Maricell®

MYCELL™ Processing Guidelines

Issue 4/2011 replaces issue 08/2010

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1. Conditioning and processing of foam cores

1.1 Storage and conditioning

Storage

All foams should be stored in a closed store at temperatures above 10℃ (50℉) and below 30℃ (86℉) and 80 % r.h. Sol vents and foam should not be stored together as the foam may absorb solvent volatiles. Long storage times will result in shrinkage of up to 3 - 5 %. One should especially account for such phenomena, if precisely cut material is stored over a long period of time. One year of shelf life is guaranteed for foam.

Direct exposure to sunlight should be avoided to prevent irregular shrinkage of the foam sheets and change of color pigments. It is highly re-commended to keep the foam for a minimum of 24 hours in the workshop before use. Especially if the storing temperature is low or of air moisture is high. The absorbed moisture on the foam surface might inhibit the chemical reaction of the resin or the different temperatures could result in a curing time other than expected.

Degassing of MYCELL™ foam cores

Due to their chemical nature and production process, crosslinked PVC-foam cores tend to release small amounts of gas during the cure of laminated skins. In order to prevent undesired effects such as delaminations, degassing procedures have been defined. The three main parameters influencing the outgassing of crosslinked PVC foams are: time, temperature and pressure. The density of the foam doesn't have an extensive impact.

The amount of escaped gas is strongly depends on the location through the thickness of the foam block or sheet. Any cutting or sanding of more than about 2 mm will change the pressure balance between atmospheric pressure and the pressure inside the cells. Consequently, the foam will outgas until the balance is reached again. Therefore it will never be possible to degas a crosslinked PVC foam block or sheet completely by a thermal treatment. Each time the material is cut, the outgassing process will start again.

The most widely used countermeasures to prevent the outgassing process are thermal treatment or controlled storage:

Thermal treatment

Applying a thermal treatment the material can be degassed effectively and in a short time period. As an experimental guideline a **thermal treatment of 40 ℃ for approx. 7 days** has proven to be the safest method for an accelerated degassing. Onlylittle warping and material shrinkage might occur.

Controlled storage

Controlled storage leads to no warping and very low shrinkage. However, the material is blocked for a relatively long time. In order to reach equal results as with thermal treatment one month storage at room temperature (23 ℃) is required. As a rule of thumb one can say that a 10 ℃ modification of treatment temperat ure will double the treatment time or divide it by two accordingly.
Examples:
50 ℃ ⇒ 3 days, 60 ℃ ⇒ 1.5 days etc. or 10 ℃ ⇒ 2 months

Basic Rules

1. In order to avoid excessive outgassing, the foam should be in an equilibrium state when being processed. This can be achieved best by thermal treating or storage after the material has been cut to the final panel sizes or kits. For further details consult MYCELL technical service customer information 1000.

2. The higher the resin content of the skin laminate the faster it bonds with PVC core material and the lower is the danger of too low peel strength or blistering of skins.

3. Extensive heat processes for laminate curing, especially for the first laminate layer against the foam, can provoke outgassing. However, after a good bondline is achieved, a post cure heat treatment is no danger to the sandwich.

4. When using prepregs at temperatures between 90 °C and 120 °C with C71.75, good results have been achieved and hardly any outgassing effects occurred. With low curing boatbuilding prepregs at 60 °C, outgassing can affect bonding as at lower temperatures, it takes longer to achieve the necessary bond strength.

5. Using epoxy prepregs, it is strongly recommended to seal the core with a thin layer of room temperature curing resin, to prevent cure inhibition by CO_2, which might be released by the core when brought to elevated temperatures. For further details consult MYCELL technical service customer information 1050.

1.2 Machining

General

MYCELL™ rigid foams of apparent densities of less than 200 kg/m³ are easy to process by mechanical methods (machining). Generally, wood-working equipment and tools are adequate. With rigid foams of apparent densities higher than 200 kg/m³, in particular foams based on thermoplastic materials, care must be taken when choosing the appropriate tool configuration and adequate cutting speed, in order to avoid local overheating and consequently unsatisfactory results.

The information given herein is intended as a general guideline based on our experience. It will, however, not dispense with the necessity of trials in specific cases to ensure optimum results.

Important Note !

Mechanical processing of rigid foams may cause environmental and health problems by suspended dust and foam particles. Proper ventilation and vacuum-assisted dust collection is essential. Regarding permissible limits for unsuspended dust and other personal safety precautions please refer to the respective material safety data sheet.

Cutting methods

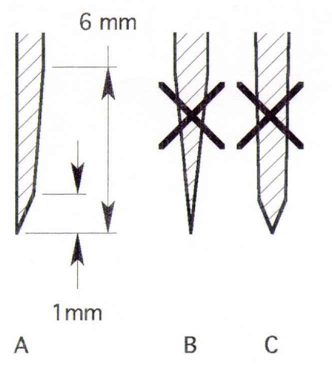
The following recommendations concern MYCELL™ M048 to M100.

Knife cutting

Thin sheets less than 10 mm (3/8") thickness can readily and with satisfactory results be cut by knife, e.g. stanley knife. Thin sheets of MYCELL™ M material, particularly of the lower density range, are more susceptible to breakage.

Steel-rule die cutting

Steel-rule die cutting is a very convenient and low-cost way to cut shapes of all kinds of small to moderate sizes from sheet material of thin to moderate thicknesses. Recommended maximum sheet thicknesses are:



MYCELL™ M	15 mm

Geometry of the cutting edge of the blade

Of the possible cutting edge configurations, we recommend type A for steel rule dies and cutters.

Machining methods for low density thermoplastic foams

MYCELL™ M can be machine processed with generally good results on all high speed wood work-ing machines and equipment. The tools and tool configurations are those common to the trade.

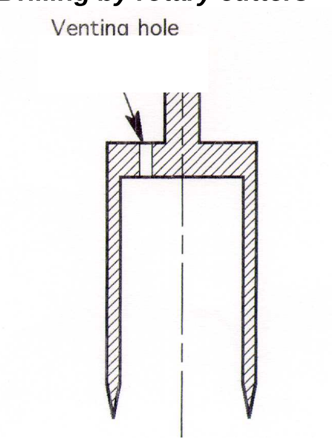
Foam type	Machining operation			
	Sanding	Drilling	Milling	Turning
M060-M100	✸	✸	✸	✸

✸ method suitable

Sanding

Particular attention should be paid to sanding operations. Problems will be created by high speed and use of an unsuitable grade and type of abrasive. Sanding of foam sheets is mainly utilized to equalize the surface of sheets to meet the tolerance requirements. Optimal sanding can be achieved with sanding paper 60 to 80 standard grit and a paper speed of 20 to 30 m/s.

Drilling by rotary cutters



The rotary cutter is a convenient tool to cut holes of larger diameter, discs and plugs from foam sheet material of low to medium apparent density. The possible maximum thickness for satisfactory results depends on the apparent density of the material and the diameter of the cutting tool. It should normally not exceed 30 to 35 mm.

The cutting speed should be limited to about 100 to 250 rpm (or about 280 m/min.) to avoid excessive friction heat. The advance should be about 0.5 to 2 mm/sec. The use of a cooling liquid is very helpful and recommended.

Important Note !

For the following lamination or bonding operations, the removal of dust adhering to the surface is essential. The use of vacuum cleaning equipment is preferable to compressed air.

1.3 Thermoforming

General

For the thermoforming process, the foam is first subjected to elevated temperature, reshaped and cooled down under pressure. For thermoformability at least a part of the foam composition must be based on thermoplastic polymers. This is the case for MYCELL™ foams and therefore in principle, they all can be thermoformed. However, the maximum capability of thermoforming depends on the type of foam and its thickness.

By thermoforming, the mentioned foams can be adjusted to 3-dimensional complex shapes often required for modern sandwich structures, without disruption in the core. It is therefore a good alternative to use thermoforming instead of the often used contoured and scrim-cloth solutions, for which the core, and as a result as well the load path is discontinuous. Compared with these solutions, thermoforming leads to lighter structures and reduced consumption of putty, adhesive or resin.

Process parameter

Heating of foam

Heating of the foam can be achieved by the following methods:

Convection: by means of circulating air in an oven or with hot air blowers
Conduction: by means of hot plates or in a hot water bath
Radiation: by means of hot wire bench, halogen or infra-red heaters

Using conduction heating, difficulties might occur because melted material from the foam surface might stick to the heated plates. Teflon-coated surfaces or release films/fabrics can reduce this problem. When immersion in a hot water bath is the chosen method, post-drying of the foam is recommended. Remaining moisture can cause poor bonding of foam core and skin material.

Radiation heating can sometimes lead to an overheating of the foam surface, especially when the radiation flux is too high and the heat cannot be transferred fast enough into the centre of the foam sheet. This usually leads to surface cell collapse, material decomposition and poor mechanical characteristics in this zone. The surface temperature of the foam should therefore be closely monitored and the radiation flux be controlled accordingly.

Generally speaking, convection is the safest method of heating foams, as it has none of the above mentioned drawbacks. Whichever of these methods is chosen, care should be taken that the foam is heated uniformly. If this is not the case, the sheets may warp due to different thermal expansion, thereby moving their corners closer to heat sources and increasing the problem of a non-uniform heating. These problems can usually be reduced by allowing more time for the heating process.

Processing temperatures

The following oven temperatures are recommended for thermoforming:

Foam type	Optimal oven temperature for thermoforming	
	(℃)	(℉)
M040-M100	115 - 130	240 - 265

Heating time

Necessary heating time depends on the heat capacity of the foam, its thickness and on factors like oven design, environmental effects (direct sunlight, draught, temperature on the work floor) and others. The heating time can be estimated as follows:

Convection heating: 0.5 – 1 min/mm
(Circulation air oven)

Conductive heating: 0.2 - 0.5 min/mm
(Hot plate apparatus)

Usually heating times are in the order of 2 to 10 minutes for thicknesses up to 20 mm.

Tooling

If only small numbers of parts need to be thermoformed, relative simple wooden or composite tools can be used. For larger series, the use of temperature controlled aluminum tools is recommended. Through temperature control it can be assured that the thermoforming conditions remain within a close processing window. If there are no close thickness tolerances required for the part, thermoforming can be performed with a male or female mould only.

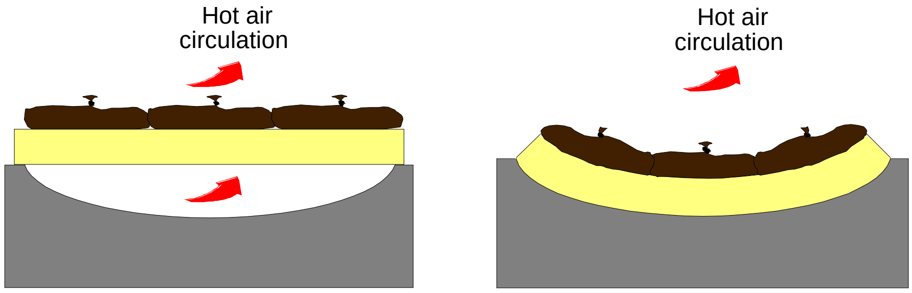
Applying pressure

Pressure can be applied in different ways:

- manually
- by means of weights e.g. sandbags etc.
- by a vacuum bag method
- by a moulding press

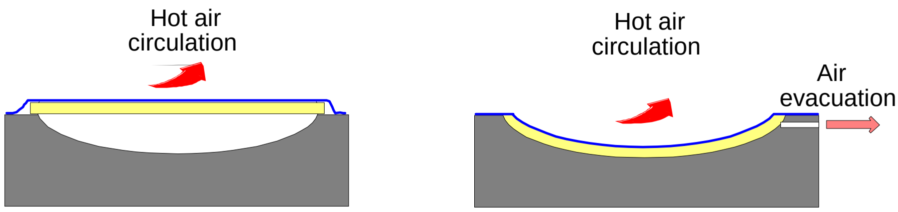
Creep forming

For creep forming, the foam core and the mould are placed in a hot air circulation oven. The heating as well as the cooling should take place under weight, e.g. by sandbags. Cycle times are in the order of 1 to 5 hours, depending on the type and thickness of the foam.



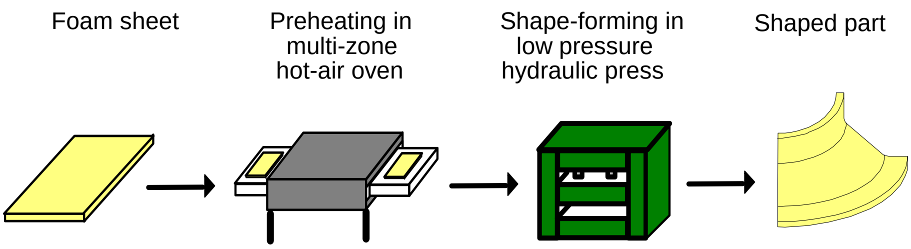
Vacuum forming

Vacuum forming can be done in a hot air circulation oven or an autoclave. It is recommended to have additional hot air circulation between foam sheet and tool. The cooling should take place under vacuum. Depending on the type and thickness of the foam, cycle times are in the order of 1 to 5 hours.



Compression moulding

For exact thicknesses within close tolerances, it is recommended to thermoform in closed moulds. Pressure can be applied by means of a simple closing or clamping mechanism or between the plates of a compression moulding press.



In a first step, the foam sheets are preheated to the required temperature. This operation takes about 10 minutes for thicknesses up to 20 mm. The metal tool for shape-forming should be temperature controlled. Cycle times under the press are in the order of 2 to 2.5 minutes.

2. Preparation of foam sheets

2.1 Grooving and perforation

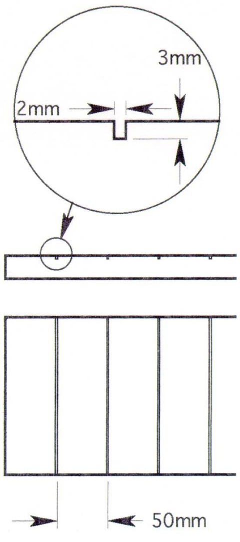
Purpose

A sandwich product consists of a tolerant core combined with tensile/compression stiff facings. It is manufactured by bonding a foam core to two faces. However, this lightweight and stiff design keeps its structural rigidity only if the bonding between skin and core does not fail even under extreme stress, overloading or impact. Due to local buckling of the skin debonding results in a fatal reduction of stiffness and strength which leans catastrophic failure of the entire part. The correct installation of the foam core is therefore mandatory and the most critical part of the sandwich manufacturing process.

Core installation can be made in different ways:

- wet lamination with vacuum bagging or sandbags (chapter 2.8)
- resin injection processes (chapter 2.5)
- bonding of skins to the foam (chapter 2.6 & 2.7)

Preparation procedure



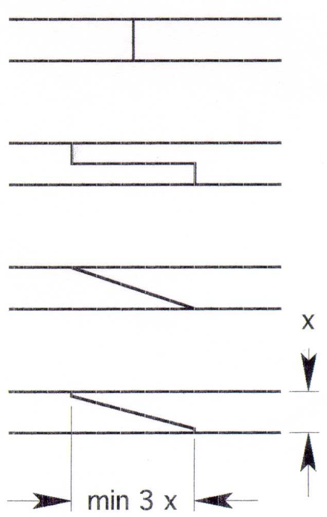
Before installation, foam sheets should be either grooved or perforated. Grooving is necessary if both skins are bonded to the foam at the same time. Perforation is required, espsecially if wet lamination in a female mould or resin injection processes are choosen. The dimensions of the grooves are shown in the picture beside.

For perforation, holes of approx. 2 to 3 mm diameter (1/16 to 1/8 in) at equal distance of at least 50 mm (2 in.) are recommended. To get an accurate distribution of holes, it is highly recommended to use a pattern made of cardboard or plywood.

Important note !

Before installation the surface of the foam sheets must be cleaned properly from adhering dust by vacuum cleaning.

Butt Joints



There are several ways butt joints of foam sheets can be made. Depending on the thickness of the foam and the desired properties of the final part, one or the other geometry is suitable. In general, it should be kept in mind that the area of the joint should be big enough. Some possibilities are shown in the pictures beside. Recommendations for adhesives to be used can be found in chapter 2.7.

Kit manufacturing

For complex 2- or 3-dimensional parts (boat hulls, wind mill blades, …) it is useful to have foam kits available that can be put into the mould very quickly and conveniently. The kit manufacturing is done the first time the foam sheets are cut-to-size in the mould. The following points have to be considered:

- When using vacuum infusion techniques (chapter 2.5) it is important to have grooves cross-wise so that the flow front is not interrupted. Neighbouring sheets have to be cut in a way that the grooves are continued.
- Foam sheets should be used in the original size in order to reduce waste.

There are different ways to put the foam kit plates into the mould. When processing by hand lay-up sheets are separately processed as described in chapter 2.3. In prepreg and vacuum infusion processes the sheets must perfectly fit to each other. In order to reduce the risk of building a flow channel between two foam parts it might be necessary to chamfer each foam sheet at 45° with respect the mould surface. Flow channels might be omitted because of the following reasons:

- Print-through effect, machining of part surface
- High temperature of the resin during curing might destruct foam
- Wrong flow front during vacuum infusion, danger of including air in the laminate

It is recommended to bond the foam sheets together during the dry lay up process. In chapter 2.7 possible foam bonding adhesives are listed. From a first cut, foam sheet templates can be made from plywood which can be used to cut additional foam kits.

Important note!

If changing from sandwich to single skin (e.g. in the keel section of a boat or in stepped chines) the foam should be chamfered at an angle of 30° to the mould plate.

2.2 Installation of foam in the mould

General

Foam sheets can be fitted into a mould by several different methods:

- Cold bending
- Thermoforming (see chapter 1.3)
- Use of scrim clothed cores (ContourKore)

Cold bending and thermoforming methods have the advantage of leading to weight optimised sandwich structures with continuous foam core. The use of scrim cloth cores is an easy and fast alternative needing no special equipment.

Installation of plain sheets by cold bending

Some MYCELL™ foam types can be formed by this process.

The minimum bending radius is dependent on the type of foam, the thickness of the sheet and to a certain amount, also on the foam density. With help of the table below the minimum bending radius can be easily estimated:

sheet thickness x multiplication factor = minimum bending radius

Foam type	M
Multiplication factor	25

Multiplication factor for determing the minimum cold bending radius

For very small bending radius the total core thickness can be built up by laminating two or more foam sheets together (club sandwich) over a male mould.

Cold bending induces internal stress in the foam core. However, depending on temperature and time this stress will continuously decrease.

By using a vacuum bagging method, the foam sheet is fixed in the desired form without any special measures. The foam can also be held in position by use of screws, glue and similar aids.

If the desired bending radius falls short of the calculated minimum value, the part is to be thermoformed (see chapter 1.3) or cut.

Comparison of scrim cloth with bending cores

With cold bending or thermoforming no gaps are produced in the core. Since any gaps have to be filled with putty or resin, the weight of scrim cloth cores is considerably higher than for bended or thermoformed ones. This is a factor not only concerning costs but also the structural integrity of sandwich composites.

Calculation

The total volume of all gaps resulting of opened cuts in scrim cloth cores can easily be approximated by the following formula:

$$V \approx d^2 * 29 * \arcsin 3/r$$

V: Volume of gaps per square meter [cm³]
d: Thickness of foam core [cm]
r: bending radius [cm]
arcsin is to calculate in degree (circle = 360°)

Example

Thickness of foam core	2.5 cm
Bending radius	100 cm
→ Gap-volume	**311 cm³/m²**

Installation of scrim cloth cores

For two and three dimensional shapes in FRP sandwich construction by the female mould technique, most of the MYCELL™ foams are available as scrim clothed core: The foam sheet is cut into squares (e.g. 30 mm) and glued to a backing of a glass-fibre fabric.

Important note !

To get optimal quality of the sandwich part, it is essential to fulfil the following requirements:

- strong bond between laminate and foam
- complete fill-up of the slits with resin or putty

There are many methods to install a scrim cloth foam core in a female mould. The method we recommend is the following:

First, the bonding surface of the scrim cloth foam core is to be primed with a catalyzed general purpose resin. A medium viscosity orthophthalic based resin of a styrene monomer content of max. 40 % or less will serve the purpose ideally. The priming should be done preferably on a curved fixture so that the cuts between individual foam blocks are slightly opened.
The resin should be forced into the open cuts with a hand roller. After turning the sheet on the curved fixture by 90°, the procedure is to be repeated to fill the other half of the cuts. The resin should be catalyzed to provide a gel-time of about 20 to 40 minutes (measured in thin layer on the foam).
Still working on the curved fixture, the slits should be filled as well as possible with putty or bonding paste. To get an even film, the putty can be spread out over the foam with a trowel or doctor blade.

There are a number of ready-formulated compounds available. Suitable are those that offer a fair degree of elasticity to the foam core / FRP interface. They generally consist of filled resin compounds on basis of unsaturated polyester or urethane acrylics, etc. and are catalyzed by the addition of a peroxide hardener. The cured compounds have a density of approx. 650 to 850 kg/m^3 (approx. 40 - 53 pcf).

Position the scrim cloth core with the treated surface onto the cured laminate. To get optimal bond between laminate and core, the laminate must be dry and dust-free. Gently and evenly roll the core surface with a standard laminating roller until the putty or bedding compound appears exits the slits between the individual foam squares at the cloth side of the scrim sheet.

The foam has to be weighted with sandbags or pressed down by vacuum bagging (see chapter 2.8). Since the resin is likely to penetrate through the gaps between the squares, it is advisable to use a release film between scrim surface and sandbag.

Whether to leave the scrim fabric in place or not is a matter of preference. To remove it, it is sufficient to wet the surface well with the laminating resin. This dissolves the adhesive and allows the fabric to be peeled off after about 10 to 15 seconds.

The inner laminate should start with a chopped strand mat (CSM) of 300 or 450 g/m^2 (1 or 1 1/2 oz/sq. ft.) next to the foam core. The laminate is laid-up in the usual manner.

In order to enable cores to adapt to curved molds other finishing options for foam to provide flexible cores without the help of scrim cloths area available. For further information please contact MARICELL technical services directly.

2.3 Laminating with UP/ VE-resins

General

Fibre reinforced plastics with a polymeric matrix on the basis of unsaturated polyester (UP) resins can still be assumed to be the most widely used facing material for rigid plastic foam cored sandwich constructions. The methods employed to produce the facings or skins are mainly the following:

- Hand lay-up
- Spraying methods
- Prepregs (chapter 2.6)
- Resin transfer methods (chapter 2.5)

Wet lay-up and spraying methods are still quite popular and widely used, particularly in boat building. Correct application provided, excellent bonds are obtained with MYCELL™ foams as core material.

There are different ways of bonding FRP laminates based on unsaturated polyester resins to rigid foams. The procedures commonly used are the following:

- Installation of the foam core in an uncured (wet) laminate
- Installation of the foam core on an already cured laminate using an adhesive, UP-resin or a UP-based putty (see also chapter 2.7)
- Hand lamination

All the above methods have the same objectives:

- To ensure a perfect and strong bond between the FRP laminate and the core
- To avoid the migration of styrene from the uncured resin into the foam core.

Priming and sealing

General

All UP- and VE-resins contain reactive organic solvents. In most cases the solvent is styrene. Since styrene can migrate into the foam core, it can cause:

- softening of the foam
- delayed or imperfect cure of the resin
- decreased performance of the foam at higher temp.
- increased creep of the foam

To avoid this, the foam core is sealed previously to the lamination process. Priming the core is a step of the lamination process providing optimum bond of laminate and core.

Sealing

MYCELL™ foam cores particularly the linear PVC materials of the R63 range and the lower density materials of the C70 range may show, under certain working conditions, a sensitivity towards styrene. Con-ditions and working parameters that can facilitate styrene migration are the following:

Conditions / Parameters	**Safe limits for lamination within precautions**
Styrene content of the resins	less than 42 % (v/v)
Shop or ambient temperatures	less 25 °C (77 °F)
Resin viscosity	above 500 mPas
Resin exotherm	as low as possible
Resin gel time	
◆ below 20 °C	60 min.
◆ below 25 °C	20 min.
Laminate thickness in one step	approx. 3 mm
Apparent density of foam	
◆ linear PVC R63	above 75 kg/m³
◆ mod. PVC C70	above 50 kg/m³

Conditions and working parameters that facilitate styrene migration

Important note !

The market offers a very large number of unmodified and modified polyester resins which, with respect to styrene migration, affect foam cores very differently. The same can be said of vinyl esters. Unless the resin is known to be of a standard grade and the user is familiar with the properties of the same, it is advisable to check on styrene migration into the foam core by conducting a simple test: a small square of approx. 25 mm (1 in.) of foam is pressed into the uncatalyzed resin spread on a flat surface. The progress of softening is noted.

A sealing layer helps to protect the foam surface from the effects of migrating styrene monomer and exotherm heat released by the ap-plication of additional layers of laminate. Sealing of foam surfaces is accomplished by applying a thin layer of catalyzed resin which is then left to cure. Naturally the treatment has to be extended to both sides of a foam sheet.

The resistance of the sealing coat to monostyrene is by no means unlimited and lasts about 1 to 3 hours, depending on the monomer content and the exothermic reaction of the resin used for lamination.

Priming

Priming of foam cores is a just-in-time operation. It is the treatment of the foam surface just prior to the installation with a moderately to fast catalyzed resin. It ensures maximum contact of the bonding agent, e. g. a bonding compound, and the exposed cut cell membranes. It is important to note that priming is only effective as long as the resin remains ungelled. Adequate canalization of the priming resin is therefore essential.

Foam type	**Sealing**	**Priming**
M060		✹
M080	○	✹

Necessity of priming and sealing

✹ Operation essential

○ Operation recommended

Choice of Resin

The choice of the type of unsaturated polyester resin for priming and sealing is in principle an optional one and a matter of preference by individual workshops. The use of pre-accelerated resin is generally preferred.

Promoter

In case of non-accelerated resin, the promoter (a solution of cobalt naphthenate or octoate in phthalate plasticizer or aliphatic hydrocarbon) has to be added to provide a gel time of 12 to 25 minutes for sealing operations or 20 to 40 minutes for priming applications in accordance with the resin manufacturing guidelines.

Prepromoted resins

Pre-accelerated unsaturated polyester resins are widely used for lamination. In these cases the gel time is controlled by the amount of peroxide catalyst in accordance with the resin manufacturer's instructions.

Important note !

As a rule the concentration of catalyst should not be less than 1 % and not exceed 2.5 % of the amount of resin.

Marking pigments

For better control of a uniform application of priming and sealing resins it is recommended to add to the resin 0.1 to 0.5 % of pigment paste, e.g. mineral ochre.

Priming with cobalt promoter

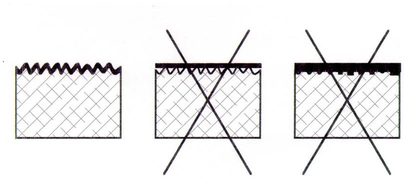
An alternative way of sealing the foam surface with unsaturated polyester resins is priming with a cobalt promoter emulsion or solution. This primer system is particularly useful for re-sealing of foam cores from which the protective resin coating has partially been removed by fairing and sanding operations or to protect open butts, gaps and edges.

Foam type	**Resin type**				
	Ortho-phthalic	Iso-phthalic	NPG	NPG/ Adipic acid	Vinylester
C70.55	✹				
C70.75	✹	○			

Recommended resin types for priming and sealing

✹ optimal choice
○ possible choice

Application of sealer resin



The application of the sealing resin is best carried out with a roller or a spraying gun. It is essential that the cut surface cells of the foam are well wetted and not just filled with resin so that a rough and not a smooth surface is obtained. For this reason it is important that after spraying the resin is well distributed and rolled into the bottom of the cut cells with a nylon bristle roller.

For sealing of rigid foam the resin has to be applied to both faces and sufficient time is to be allowed for proper cure, (at least 3 to 4 hours) prior to installation of the core

For sealing the following amount of resin is recommended:

Foam type	**Resin required**	
	(g/m²)	(oz./sq.ft.)
M060	220	0.72
M080	180	0.59

Amount of resin required for priming and sealing of foam cores

Roller application

If the sealing coat has to be applied manually it is best done with a bristle roller. About 50 to 100 g (2 to 4 oz) of the resin formulation should be allowed extra for wetting of the roller. Under no circumstances at the beginning of the operation the resin should be poured on the foam surface and then distributed with the roller. This practice causes a very uneven distribution of the resin and facilitates local styrene migration.

Application of primer resin

The primer solution should contain about 0.5 to 1 % of cobalt and is prepared:

- by diluting an emulsifyable cobalt octoate concentrate (about 6 to 8 % cobalt content) with distilled or de-mineralized lukewarm water
- by diluting a cobalt naphthenate promoter concentrate (about 6 % cobalt content) with a low-boiling aliphatic hydrocarbon (preferably white spirit). Attention: flammable liquids.

The primer is applied with a brush for smaller parts or spraying for larger areas. The treated foam surface must be let to dry, which in case of the water-emulsion takes somewhat longer than with the hydrocarbon solution. Well ventilated working areas are essential.

Installation

Core installation into incured (wet) laminates

This method is employed for relatively thin laminates (two to three layers of reinforcements) and small to medium sized areas. The foam is pressed into the uncured laminate and weighted down usually with sandbags. To ensure complete removal of entrapped air particularly from larger flat areas or shaped parts, it is essential to groove the foam sheets and/or penetrations (see chapter 2.1).

For the installation of scrim core (ContourKore) types grooving is not required. However, the increased consumption of resin required to fill the slits between the foam cubes should be taken into account (see chapter 2.2).

Core installation on cured laminates

All relatively freshly cured laminates (not more than 72 hours old) are considered suitable for immediate core installation. Older and factory-produced laminates require a surface treatment. Usually a simple solvent treatment (a rag soaked in styrene is recommended) is sufficient. In some cases mechanical processing, such as sanding is essential. Care must be taken that any dust created thereby is being properly removed (vacuum cleaner is recommended).

Core installation with adhesive

See chapter 2.7.

Core installation with UP resin

The bonding layer should consist of a chopped strand mat (CSM), preferably 300 g/m² (1 oz/sq.ft.) to 450 g/m² (1½ oz./sq.ft.), with a resin to glass ratio of 2. Provided that no separate pretreatment of the core surface is required the foam should be thoroughly wetted with the bonding resin, using a roller, prior to installation. After installation on the laminate, the core is weighted with sandbags or vacuum bagging until the resin is cured.

Core installation with a bonding compound (putty)

This method is particularly recommended for the "contoured" and "scrim-cloth" variety of MYCELL™ core materials (see chapter 2.2). Naturally, it can also be employed for the installation of plain sheet cores. In this case it is advisable to replace the grooves by regular pattern of punched "bleeder holes".

a) Bedding, bonding compound or putties

They usually consist of a UP or modified UP resins. Lightweight fillers, such as micro balloons, a thickening agent, such as kieselgur and sometimes also short chopped glass fibres can be used. The cured compounds may range in density from 400 kg/m³ (25 pcf) to 800 kg/m³ (50 pcf). Some workshops prefer to prepare putty with their own composition. This practice cannot be recommended for consistent quality reasons (difficulties in preparing a homogeneous mixture). There are a large number of reliable and suitable products on the market, some of them accompanied with detailed instructions for installation of core material.

b) *Preparation of foam surface for installation with putty*

Core installation with putties brings some advantages, such as reduced weight, considerably less styrene emission and, therefore, reduced styrene migration. This is important if a styrene sensitive core material is being used.
Problems encountered with putties often are the removal of entrapped air and adequate bond between laminate and core material. Therefore - unless special surface treatment of the foam (see elsewhere in this chapter) is recommended - the foam core should always be rolled with a thin coat of un-catalyzed UP resin.

c) Cure procedures

Putties are ideally suited for the vacuum bagging method (see chapter 2.8). It is also possible to cure them in a press.

The hand-lay-up process

The hand-lay-up process to produce FRP skins on rigid foam cores is relatively simple and generally (provided that the foam surface is clean and dust-free) yields good bonds. Problems can occur with extremely fine-celled foams of the higher density range. In such cases it is advisable to apply a primer coating (see chapter 2.3) prior to lamination. Always use a chopped strand mat (CSM) next to the foam. Never begin to build-up a laminate with a woven roving or a glass woven fabric.

Some foam cores, particularly of the lower density range, are more sensitive to styrene migration than others. To prevent foam core softening and styrene-depletion of the laminate interface, precautions outlined elsewhere in this chapter must be taken.

Another method is to begin the lay-up with a mat (CSM) and suitably catalyzed resin and let the same cure before continuing with the lay-up. This method is particularly recommended for lay-up of thick laminates.

RTM process (Resin transfer moulding methods)

Under this heading, many methods are used that range from relatively simple to high technology ones. In view of the many different technologies used and the sometimes special resin formulations, it is difficult to state valid guidelines for the various types of MYCELL™ foams. However, technical service are always available to assist prospec-tive customers with the necessary guidance concerning MYCELL™ rigid foam cores and RTM processes.

2.4 Laminating with EP-resins

General

Epoxy (EP) - resin systems are frequently used in preference to unsaturated polyester systems for structural applications because of their longterm stability, low shrinkage on cure, their suitability for vacuum bagging and availability in form of prepregs (see chapter 2.6). Epoxy resins as a rule are solvent-free systems. The problem of solvent migration does not exist. Sealing of the foam is therefore generally not necessary. On the other hand the agent responsible for a good (chemical) bond with the foam structure is missing. The bond strength of epoxy laminates with plastic foam cores solely depends on the compatibility and adhesion of the epoxy resin system. Priming of the foam core is a strongly recommended procedure, particularly if very dry laminates with a high content of fibre reinforcements are used. It must also be beard in mind that not all epoxy laminating resin systems bond directly to plastic foam cores.
Problems occur especially with low viscosity types and relatively high curing temperatures. Since the problems are very specific for the resin and production process, no general recommen-dation can be given. For specific questions, the technical service of Maricell will gladly assist you.

Priming of foam cores

Cold and rapidly curing resins are recommended for priming purposes. Often the resin manufacturer offers special resin formulations to bond the foam core to epoxy laminates. It is advisable to take note of such recommendations. This applies particularly to the bonding of laminates with high fibre content and correspondingly low resin fractions. The following primer quantities are recommended:

Foam type	**Primer quantity**	
	g/m²	oz/sq.ft
M060 - M080	200 - 300	0.65 - 1.00

Recommended primer quantities

A tinted primer resin helps to control an even application on the foam surface. About 0.6 to 1 % of red ochre is a suitable and inexpensive pigmentation. The primer foam sheets are left to cure for 3 to 6 hours, or overnight, depending on the resin system.

Curing

To obtain the maximum mechanical strength of epoxy laminates, as a rule, cure or post-cure at elevated temperature is recommended by the resin manufacturers. From the foam core point-of-view the following maximal temperature should be observed:
Higher temperature treatments may applicable dependant on the dwell time. Nevertheless, the maximum dwell time for temperatures exceeding the limits given below, should be verified in experiments.

Foam type	**Temperature**			
	Cure		**Post-cure**	
	°C	**° F**	**°C**	**° F**
M	60	140	60 - 90	140 - 190

Maximum curing temperatures

2.5 Resin Infusion and Injection

General

In the infusion or injection process, dry fibres (mats, woven fabrics, stitched mats and foam core) are placed on the mould and compressed in the mould or under a vacuum bag. Afterwards, the mixed resin is pressed through the open cavities in the laminate until all fibres are wetted and impregnated with resin. After the cure of the resin the complete part can be de-moulded.

Advantages of vacuum infusion versus hand lay-up

All vacuum infusion processes show lower emission of solvent during production of sandwich parts. This advantage over the hand lay-up process is well seen if polyester- or vinylester-resins are in use. In addition the reproducibility of parts with vacuum infusion is increased and the number of rejected parts is minimised. If vacuum infusion is used the fibre content in the sandwich parts is generally higher and therefore the mechanical values are improved. The number of bad spots and pin holes in the sandwich are minimised and the adhesion skin to core is increased. The labour costs to produce large sandwich parts can be reduced and it is possible to build up a cost effective rationalised production.

Vacuum Infusion Process

There are different ways to do vacuum infusion. They differ in the way the resin is transported through the dry laminate and weather there is an additional pressure on the resin. The table below shows the different methods and process parameters:

	Vacuum for resin flow	Pressure on resin	Mould closing
Vacuum infusion with flexible bag	0.5 – 1 bar	-	vacuum bag
Vacuum infusion with closed FRP mould (RTM light)	0.3 – 0.6 bar	Up to 1 bar	vacuum / mechanical
Resin Transfer Moulding (RTM)	up to 1 bar	2 – 12 bar	mechanical

The mould needs to be stiffer the more pressure is applied on the resin. Moulds for RTM processing are made of steel or aluminium. They are usually equipped with a heating system to assure a constant and fast production cycle. Vacuum infusion moulds are generally made of wood or glass fibre reinforced plastics, which may be heat able as well.

Vacuum infusion with flexible bag

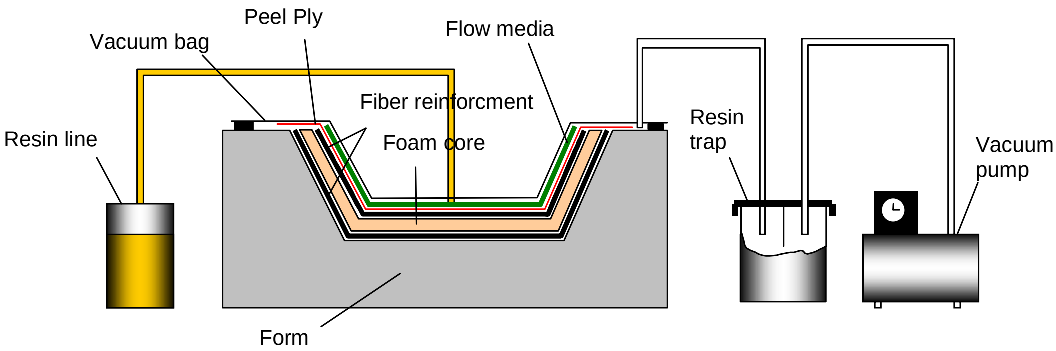
This method is well suited for those who want to switch from hand lay-up to vacuum infusion, as well as for single pieces or prototypes. The existing moulds can still be used. Some modifications have to be done at the flanges in order to be able to place a vacuum bag on the mould. Furthermore a vacuum pump, hoses made of low density polyethylene (or another semi rigid plastic), a resin trap, and the standard equipment for making vacuum bags (tacky tape, vacuum bag, peel ply) are needed and the vacuum infusion process can be started. In chapter 2.8 the set-up of vacuum bags is described in more details.
There are different ways for the resin inlets, e.g. using metal or plastic spirals or open triangular plastic strips. Another possibility is to use special distribution media strips (Enkamat), which can be integrated into the laminate.
The distribution of the resin in the laminate can be done in three different methods. They differ in the way the resin is transported.

SCRIMP™: Seamann Composites Resin Infusion Moulding Process. (Resin flow through flow medium outside of the laminate)

The SCRIMP™ process is characterized by an additional resin flow media outside of the sandwich part. During the infusion process the resin flow media is distributing the resin quickly over the surface of the part from where it infuses into the sandwich component.
Because the resin flow media shall not be part of the sandwich construction peel ply or perforated foil is placed, between the flow media and the surface of the sandwich component. Both layers are designed for one way use and need to be disposed of after curing of the resin.

SCRIMP™ is a patented process owned by TPI.

The following drawing shows the set up for vacuum infusion by the SCRIMP™ process. The resin flow media (green) is separated by the peel ply (red) from the surface of the sandwich component. A vacuum pump is producing the surface pressure by the foil and the suction effect to the resin. This example is using perforated foam core. This allows the resin to flow easily to the other side of the foam core and build a close resin film.



The SCRIMP™ process has some disadvantages. The flow medium and other plies give lot of waste. Also more resin as required by the part is used.
New reusable silicon vacuum bags were developed to reduce the amount of waste. However new design of mould needs a specially produced foil with integrated runner moulds. The fact the foils are reusable give advantages in small and medium number of parts production.

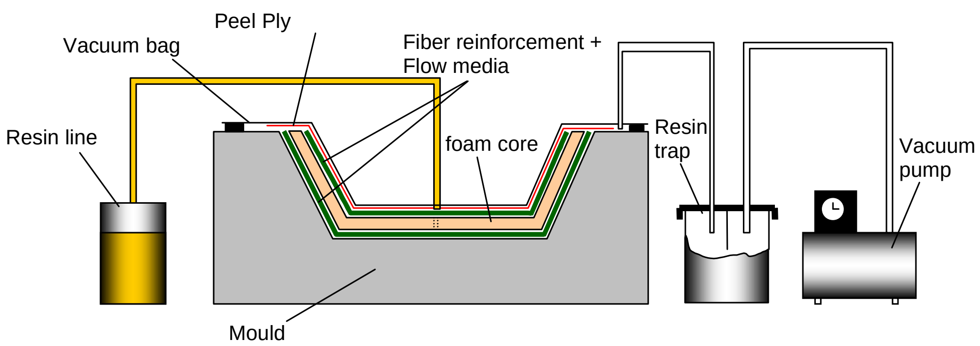
Important note !

SCRIMP™ is a patented process owned by TPI. To use this process for production of FRC components it may be necessary to be in possession of a licence. Additional information about the process and patent condition can be found on http://www.tpicomposites.com

Flow medium

Instead of using a flow medium outside of the sandwich part there is the possibility to use a flow mat which is performing directly as flow media. Continuous fibre mats, e.g. Unifilo from Saint-Gobain Vetrotex or mixed mats of glass- and polyester fibre like Rovicore (mixed fibre mat of polyester fabric covered by two CSM mats) are good examples for such mats. Using such types of mats will reduce the waste but increase the resin content in the composite, therefore reducing the fibre content.

The thickness of these fibre mats before using is some millimetres. Applying the vacuum compresses the mat significantly and reduces the resin flow strongly. For this reason it is not recommended to apply the maximum possible vacuum pressure if using fibre mats as flow medium. The optimal pressure differs, depending on the part between 0.3 and 0.5 bar (4 to 7 psi).
The set up if using flow mats (dark green) is given in the following drawing. Similar to the SRIMP process the foam core must be perforated to wet uniformly both sides of the sandwich.



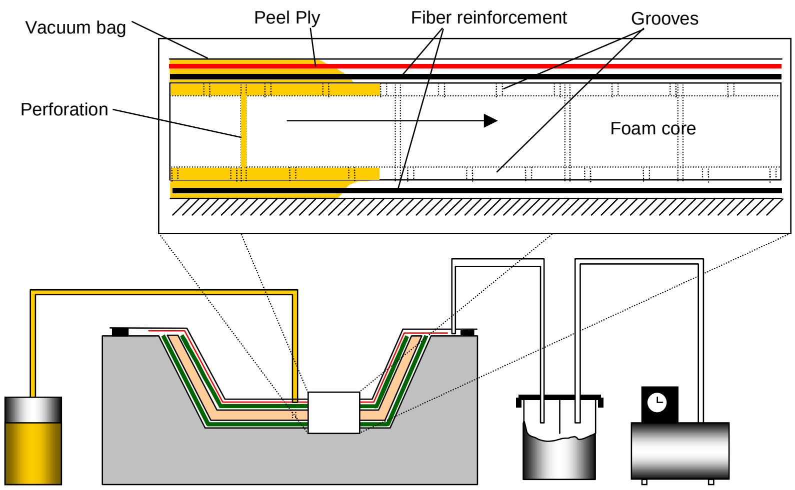
The disadvantage of flow mats is that resin rich skins are produced. The fibre content is reduced to 20 percent or even less.

Grooved Foam

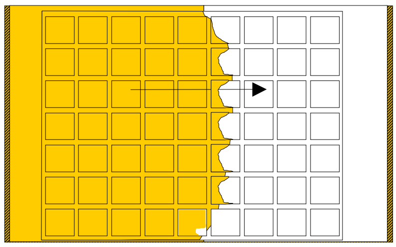
Grooved foam enable the resin to flow easily and quickly trough the grooves and holes and to distribute uniformly in the sandwich construction. With grooved foam there is no need for additional flow mats or flow media. For almost all applications the following pattern of grooves can be recommended.

For resin transport a square pattern of grooves are millcut in one or both sides of the foam. The ratio of width to depth of the groove is quite low. The depth of the groove is larger than the width. This minimise the risk of print-through on the gel coat. The distance between the grooves is designed to avoid dry parts, areas with insufficient resin impregnation. In addition the foam is perforated with holes of about 2 mm in diameter in a distance of approximately 50 mm. The perforation will ensure the resin transport and the uniform wetting on both sides of the foam core

The principle of infusion with the foam core acting as resin transportation medium is shown in the following drawings.



Cross section

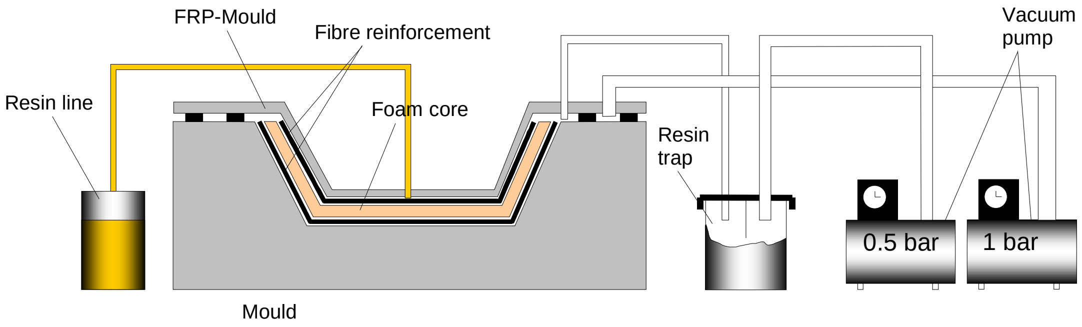


Top view

Vacuum infusion with closed FRP-mould (RTM light)

Closed moulding vacuum infusion gives the opportunity to produce ready to use surfaces on both sides of the composite in one single shot. In this process the flexible vacuum bag is replaced by a FRP counter-mould of some millimetre thickness. This mould must be fixed on the edge of the base mould either by clamps or by an additional, second vacuum line (see drawing). The compression of the laminate is applied in a similar manner as in the infusion method with flexible bags.

The resin flow can be checked easily through the thin FRP skin. The applied vacuum is pushing and distributing the resin in the mould. If the vacuum level is too high cavities in the laminate can be closed and the resin flow significantly reduced. This is the reason why the vacuum level for this process should not exceed 0.5 bar (7 psi) depending of the type of fibres laminate. The filling up time of the resin can be reduced by applying a slight pressure on the resin. It is important to bear in mind, that the counter-mould should not be damaged or pushed away during the infusion by the applied pressure.



RTM-Process

The Resin Transfer Moulding Process is using high pressure to bring the resin into the mould. The mould can contain single laminates or sandwich laminates. The high temperature and pressure applied with this process requires higher mechanical and thermal properties of the foam. More details to the RTM process will not be given here. A lot of information and publication concerning the RTM process can be found in the literature.

Requirements for the infusion process

The vacuum infusion technique set up new requirements to resin, fibre mats or fabrics and foam core.

Resin

As opposed to the hand lay up process the resin must have a significantly lower viscosity to penetrate easily into the small cavities in the dry laminate. To prevent imperfect filling of the laminate the gel time of the resin should be set longer compared to the hand lay up resin. As a rule of thumb:

Viscosity	< 300 mPas
Gel time	50 – 90 min or more

Most of the resin producers have such resins in their program. They also provide assistance to increase the gel time without changing the final properties of the resin.

Fibre mats

CSM (Chopped strand mats), woven fabrics and stitched mats can be used also for infusion techniques. However, the resin flow through these mats is quite slow. This was the reason for the development of special flow fabrics. It is possible to incorporate these fabrics in the laminate to accelerate the resin flow. It is possible to arrange in order the different flow fabrics as followed:

- Continuous fibre mats
  e.g. Unifilo of Saint-Gobain Vetrotex
- Flow fabrics with reinforcement effect
  e.g. Rovicore; Chomarat
- Flow fabrics without reinforcement effect
  Polyester fabric

Today stitched mats with incorporated flow layers are available. The development of special fabrics for vacuum infusion is ongoing. Beside of these special flow fabrics the use of standard fabrics, stitched mats, combimats and other mats is still common. These products have partly very high grammage or additional stitched fibre mats.

Foam core

In sandwich constructions the foam core is notably qualified for resin distribution with vacuum infusion technology. The grooves in the foam surface allow the resin to flow easily and the perforation of the foam helps the resin flow on both sides of the laminate at the same speed. The requirements to the foam are:

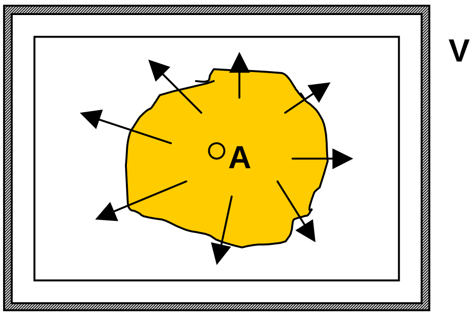
100 % closed cell structure
Styrene resistant (if UP and VE resins are in use)
Resistant to vacuum under the curing temperature

Strategies for the infusion

One of the most important questions considering vacuum infusion is the strategy of wetting out. Where should the resin start to penetrate and where should the vacuum be applied? There are several strategies. The selection of the strategy varies from part to part. The following strategies are known:

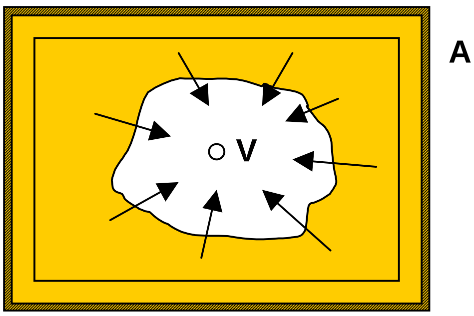
Point feeding

The vacuum line is positioned around the sandwich part. The feeding point of resin is centred. With this strategy the resin flow gets slower and slower during the infusion. The resin mass flow keeps constant while more fabric area must be wetted.



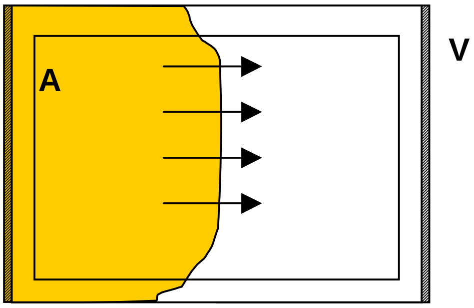
Edge feeding

The vacuum line is placed centred on the sandwich part. The resin flow starts from the edge of the part. This strategy is very quick and dry, not wetted areas are avoided. Additionally the waste of resin is minimised.



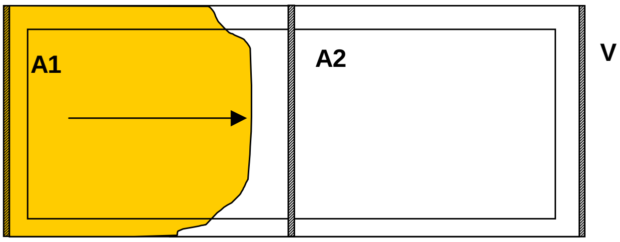
Line feeding

This is the standard strategy for almost all forms to fill. Important for the quality of the infusion is the distance between the vacuum line and the resin feeding. A short distance allows a quick filling of the part. It is recommended not to place the vacuum line more then 50 – 100 cm apart from the resin feeding point.



Multiple feeding

Especially for larger parts it is useful to have more then one feeding lines for the resin. The opening of each point follows the flow of resin. In the shown example, first the feeding point A1 is opened until the resin front reaches point A2. Then A2 opened as well. This strategy can also be used in combination with point feeding.



The chosen strategy depends on many different parameters. The edge feeding is very useful for smaller part up to 100 cm size. The point feeding is useful for the SCRIMP process. Line feeding is on first grid if no marks of the feeding points are allowed on the inside of the FRP-parts.

Further guidelines

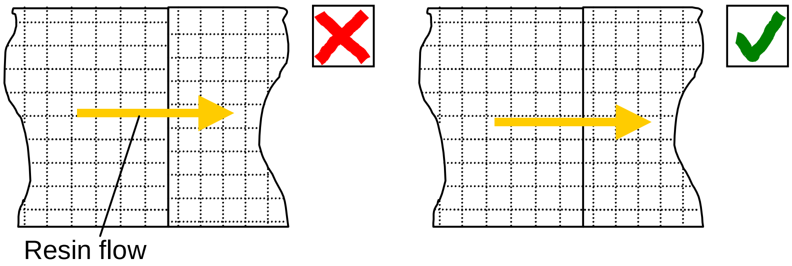
For vacuum infusion you should bear in mind the following points:

Fibre lay-up in the mould

The lay-up of the mould with dry fabric and foam core is difficult and must be evaluated and done very carefully. In case of vertical or inclined positions in the mould the layers must be fixed with adhesive or mechanically. Areas with adhesive can create weak parts in the finished sandwich construction. A good solution is the use of spray adhesive for the fixation of layers.

Assembling of foam

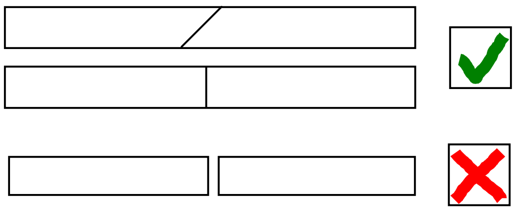
The assembly of foam in the mould need to be done carefully. No gaps between the foam sheets are allowed, since these will act as resin runners. In the resin flow direction, the groove pattern of the sheet must match that of the next sheet.



The foam sheet must be assembled without any gap. Void volumes between two sheets crate higher resin flow along the edge of the sheet. During the infusion process this problem can lead to en-trapped air.
Qualified techniques for assembling foam sheets are:

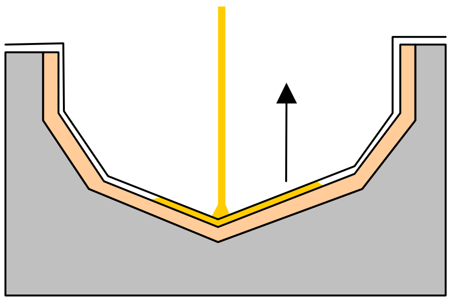
45° or 30 ° chamfered / mitred (with or without bon ding)
90° butt joint (with putty or hot melt bond)

With thin skins the 90° butt joint can print trough on the surface.



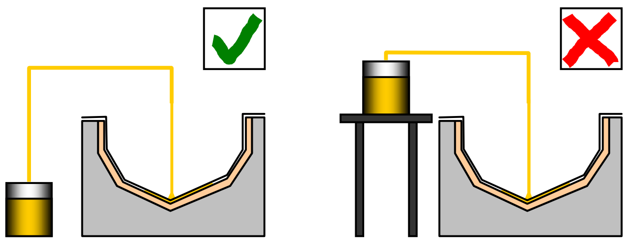
Resin flow upwards

With 3 dimensional sandwich part's the resin should flow always upwards.



Resin tank below feeding point

The resin reservoir must be placed below the feeding point other-wise resin rich area will be generated.

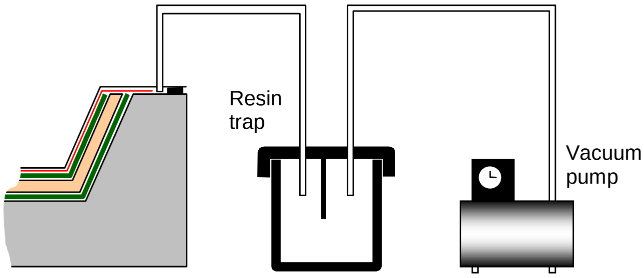


Temperature control

To set up the gel time of the resin it is important to know the temperature of the mould and of the resin.

Resin trap

To avoid resin flow into the vacuum pump a resin trap must be used between the vacuum pump and the part.

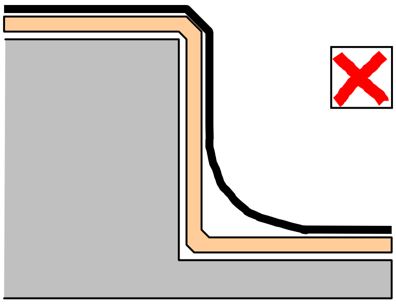


Number of feeding points

It is recommended to have as many feeding points as possible. If one is not needed during the infusion process - no problem. If one is needed urgently but is not available trouble will start.

No bridge-building with 3D parts

The vacuum bag must be placed over 3-dimensional parts in such a manner that no bridge-building is possible. Bridges act as resin channels and will be filled very quickly with resin. The foreseen resin front will be destroyed and dry spots could be build in the part.



Additional Information

There are various sources for further information about vacuum infusion process.
Many producers of resins provide special resins for the infusion technology and have additional information about vacuum infusion. Also, producers of fabric and stitched mats can supply information about the fabrics and their use for vacuum infusion process.
Vacuum consumables needed for vacuum infusion technology can be bought from different dealers. These companies run a large range of products for vacuum infusion process.

For further information please also consider professional literature. Many publications about vacuum infusion technology area available from journals like «professional boatbuilder» or «reinforced plastics» or on the internet.

2.6 Processing with prepregs

General

The use of prepreg - normally pre-impregnated woven fabrics - has a number of advantages over wet lamination processes: by their use, laminates with higher fiber contents within closer weight tolerances can be achieved. This results in higher and more constant mechanical properties, leading again to lower structural weights. Furthermore, lay-up times are shorter, labour costs are smaller, the manufacturing process is cleaner and the emission of volatiles is lower. Commonly used prepreg systems are based on epoxy and phenolic resins.

Processing

Prepregs are normally processed using one of the following methods:

- Vacuum bagging
- Autoclaving
- Compression moulding

Vacuum bagging

For processing at low pressures, vacuum bagging is the cheapest method. Tooling can be kept relatively simple and curing can take place in a standard hot-air circulation oven.
The face sheet under the vacuum bag usually shows a pattern of fine resin-rich surface lines, caused by the occurrence of wrinkles in the bag when vacuum is applied. Further, placement and sealing of a vacuum bag is a time consuming process.

Autoclaving and compression moulding

If for optimum laminate properties higher pressures are recommended by the prepreg suppliers, processing has to take place in autoclaves or compression moulding presses. If there are optical requirements only for one face of the sandwich structure, processing can take place in an autoclave. In this case, only one tool half is needed. If both surfaces have to fulfil optical requirements or if large series have to be manufactured, it is recommended to use a press with a pre-heated, temperature controlled male/female mould.

Recommendations with respect to the optimum curing temperature and pressure should be taken from the processing guidelines supplied by the prepreg manufacturer. However, these often specify relative high pressures. This to make sure, that void-free laminates are manufactured in all cases, including for relative thick laminates. For this, high pressures are required to squeeze entrapped air out of the centre of the stacked prepreg lay-up through a large number of plies. For sandwich structures however, face sheets are normally relatively thin and consist of only a small number of prepreg plies. In these cases, lower pressures can be used without reduction of the mechanical properties. The optimum pressure can, and sometimes needs to be adjusted to the compressive strength of the foam at the curing temperature.

Foam preparation

For vacuum bagging and autoclave processing, the foam normally doesn't need to be prepared other than pre-cutting its overall dimensions.

To take air entrapments and excessive resin out of the laminate, vacuum is applied and perforated release films or bleeder fabrics are placed on top of the prepreg lay-up.

By compression moulding excessive resin can not be extracted from the laminate. Therefore it is recommended to mill a groove pattern into the surface of the foam. Otherwise a relative thick interface between face sheets and foam with poor mechanical properties is created. To know how to apply the grooving, consult chapter 2.1. Needling or perforating holes in a regular pattern can also be done. However, it should be checked, that relaxation of material pushed back by the needle does not result in re-closure of the holes during the time between needling and further processing.

Interface layer

As prepregs are supplied in a, to a large degree, weight optimised form, they do not contain much excessive resin. On the other hand, the surface of a foam consists of open cut-through cells and needs to pick-up a relative large amount of resin. For proper bonding it is therefore often necessary to apply a special interface layer.

Prepreg with increased resin content

As first ply directly on top of the foam, it is recommended to use a prepreg with a slightly increased (5 – 10 % by volume) resin content, in order to compensate for the resin absorption of the core. For the remaining plies of the lay-up, prepregs with standard resin contents may be used.

Adhesive film

Alternatively, an adhesive film can be added between foam core and prepreg lay-up to compensate for the lack of resin at the foam interface. In this case, the compatibility of the adhesive film and the resin of the prepreg should be checked first with the prepreg supplier. The addition of an adhesive film can have further advantages. For instance, by using an adhesive resin with a higher strain at break than the resin of the face sheets, the peel strength of the sandwich structure can be much increased. Furthermore, adhesive films can function as a barrier ply between foam and prepreg in case the two materials should show incompatibilities.

The recommended area weight of adhesive films lies between 80 and 150 g/m² (0.25 - 0.5 oz/ft²), depending on the type of density of the foam. Lower density foams require more adhesive, because of the larger volume of the cut-through, open surface cells.

Compatibility of foam and prepreg

Direct bonding of prepregs to foam can be achieved through the pre-impregnated resin during the curing process. This so called co-curing of prepregs to core materials represents a cost-effective method of production. However, before manufacturing a sandwich part, the compatibility of foam and prepreg needs to be verified.

Thermoplastics can basically be solved in certain liquids. Since all foams from MYCELL™ foams are thermoplastic, some liquid resins can lead to solvation phenomena. The requirements for this to happen are a high temperature close to the melting point of the foam and a low viscosity of the prepreg resin.

Prepreg resins usually go through a low-viscosity phase during curing. This allows the entrapped air to evacuate before the viscosity of the resin rises and it fully cures. Under these conditions, surface cells at the foam prepreg interface can be dissolved. In extreme cases this can result in an undesired reduction of the initial core thickness and a too thin sandwich structure after processing. This again could lead to too weak structures.

Therefore, it is very important to check the occurrence and degree of solvation phenomena. General rules cannot be applied since several factors such as prepreg type, resin viscosity profile, curing cycle, shelf life behaviour, foam type and foam density are involved.

If solvation should occur to an extent which is unacceptable, the following counter measures can be taken:

- An alternative curing cycle with a different viscosity/time curve can be chosen
- The prepreg can be allowed to age at room temperature before processing (of course within the allowable remaining storage time). This normally increases the minimum viscosity of the resin.
- Adhesive films can be placed as barriers between foam and uncured prepreg.

2.7 Bonding of different skin materials to foam

General

Bonds generally serve one of the following purposes:

- joining sheets of the same material
- bonding of foam cores to metallic, plastic, composite or wood faces

Bonding of MYCELL™ cores to themselves or other materials in general does not pose any problems, if the proper type of adhesive system, bonding method and equipment is used.

Before bonding core materials to metal skins, please consult your material supplier first for the required surface treatment of the skin material and your adhesive supplier for the required bonding system. Keep in mind that some metallic surface treatment systems have a limited storage life.

Of the range of possible adhesive types, two kinds are suitable for foams:

- Thermoset adhesives
- Hot-melt adhesives

Important note !

Adhesive systems containing water or higher amounts of solvents may not work as the foam or skins are an impermeable barrier to volatiles. Contact adhesives therefore are not suitable for bonding of large areas. The systems contain solvent that has to evaporate before bonding. The time for this evaporation process is to choose accordingly to the adhesive supplier's instructions. The great advantage, however, is that an immediate bond is produced by pressing the parts together.

Thermoset adhesives

Thermoset adhesives are supplied as film, paste or liquid. They can be cured at room or elevated temperature. Make sure that processing parameters will not cause any distortion of foam or sandwich during curing or post-curing at higher temperatures and longer times.

The table given below is a guide to what type of adhesive we recommend for the most common combinations of our foams with other materials.

Adhesion to	Type of foam					
	R63	**R82**	**C51**	**C70**	**C71**	**T90/92**
Foam	PUR, UP EP	EP, PF	PUR, UP, EP	UP, EP PUR, VE	UP, EP PUR, VE	UP, EP PUR, VE
Metals	PUR, EP	EP, PF	PUR, EP	PUR, EP	PUR, EP	PUR, EP, PF
FRP cured	PUR, UP, EP	EP	UP, PUR	UP, PUR, EP	UP, PUR EP	UP, PUR, EP
Wood (Plywood)	EP, PUR	EP, PUR	EP, PUR	EP, PUR	EP, PUR	EP, PUR
Plastics (Thermo-plastics)	PUR, EP	PUR, EP	EP, PUR	EP, PUR	EP, PUR	EP, PUR

Recommended thermoset adhesive types for bonding of foams to other materials

PUR: Thermoset Polyurethane; UP: Unsaturated Polyester; EP: Epoxy;
VE: Vinylester; PF: Phenolics

Polyester (UP) and Vinylester (VE) resins

Particularly in boat building, they are the most frequently used adhesives to bond foam cores to FRP skins. They are relatively inexpensive, easy to handle, cured at room temperature and have a good moisture resistance.

Both, laminating resins as well as polyester based putties are suitable for bonding, provided no air remains trapped during the process and the bonding surfaces are clean. We recommend that the foam be primed with a thin layer of promoted resin (see chapter 2.3)

A laminate laid up in a female mould should be cured before the foam is bonded to it, because the thermal insulation provided by the foam and the mould will otherwise cause a strong exotherm build-up, leading to damage of the mould and the core.

Viscosity and elongation at break are the main factors influencing the final bond.

Epoxy resins (EP)

Epoxy systems applied either wet or as film are used for structural applications because of their long-term stability, low shrinkage and suitability for vacuum curing.

When post-cured, these systems have high elongation and excellent mechanical properties.

The MYCELL™ M foam materials may be used together with wet lay-up systems as well as low temperature cure adhesives. For further information see chapter 2.4.

Polyurethane resins (PUR)

Polyurethane two component systems suit a wide range of applications as they offer excellent properties at moderate costs.

Many of these systems require heat curing to obtain a reasonable cycle time. If exposure to humidity in the application is expected, the system will have to be chosen accordingly.

Phenolic resins (PF)

Phenolic resins are used for aluminum skins, fire or corrosion requirements. When cured adapt the time-temperature-pressure curing cycle to avoid debonding or blisters caused by the water, which is created by the chemical reaction.

Because of the chemical nature of all MYCELL™ foam cores, the water will not be absorbed from the material or steam off in a reasonable time.

Important note !

Postcuring at temperatures above the glass transition temperature of the foam is possible with a balanced time-temperature cycle. It is important to run own tests in advance and verify that dimensions and mechanical properties of foam cores remain unchanged.

Thermoplastic hot-melt adhesives

Hot-melt adhesives are thermoplastics that become tacky when they are molten. At room temperature they look like normal plastic films and are not sticky. To achieve bonding, the adhesive film has to be heated above its melting point and the parts should then be pressed together.
Hot-melt adhesives can only be used to bond skins onto foam. However, they make it possible to easily bond skins made from polyolefins or polyamide to foams.

The table below is a guide to what type of thermoplastic adhesive we recommend for the most common combinations of our foams with other materials.

Important note !

The maximum service temperature of hot-melt adhesives is usually about 30 °C (55 °F) below the adhesive melting temperature.

Adhesion to	**Foam type**					
	R63	**R82**	**C51**	**C70**	**C71**	**T90/92**
Metals/Wood	PE, PP	PE, PP	PE, PP	PE, PP	PE, PP	PE, PP
FRP cured	TPU, PA	TPU, PA	TPU, PA	TPU, PA	TPU, PA	TPU, PA, PU
Plastics (Thermo-plastics)	PE, PP EVA, TPE	PE, PP EVA, TPE	PE, PP EVA, TPE	PE, PP EVA, TPE	PE, PP EVA, TPE	PE, PP EVA, TPE

Recommended hot-melt adhesive types for bonding of foams to other materials

PE: Polyethylene; PP: Polypropylene;TPU:Thermoplastic Polyurethane; EVA:Ethyl-Vinyl-Acetate; PA: Polyamide; TPE: Thermoplastic Polyester

Polyethylene (PE)

PE-based adhesives are all purpose adhesives with reasonable costs and fast processing times. Their maximum application temperatures and peel strength is fair.

Polypropylene (PP)

PP-based adhesives are used to achieve a higher bonding strength and high service temperatures. The range of materials bond as skins on the foam is wider than with the PE adhesives.

Thermoplastic Polyurethane (TPU)

TPU adhesives give good bond strength of skin and core up to a reasonable temperature. They can be used in prepreg processing with phenolic resins to act as a moisture barrier and increase the peel strength of the laminate. High peel strength is achieved with aluminum skins.

Ethyl-Vinyl Acetates (EVA)

EVA adhesives resist plasticiser migration and give a good bond to polyolefine skins.

Polyamide (PA)

PA adhesives allow the highest service temperature of all adhesives. The possible range of materials which can be bonded is limited.

Thermoplastic Polyester (TPE)

TPE adhesives give an outstanding bond to PVC and resist plasticiser migration. The resistance to cleaning agent or other media is good.

Equipment

A check-list of equipment will include the following items:

- Roller, doctor blade, trowel or squeegee
- Spraying or dispensing equipment, if available
- Vacuum-bagging equipment, an advantage but not a must
- A press, preferably equipped with heating and cooling arrangement
- Sand bags or lead weights

Important note !

The quality of workmanship is the governing factor to obtain high quality bonds. Proper equipment will assist but not ensure perfect bonds.

Bonding procedure

There are three separate steps in bonding:

- Preparation of the surfaces
- Applying the adhesive
- Pressing the parts together

Thermoset adhesives
Preparation of the surfaces

All surfaces must be dust and grease free. Surfaces like cured composite laminates or metals might need to be roughened, aluminium requires priming.

If both skins are bonded onto the foam at the same time, the foam surface must be grooved on both sides to let out entrapped air. Grooving is recommended as well if a press is taken to bond the skins onto the foam. If the vacuum bag processing is chosen and the foam is bonded on a cured laminate or on metal skins, holes of approx. 2 to 3 mm (1/16 to 1/8 in) diameter and at equal distances of 50 - 100 mm (2 - 4 in) apart are recommended (chapter 2.1).

Priming the foam itself is recommended, as it increases the peel strength. Where a bonding putty is used, make sure it not only bonds the foam, but also fills voids in the core (contoured or scrim cloth type cores).
The amount of resin used for priming the core must not exceed 200 g/m² (19 g/ft²) for core densities below 100 kg/m³ (6.25 pcf) and 100 g/m² (9 g/ft²) at higher densities.

Applying the adhesive

Take great care to apply the amount of adhesive recommended by the manufacturer. Use a roller to spread the resin and a squeegee to ensure that the resin spreads along the cut cell walls.

The minimum amount of adhesive used for bonding is given in the table below:

Density of foam		**Minimum amount of adhesive**	
kg/m³	pcf	g/m²	oz/sq.ft
below 50	below 3.15	500	1.6
50 - 100	3.15 - 6.25	300	1.1
100 - 200	6.25 - 12.5	200	0.7
above 300	above 18.75	150	0.5

Minimum amount of adhesive used for bonding

Pressing the parts together

Take measures to avoid parts moving into undesired positions while bonding them together. Use clamps or other fixing devices.

It is recommended to cure reactive adhesives under vacuum (between 0.2 to 0.3 bars absolute = 3 to 4.5 psi abs). The viscosity of these systems should be low enough to allow some resin to penetrate the cut surface cells. If sand bags or lead weights are used make sure that debonded areas between them do not occur.

If you intend to postcure the bond at higher temperature, the table below gives the maximum operating temperature for the various foam types. Postcuring under low compressions may be undertaken at temperatures 20 to 30 °C (65 to 85 °F) higher th an the operating temperature.

Foam	M
Temp. °C	100
°F	210

Maximum temperature for postcuring of thermoset adhesives

Important note !

Remember that the foam has lost part of its stiffness at these temperatures. It is necessary to properly protect the geometry by using distance bars when curing.

Reactive adhesive films need to be warmed prior to bonding. Grooved sheets are helpful to allow volatiles and air bubbles to be evacuated when gluing under vacuum.

Important note !

Air bubbles must be avoided at any cost when bonding parts together, otherwise the bond will be dramatically weakened.

Hot melt adhesives

Preparation of the surface

All surfaces must be dust and grease free. Surfaces like cured composites laminates or metals might need to be roughened. Aluminium requires priming.

Applying the adhesive

Dependant on the cell size we recommend adhesive films between 50 to 300 g/m² (0.16 to 1 oz/ft²). Perforating the film in regular intervals helps to prevent bubbles building up. For all bonding surfaces the foam must be grooved to get out entrapped air. If one side is bonded first, holes of approximate 1 - 2 mm diameter (1/32 - 1/16 in) at equal distances of 50 mm (2 in) are required.

Pressing the parts together

We recommend 1 to 5 bar pressure depending on the foam density and treatment temperature. An additional thickness of 1 to 2 mm related to the foam thickness of the final part will help to increase the bonding strength. This additional thickness compensates manufacture tolerances of the thickness, makes a constant high pressure reliable and takes creep into account. Distance bars might help to achieve the final thickness.

Important note !

If the total handling cycle is not longer than 40 sec. and spacer bars are used to prevent excessive compression of the foam the following surface temperatures are allowable:

Foam type	M
Temp. °C	150
°F	300

Maximum temperature for bonding with hot melt adhesives

2.8 Processing by vacuum bagging

General

Vacuum bagging is an effective and comparatively inexpensive method of using atmospheric pressure to achieve a uniform and readily controllable pressure on flat and three-dimensionally shaped panels. The maximum theoretical pressure is about 1 bar (14.5 psi). The maximum pressure achieved with standard equipment range from 0.8 to 0.9 bar (11.6 to 13 psi). Vacuum bagging is used for thermoforming (chapter 1.3), simple bonding of foam (chapter 2.7), foam core installation (chapter 2.3) as well as for prepreg facings (chapter 2.6). The techniques vary according to the nature of work in hand. Generally the method of "dry-bagging" is used in conjunction with foam cores, as opposed to "wet-bagging", the method used in the manufacture of reinforced plastics of comparatively high fibre content.

Processing aids

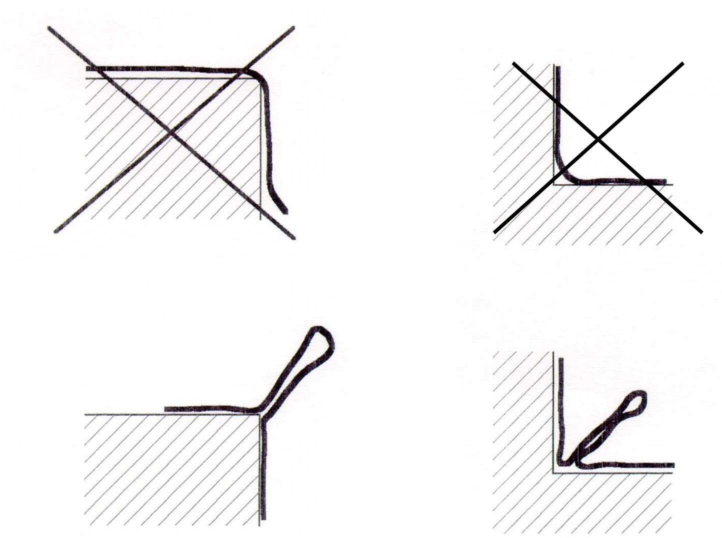
Bagging film

Bagging films are next to the vacuum pump the most important item of equipment. Bagging films must be flexible, tear resistant, non-porous and compatible with the resin systems, in particular styrene.
While reusable vacuum bags are made of elastomeric material (rubber), disposable vacuum film bags can be made of polyethylene (PE), nylon (PA) or silicone. There are no restrictions on the film gauge as long as it stretches easily and it holds the vacuum. Heat resistant films will be necessary if curing of the resin at elevated temperature is required.

Handling of disposable bagging film

Disposable bagging films cannot be stretched in the manner as an elastomer material can. They do not always conform well to the part. For plastic film bags, pleating is the remedy and it is also one method of avoiding stress concentrations particularly on low density foam cores.

Edges Corners



Sealant tape

Sealant tapes must be pliable and tacky. They are designed to form a vacuum tight seal between bagging film and the tool surface. During the resin curing process they cure to a tough rubbery material. When the vacuum bag is dismantled, the sealant must peel off the mould surface without leaving a residue.

Peel ply / bleed ply

Peel plies or bleeding plies help to extract excessive resin and result in a higher fibre content of the laminate.
For simple installation of foam cores it is not necessary to use special peel and bleed plies. Instead it is sufficient to cover the core area and wrap laminate and core together in an ordinary polyethylene film. This applies in particular to core materials of the "contoured" and "scrim cloth" variety.

Breather

The breather ply should consist of a material which under vacuum pressure will not entirely compress and block the passage of air. Bubble plastic film or veil may be used as readily available materials. Care must be taken to extend the breather ply right under the vacuum valve in order to secure an uninterrupted air flow.

Vacuum valves

The vacuum valve consists of a metal base plate, gasket, pressure plate and lock-ring. It is installed in the vacuum bag by cutting an X into the same.

The following is a guide for determining the number of valves needed for installing a certain core area:

Area	**Number of valves**
< 2 m^2	1
2 - 10 m^2	2 – 3
10 - 50 m^2	4 – 6

Number of valves needed for installing a certain core area

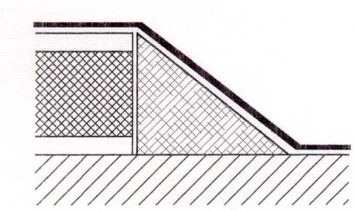
Vacuum source

An electrically operated vacuum pump is the most common source of vacuum. Instead of a vacuum pump a venturi block may serve the same purpose, particularly for minor work.

Fabrication

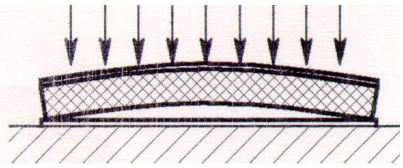
Bonding

The manufacture of flat, two, or three-dimensionally shaped sandwich panels with facings of FRP, thermoplastic plain or reinforced sheets, follows to a great extent the working practise outlined in the foregoing chapters.



Bonding both faces simultaneously usually causes problems with entrapped air between three faces and the core. Single or cross-wise grooved core must be used (see chapter 2.1).

The upper edges and corners of sandwich panels, especially those with thicker low density foam cores should be protected from localized stress by framing the panel with wedges of suitable dimension made of wood or plastic foam.



It is imperative that foam core panels, especially thick panels, above approx. 40 mm (1½ in), intended for simultaneous bonding of the faces are absolutely flat, e.g. free from dishing.

To assume that a dished thick foam core panel will be pressed flat under full vacuum pressure is a hope against hope. The bending stiffness of a thick foam panel is more often than not quite sufficient to withstand full vacuum pressure. The resulting void will cause the growth of a bubble or blister, particularly if a styrene containing resin or putty is used for bonding.
Dished panels can be straightened by heating above softening temperature and cooling under pressure in a press.

Prepreg processing and laminating by the vacuum bagging method

Prepreg processing on foam cores or curing of wet laminates at ambient or elevated temperature by the vacuum bagging process require a somewhat more advanced technology than the simple installation of foam cores on prefabricated or cured laminates or the adhesive bonding of entire sandwich constructions.
First of all, there is the surface texture of the finished laminate to be considered and secondly the quality of the bond between laminate and foam core. These items are dealt within the chapter 2.8.