brush, paint roller or spraying from a gun
4. Reinforcing fibres (Glass, Aramid, Carbon) in the form of tissue, cloth, chopped strand mat, or fabrics are placed onto the mould by hand[2,3].
5. Manipulate the reinforcement into all radii and details of the mould to ensure no bridging occurs and creasing is minimised.
6. Thoroughly wet the reinforcement and consolidate the laminate with a roller to remove entrapped air.
7. Further layers of fibreglass reinforcement and catalysed resin are added in the same manner to build the required thickness. As a guide no more than four layers of resin and reinforcement should be applied at any one time to prevent excessive exotherm of the laminate causing problems with product quality. Where thick laminates are needed, each series of four layers should be allowed to exotherm and return to ambient temperature before subsequent layers are applied.[4,5]
8. Flowcoat is used in place of resin in the final layer to prevent air inhibition and tackiness.
9. The curing reaction occurs at room temperature.

Notes

[1] To optimise the manufacturing process and final laminate performance the suppliers' instructions for mix ratios of resin and catalyst should always be followed. The resin and catalyst should always be measured accurately on calibrated scales/measuring cylinders.

[2] Resin is applied first before the dry reinforcement to enable thorough wet-through of the fibres, and reduce possibility of air bubble entrapment.

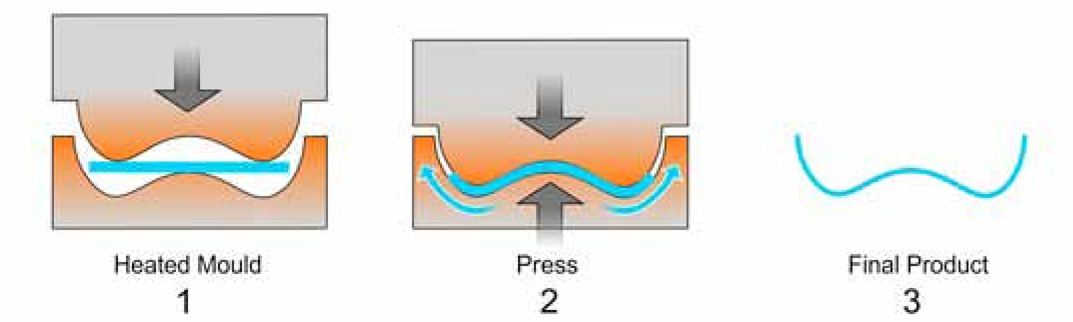
[3] A finer reinforcement such as tissue, print blocker or light weight chopped strand mat used in the reinforcement layer against the gelcoat will minimise fibre print through, providing a smoother, high quality surface finish.

[4] The surface should be cool and tacky.

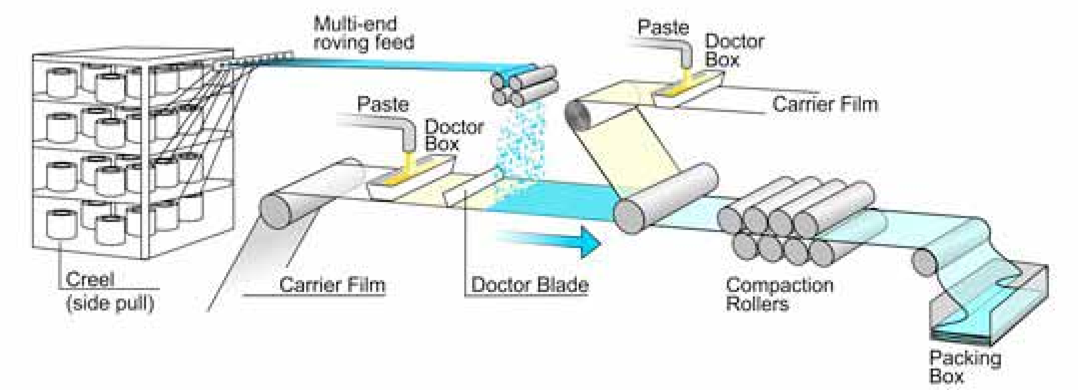
[5] If the laminate has been left for a long period of time, i.e. 72hrs or more, the surface should be abraided/sanded before subsequent laminate is applied. 40 grit sandpaper or discs are recommended. This assists bonding between existing and subsequent laminate layers.

Hot Moulding Processes

Hot Moulding applies to processes that utilise pressure and temperature to shape and cure the finished parts. These often involve hydraulic presses to close the heated matched dies required to shape and cure the parts. Cycle times vary from 30 seconds to 4 minutes. Hot moulding processes are used for high volume production requiring relatively high dimensional accuracy.



Sheet Moulding Compound (SMC)



This is a mixture of resin (usually polyester), filler, catalyst and chopped reinforcing fibres (usually E glass) in 20-50mm lengths, in the form of a compounded sheet. In SMC manufacture the glass strands are sandwiched between two layers of film, which already have the resin mixture applied to them. This is then compacted and stored for several days to reach optimum properties. The sheet formed by this process is malleable but non-tacky.

Dough Moulding (DMC) & Bulk Moulding (BMC) Compound

This is a mixture of resin (usually polyester), filler and 15-20% chopped reinforcing fibres (usually E glass) 3-12mm in length. Most moulding compounds are un-thickened, although in the past BMC contained a chemical thickener. The terms DMC and BMC are now used interchangeably.

Dry reinforcement, catalysed resin, fillers and additives are mixed into a dough like consistency, before being placed into the mould.

Both SMC & DMC/BMC are shaped & cured by hot moulding

1. In the case of SMC, the sheet is cut to the required dimensions, then placed in the heated mould. For DMC/BMC the measured quantity is placed between heated matched moulds.
2. A hydraulic press brings the moulds together under pressure at temperatures around 100-170°C.
3. The pressure and elevated temperature cause the compound to flow and completely fill the mould cavity.
4. Once cured, the pressure is then released and the part removed from the mould. Cycle times vary from 30 seconds to 4 minutes. Hot moulding processes are used for high volume production.

Lite-RTM

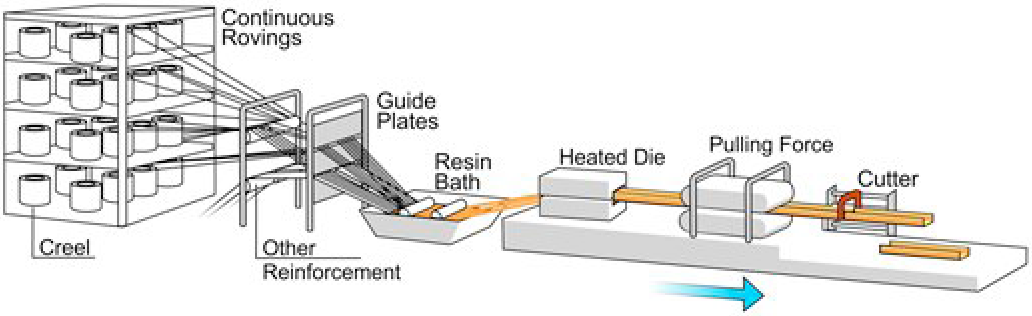
Lite-RTM is used where lower volumes are involved, and may not justify the expense of heavy duty tooling required for RTM.

Pressure is a major difference between RTM and Lite-RTM processes. RTM is when pressure in the mould is higher than atmospheric pressure. Lite-RTM is when pressure in the mould is lower than atmospheric pressure.

The top mould used in Lite-RTM is not made of the same heavy duty material as in RTM. Fibreglass laminates may also be used.

Pultrusion

Pultrusion is used for producing continuous lengths of reinforced composite with a constant cross-section. During pultrusion a continuous pulling device (such as grippers or pads) pulls the material in line through the process. Most pultrusion processes run horizontally; however, specialised vertical processes also operate.



Although the mechanical properties are strongest in the machine direction (due to reinforcement fibre alignment), they can be improved in the cross wise direction by the introduction of continuous filament mat or fabrics. See also Pull Winding.

Allnex Products Commonly Used:

- Resin
- Catalyst
- Additives (pigments)
- Single end roving
- Fabrics
- Continuous filament mat
- Mould release

Pull Winding

Pull Winding is a variation of pultrusion where winders introduce fibres in a cross wise direction (out of alignment with the machine direction), hence increasing the out of plane mechanical properties of the final product.

Steps

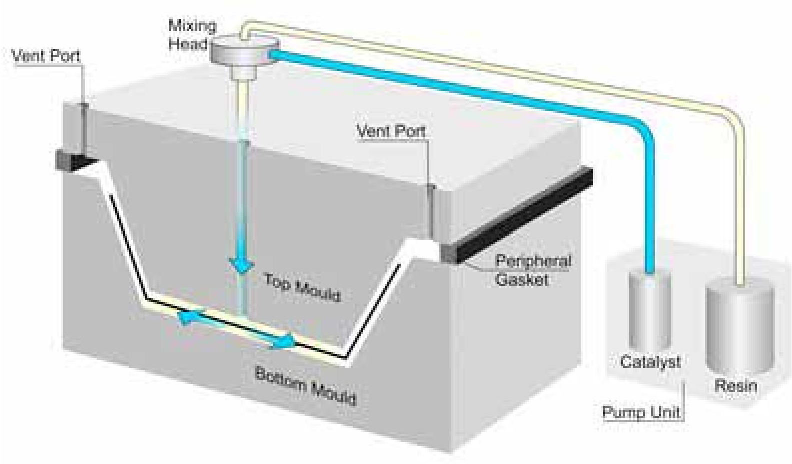
1. A combination of fibre reinforcements (typically continuous roving, continuous filament mat, cloth or veil) are pulled from creels into either a catalysed resin bath or injection die where it is thoroughly wet out by the resin. Alternatively, catalysed resin may be injected at the front of the die. The resin may contain fillers and/or specialised additives.
2. The resin saturated reinforcement then proceeds through bushings where excess resin is removed.
3. The material passes through a heated steel forming die, where it forms into the exact geometry of the die. The heat of the die initiates the gelation and curing of the finished part.
4. The material is cut in line to length. Most resins and reinforcements can be used with pultrusion. The curing system for polyester and vinyl ester resin usually consists of highly reactive 'kicker' peroxide for initial cure, in combination with medium or low reactivity peroxides to give a more gradual cure.

Hints & Comments

1. Parts produced by pultrusion have a constant cross-section, although some variation in cross-section is possible with variations of the process.
2. Since parts are produced with straight fibres and glass content as high as 75%, they have very high mechanical properties in the longitudinal direction.
3. The resin system can be enclosed to limit volatile emissions.
4. Once the intensive set-up is complete, Pultrusion is a medium speed, economical process with a relatively low labour component.
5. It is best suited for high volume (long) continuous runs of the same product.
6. The disadvantages of pultrusion are that parts are limited to constant or near constant cross-section, and the equipment and die costs can be high.

Resin Transfer Moulding

Resin Transfer Moulding (RTM) fits into the broad fabrication category of closed moulding processes, where composite manufacturing is conducted within an enclosed cavity.



Since it can be automated and is capable of rapid production cycle times, RTM is suitable for medium to high volume production, producing relatively low cost parts. Higher production rates can be achieved by heating the moulds, using preform reinforcements and resins with short gel and cure times. RTM involves a capital investment in tooling and infrastructure that is higher than vacuum infusion but lower than compression moulding.

RTM uses two matched moulds - a bottom mould and a top mould - brought together to produce parts with two finished surfaces.

Steps

1. The top and bottom moulds are firstly gelcoated.
2. Dry fibreglass reinforcements (and core if required) are placed by hand or robot into the bottom mould. The use of preforms will reduce loading times.[1]
3. The two moulds are brought together and clamped.
4. The catalysed resin is injected under pressure into the cavity between the moulds until this is full and resin comes through the air vents in the bottom mould.
5. Vacuum can be used to enhance the resin flow as it wets out the reinforcements.
6. The part is cured in the mould.
7. The two moulds are separated and the completed part removed.

Notes

[1] Preforms are reinforcements that have been pre-shaped in a separate pressing process to speed up positioning in the mould.

Hints & Comments

1. Moulds for RTM range from low cost composite moulds to higher cost temperature controlled metal moulds.

2. To withstand the pressures of RTM, moulds must be relatively heavy.

3. Part thickness in RTM is determined by the size of the cavity between the moulds, with relatively high tolerance and high repeatability achievable.

4. Being a closed mould process, the resin is enclosed and emission of volatiles is minimised, resulting in improved workshop conditions.

5. Lower labour costs become more apparent as the volume increases

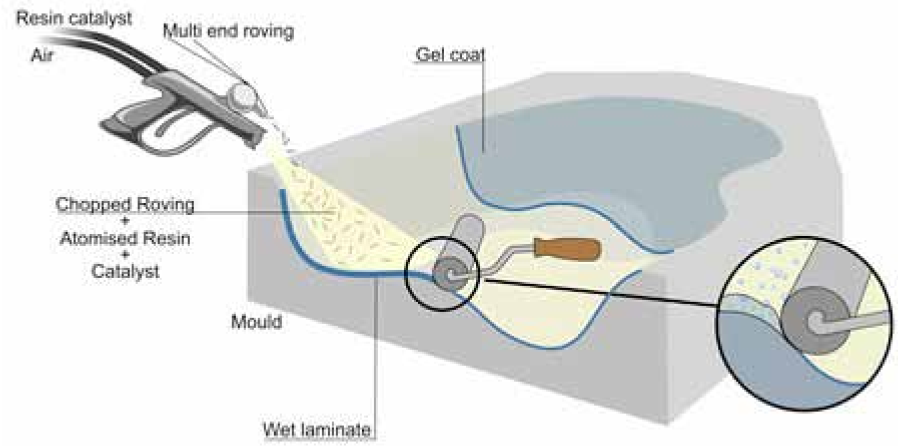
6. Epoxy, polyester, vinyl ester and other resins can be used in RTM.

7. Most reinforcements and cores can be used with this process with the exception of honeycombs.

8. RTM produces parts with very low void content, and high fibre volume can be achieved.

Spray-Up

Spray up is good for low to medium volume production. It can be used on smaller parts but it is also very well suited to larger parts such as swimming pools or boat hulls. Spray-up is a faster process than hand lay-up.



Although the process can be robotised, it generally requires skilled operators to obtain consistent high quality parts. The same low cost open moulds that are used in hand lay-up are used in spray-up application. Spray-up is primarily for polyester and vinyl ester resins and glass fibre.

Many types of spraying systems are available. The three main pump systems are:

- Airless atomisation
- Air assisted airless
- High volume low pressure systems

Other types of spray equipment are gravity fed, siphon and pressure pot systems.

Allnex Products Commonly Used:

- Mould preparations
- Gelcoat, flowcoat (optional)
- Unsaturated polyester resin or vinyl ester resin
- Catalyst
- Reinforcements: multi-end (gun) roving
- Accessories (rollers)
- Chemicals (acetone)
- Complimentary (fabric reinforcement and cores)

Steps

1. The mould surface must be well prepared with a release agent.

2. Gelcoat is firstly applied to the waxed mould surface either with a brush or with a spray gun and allowed to cure.

3. A hand held gun is then used to spray catalysed resin and reinforcing fibres onto the mould at the same time. The fibres are fed into the gun as continuous multi-end roving and chopped to lengths of 20 to 75mm by the chopper unit attached to the spray gun. The resin can be catalysed before it passes through the spray gun (internal mix), or alternatively catalyst can be sprayed at the same time as resin from the gun tip (external mix). The catalysed resin wets out the chopped fibre as it is sprayed onto the mould.

4. A hand held roller is then used to consolidate the laminate and remove entrapped air.

5. Additional layers of chop laminate are added to obtain the required thickness.

6. Roll stock reinforcements such as fabrics as well as core materials can be used in conjunction with the chopped laminate.

7. The curing reaction occurs at room temperature. At ambient temperature, initial cure occurs within first 24 hours at ambient temperature, and full laminate cure may take up to 28 day.

8. Finished part to be removed from the mould after initial cure is complete.[1]

9. A Flowcoat may be applied to the cured laminate as a cosmetic enhancement.[2]

Notes

[1] Early removal from the mould often results in damage to the laminate and loss of surface finish integrity of the parts.

[2] The laminate surface must be abraded/sanded before flowcoat application to assist bonding.

Vacuum Bagging

The Vacuum Bagging process is a relatively low cost method to consolidate a wet lay-up (see Hand Lay-up) during the curing using atmospheric pressure. Often used for complex shapes and large components where other methods of pressurisation are not achievable or cost effective.

Prepregs may also be consolidated using the vacuum bagging process, however they must be cured within an enclosed oven, which adds to the process cost.

The atmospheric pressure applied during cure compacts the laminate, facilitates removal of excess resin, improves fibre wet-out and lowers void content. The vacuum bag reduces the amount of volatiles emitted during cure thus improving health and safety in the workshop. Vacuum Bagging results in good quality parts which have a higher reinforcement content and better adhesion between layers when compared with parts prepared using the hand lay-up process.

Considerations must be made for the relatively low cost equipment, cost and disposal of the consumables and the additional time involved in bagging and consolidating the laminate. Fabricators must also have a higher level of skill than for hand lay-up. Re-usable bags may be utilised.

Allnex Products Commonly Used:

- Resins (UPE, vinyl ester, epoxy)
- Catalyst
- Gelcoats
- Reinforcements (chopped strand mat, fabrics, tissues, speciality fabrics)
- Accessories (brushes, rollers, bags, peel ply, breather cloth, flow mediums, tacky tape)

Steps

1. The wet lay-up is prepared as normal in the mould.

2. Peel ply and breather materials are placed over the laminate, followed by a flexible plastic film ('bag') which is placed over the top and sealed to airtight around the edge of the mould[1].

3. The air under the bag is then extracted with a vacuum pump, achieving up 1 atmosphere (14psi) pressure evenly across the laminate in the mould. Resin flow and cure can be further assisted by oven heating the assembly, as required for prepregs

4. Once the resin is cured the peel ply, breather materials and bag are removed from the part.

Notes

[1] Any vacuum process requires a near perfect seal between the bag and the part to be an effective process and achieve a good finished result.

Hints & Comments

1. Wet bagging is well suited when epoxy resins are being used.
2. When using polyesters and vinyl esters use <1 atmosphere pressure. Doing so will reduce the amount of styrene loss, which would otherwise have a detrimental effect on cure.

Vacuum Infusion/Resin Infusion

Resin or Vacuum Infusion fits into the broad fabrication category of closed moulding processes, where composite manufacturing is conducted within an enclosed cavity. In vacuum infusion the mould cavity pressure is lower than atmospheric pressure, i.e. resin flow is driven by vacuum.

Steps

1. Apply mould release to the mould surface carefully.
2. If a gelcoat surface is required, apply directly to the prepared mould and allow to cure.
3. Locate and stack all dry reinforcements into the mould in pre-determined locations that optimise the laminate performance. This may include surface media[1], glass reinforcement in the form of fabrics and continuous filament mat and core[2]. A peel ply is often positioned over the dry stack to ease the separation of the cured laminate from the vacuum bag[3].
4. A flexible film ('vacuum bag') is laid over the reinforcements and sealed airtight around the edge of the mould, beyond the perimeter of the required laminate.
5. A minimum of two connections are put into the vacuum bag. One is for resin entry, the other for air removal to achieve vacuum.
6. With the resin entry point closed, the area under the bag is placed under vacuum by use of a vacuum pump. This compacts the reinforcement stack and removes all air from the system. The vacuum integrity of the system can be tested using a leak detector around all seals. All leaks need to be corrected before continuing.
7. A drop test which isolates the part from the vacuum pump via the catch pot must be carried out to ensure the part can maintain full vacuum integrity for at least 15 minutes. The gauge on the catch pot must not show a drop in vacuum of more than 1" of vacuum over 15mins. Any drop in vacuum noted indicates air leaks in the system. These need to be located and sealed before the drop test is repeated and infusion begins
8. Once the system is deemed leak proof, the vacuum point is reopened.
9. The container for resin supply is filled with the required amount of catalysed resin and the resin supply connection is opened so the vacuum pulls the resin through the tubes to enter into the reinforcement filled cavity between the vacuum bag and mould.
10. Once the part is fully infused with resin, it is allowed to cure. Timing depends on the resin system and conditions, which may be hours or overnight.
11. The bag and other consumables are removed from the part and disposed of. The remaining laminate will be one homogenous structure. Some minor finishing will be needed to grind off the flange edges and some sharpened areas where resin has cured into the creases in the vacuum bag.

Notes

[1] A finer reinforcement such as tissue, print blocker or light weight chopped strand mat used in the reinforcement layer against the gelcoat will minimise fibre print through, providing a smoother, high quality surface finish.

[2] Reinforcements such as chopped strand mat are not recommended for reinforcement as they will wash and relocate when the resin breaks down the binder system and moves the glass strands in the direction of resin flow.

[3] To facilitate resin flow, flow media need to be utilised. Interlaminar flow can be achieved via the use of speciality infusion products which remain as part of the finished laminate, or disposable surface flow media.

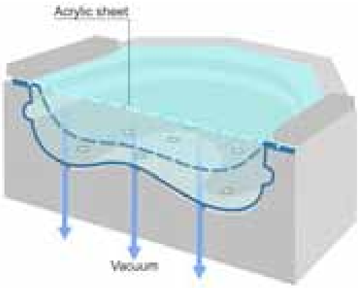
Hints & Comments

1. Open moulds similar to those used in hand lay-up are used for infusion, however more care must be taken to ensure the entire mould surface is air tight. Larger flanges are also required to allow for the necessary vacuum lines
2. Accurate reinforcement placement provides localised strength and compression without unnecessary additional weight. This includes the inclusion of stiffeners and/or the addition of high density inclusions (e.g. metal, high density core) in areas where localised screwing may be required. Resin flow software is available to optimise the process.
3. The end laminate has one finished (moulded) side only.
4. Vacuum infusion can be used with epoxy, polyester and vinyl ester resins, most conventional fabrics and cores with the exception of honeycombs.
5. Workshop conditions are much improved compared to open mould processes due to the reduction in volatile emissions.
6. Infusion process is suitable for limited production runs, and parts requiring higher glass content than can be achieved with open mould processes such as spray-up or hand-lay up. It is also suitable for extremely large and or detailed parts.
7. Compared to hand lay-up, this process gives better fibre wet-out, lower void content, higher reinforcement content and better adhesion between layers. Laminates made by vacuum infusion therefore have higher mechanical properties than those made by hand lay-up.
8. Skilled fabricators are required for vacuum infusion.
9. Thicker parts can be achieved by the inclusion of light weight core materials to the laminate, which contribute greatly to stiffness but not to overall part weight.

Vacuum Form Acrylic Process

The vacuum forming process moulds the acrylic sheet as the outer surface. Fibreglass Bonded Acrylic involves a secondary step to add the fibreglass laminate to the underside to provide rigidity.

Acrylic sheeting provides an inherently durable outer surface, exhibiting high abrasion and solvent resistance, while maintaining high gloss and good aesthetics. Excellent formability enables sharp definition of shapes while maintaining a relatively even surface thickness.



Fibreglass Bonded Acrylic is being used with great success in the manufacturing of bathroom fixtures, boats, furniture, storage tanks, stadium seating and recreational vehicles, including dune buggies, snowmobiles, campers and trailers.

Allnex Products Commonly Used:

- Acrylic back-up resin
- Vinyl ester resin (chemical barrier coat)
- Gun/Chopper rovings
- Catalyst
- Release agents

Steps

1. Acrylic sheet is heated to forming temperature, then using vacuum, it is stretched into a single-surface mould and held in place until cooled.
2. A layer of specially formulated resin[1] and fibreglass is sprayed to the underside of the formed sheeting to a predetermined thickness, and allowed to cure.

Notes

[1] A general purpose resin is not suitable for this application. The resin must be specially formulated to bond to the acrylic during the curing process to ensure a consistent and permanent bond is obtained between the sheeting and the laminate. Further consideration is required if the end use application involves holding water for long periods, in this case a chemical resistant tie layer must be applied directly to the acrylic sheeting. The resin is often heavily filled to create thickness at a low cost.

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