PROCESSING GUIDELINES

Contents

Europe | Middle East | India | Africa
Airex AG
5643 Sins, Switzerland
T +41 41 789 66 00 | F +41 41 789 66 60
corematerials@3AComposites.com

North America | South America
Baltek Inc.
High Point, NC 27261, USA
T +1 336 398 1900 | F +1 336 398 1901
corematerials.americas@3AComposites.com

Asia | Australia | New Zealand
3A Composites (China) Ltd.
201201 Shanghai, China
T +86 21 585 86 006 | F +86 21 338 27 298
corematerials.asia@3AComposites.com

1 Purpose/Scope

This processing guideline should help working smoothly with AIREX® core materials.
It is a general tool to give guidance and is based on working experience. The guideline is divided in two sections showing in a first part how to condition and process foams themselves and in the second part all important steps to produce sandwich structures with AIREX® foam cores. Since processing of foam also may influence sandwich manufacturing, some aspects are covered only in one or the other section.
In case of further information needed, please contact AIREX® Technical Services.

2 Conditioning and processing of AIREX® foam cores

2.1 Storage

Storage

All foams should be stored in a closed storage room at temperatures above 10 °C (50 °F) and below 30 °C (86 °F) and below 80 % R.H. Solvents and foam should not be stored together as the foam may absorb solvent volatiles.
Long storage times may result in change of dimensions 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.

Especially for PVC, direct exposure to sunlight should be avoided to prevent irregular shrinkage of foam sheets and change of colour pigments.

It is highly recommended to keep the foam for a minimum of 24 hours in the workshop before use, especially if the storing temperature is low or 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.

2.2 Conditioning of cross-linked PVC foam

Degassing of cross-linked PVC cores

Due to their chemical nature and production process, crosslinked PVC-foam cores (e.g. AIREX® C70 and C71) tend to release small amounts of gas during the skin curing process.

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.
Mainly cutting or sanding operations activate outgassing due to exposition of new foam cells to atmospheric pressure. The outgassing continues until a new equilibrium is reached.
Therefore it will never be possible to entirely degas a crosslinked PVC foam block or sheet. Each time the material is newly cut, the outgassing process will start again.
In order to prevent undesired effects such as delaminations, degassing procedures have been defined. The main parameters influencing the outgassing of crosslinked PVC foams are time and temperature.

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

Thermal treatment

By 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 °C for approx. 7 days** has proven to be the safest method for an accelerated degassing. Only little 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 °C) is required. As a rule of thumb one can say that a 10 °C modification of treatment temperature will double the treatment time or divide it by two accordingly.
Examples:
50 °C ⇒ 3 days, 60 °C ⇒ 1.5 days etc. or 10 °C ⇒ 2 months

Basic Rules

1. In order to avoid excessive outgassing, the foam should be in an equilibrium state before being processed. This can be achieved best by thermal treatment or storage before and after the material has been cut to the final panel sizes or kits. For further details consult AIREX® technical service

2. Extensive heat processes for sandwich curing may provoke outgassing. However, after a good adhesion between core and skin is achieved, a post cure heat treatment is no danger to the sandwich.

3. High accumulation of resin (e.g. large gaps, wide and deep cuts or grooves) can provoke a high exothermic reaction before the resin has cured. The elevated temperature accelerates the gas diffusion and can cause outgassing reactions which results in trapped gas lifting the skins and causing a delamination or never-bond area.

4. In some rare cases epoxy resins may be inhibited by the CO_2 developed during outgassing. In such cases it is recommended to seal the core with a thin layer of room temperature curing resin.

2.3 Mechanical conversion processing

General

AIREX® rigid foams are easy to process by mechanical conversion methods. Generally, wood-working equipment and tools are adequate. With rigid foams of higher densities, 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 dust and foam particles. Proper ventilation, vacuum-assisted dust collection and personal protection are essential. Please refer to the respective material safety data sheet.

Cutting methods

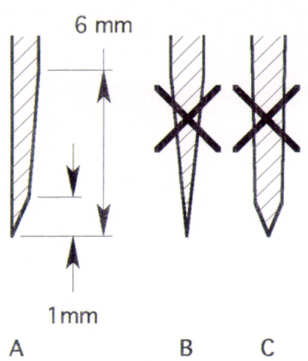
Up to a certain thickness and depending on density and material type, sheets can readily be cut by knife, e.g. Stanley knife.

Knife cutting

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.
For densities below 130kg/m^3, maximum sheet thicknesses typically are:

AIREX® R63	25 mm
AIREX® R82, C51	20 mm
AIREX® C70 / C71 / T90 / T92 / T10	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

Generally AIREX® foams can be processed with typical wood working machines and equipment with commercially available tools.

Foam type	Machining operation			
	Sanding	Drilling	Milling	Sawing
R63	✸	□	○	○
R82	✸	✸	✸	✸
C51	✸	□	✸	✸
C70/C71	✸	✸	✸	✸
T90/T92/T10	✸	✸	✸	✸

✸ method suitable
○ suitable, but special attention to cutting speed and tool configuration needed
□ method can be used, but better alternatives are available (e.g. punching)

Important Note!

After machining operations it is essential to remove the dust to avoid poor adhesion between core and skins.
The use of vacuum cleaning equipment is preferable to compressed air.

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.

Because of the high speed at the outer perimeter, portable circular sanding equipment can cause superficial melting of thermoplastic foams such as T90/T92/T10.

A good alternative are oscillating sanding tools.

Cutting of plugs and large diameter holes

Plugs or large diameter holes can be cut-out even from higher density foam sheets with the help of special cutter cylinders. The numbers of bits are preferably kept low (for example about four). The use of hard-point tools is recommended. The cutting speed and feed-rate depends on the material characteristics and is best ascertained individually.

Milling

Rigidly built high speed machines with solid bearings of the type used for machining of light alloys, permit the high cutting speeds at minimum feed rate, which are essential for machining the higher density (thermoplastic) foam materials. The rake angle should be small. Together, high cutting speed at minimum feed rule and small rake angle help to minimise the heat development and therefore avoid softening or even melting effects.

Machining of finished sandwich panels

Cutting tools are to be selected according to the facing materials (FRP, metals, plastics, etc.) and the desired quality of the cut surface. Cutting speed and feed-rate are to be chosen such as to prevent the core temperature rising above 50 °C (122 °F).

To prevent the lower sandwich facing from possible forced delamination and damage, we strongly recommend the use of fore-cutters and a strong supporting material, for example plywood.

2.4 Thermoforming

General

For the thermoforming process, the foam is first subjected to elevated temperature (above glass transition Temperature Tg, below melting Temperature Tm), 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 AIREX® 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 infrared heaters

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.

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. Generally speaking, convection is the safest method of heating foams.

Processing temperatures

The following oven temperatures are recommended for thermoforming:

Foam type	Optimal oven temperature for thermoforming (°C)	(°F)
C51	140 - 160	285 - 320
R63.50	90 - 95	195 - 205
R63.80	95 - 105	205 - 220
R63.140	100 - 110	210 - 230
C70.40 - 90	115 - 130	240 - 265
C70.130 - 200	120 - 135	250 - 275
C71	140 - 155	285 - 310
R82.60	205 - 210	400 - 410
R82.80	210 - 215	410 - 420
R82.110	215 - 220	420 - 430
T90/T92/T10	155 - 190	310 - 350

Heating time

Necessary heating time depends on the heat capacity of the foam, its thickness and tool and shop environment factors.
The heating time can roughly be estimated as follows:

Convection heating: 0.5 - 1 min/mm core thickness
(Circulation air oven)

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

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 aluminium tools is recommended. Through temperature control it can be assured that the thermoforming conditions are reproducible. If the required dimensional tolerances are not too tight, thermoforming could be performed with either a male or female mould only.

Applying pressure

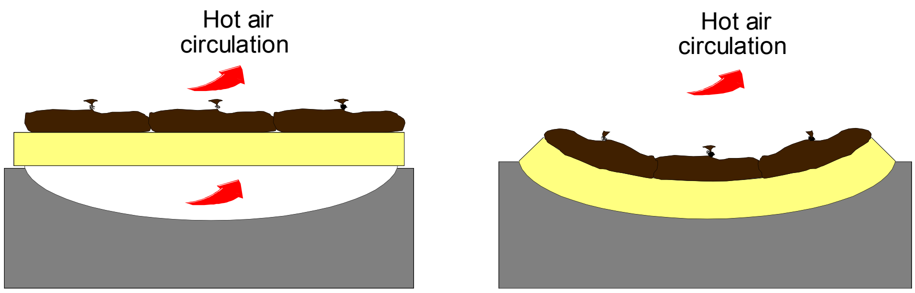
Pressure can be applied in different ways:

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

Within the same product line, for higher densities, higher pressure at same temperature is required.

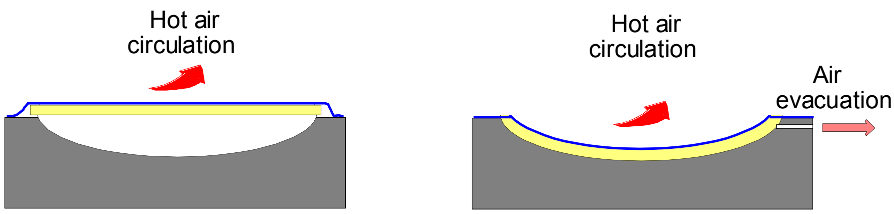
Creep forming

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.



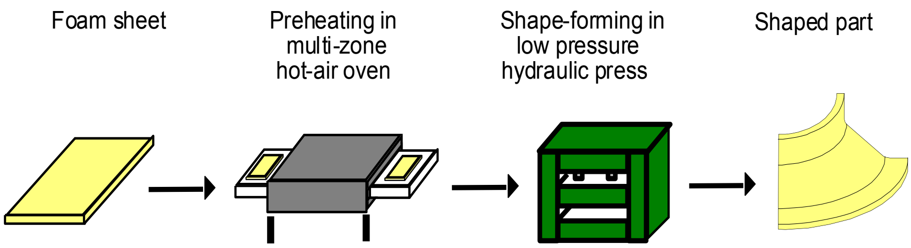
Vacuum forming

Vacuum forming can be done in a hot air circulation oven or an auto-clave. 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 parts with tight dimensional 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 should be long enough to reach the desired temperature in the centre of the core. The metal tool for shape-forming should be temperature controlled. The mould can be opened only after the core has reached a temperature below Tg also in the centre.

2.5 Bonding of different skin materials to foam

General

Bonding 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 AIREX® 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 skin supplier first for the required surface treatment of the substrate and your adhesive supplier for the required bonding system. Keep in mind that some 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. Such systems contain solvents that need to evaporate to enable bonding.

2.5.1 Thermoset adhesives

General

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.

Important note!

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

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 ***Priming (Pre-wetting)*** in **paragraph 3.4.1**)

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.

Please pay attention to the viscosity and elongation at break when selecting the system, as they 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.

AIREX® R63 and the AIREX® C70 foam materials may be used together with wet lay-up systems as well as low temperature cure adhesives. High temperature adhesives may be used on the AIREX® C71, AIREX® R82 and AIREX® T90/T92/T10 types. For further information see **chapter 3.3**.

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 fire requirements. When cured adapt the time-temperature-pressure curing cycle to avoid de-bonding or blisters caused by the water, which is created by the chemical curing reaction.

Because of the chemical nature of all AIREX® foam cores, the water will not be absorbed from the material.

Recommended thermoset adhesive types for bonding of foams to other materials					
AIREX®	**R63**	**R82**	**C51**	**C70/C71**	**T90/T92/T10**
Foam	PUR, EP	EP, PF	PUR, EP UP	PUR, EP UP, VE	PUR[1)], EP UP, VE
Metals	PUR, EP	EP	PUR, EP	PUR, EP	PUR[1)], EP
FRP cured	PUR, EP	EP	PUR, UP	PUR, EP UP	PUR[1)], EP UP
Wood (Plywood)	PUR, EP	PUR, EP	PUR, EP	PUR, EP	PUR, EP
Plastics (Thermo-plastics)	PUR, EP	PUR, EP	PUR, EP	PUR, EP	PUR[1)], EP
	PUR: Thermoset Polyurethane; UP: Unsaturated Polyester; EP: Epoxy; VE: Vinylester; PF: Phenolics [1)] one component PUR is not recommended				

Bonding procedure

There are three separate steps in bonding:
- Preparation of the surfaces
- Applying the adhesive
- Pressing the parts together

Equipment

A check-list of equipment can 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 arrange-ment
- 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.

Preparation of the surfaces

All surfaces must be dust and grease free. Surfaces like cured com-posite 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 3.1**).

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). Further information on priming is given in **chapter 3.3**.

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. If lower amount is used to optimize weight prior adhesion tests are necessary.

Density of foam		**Minimum amount of adhesive**	
kg/m³	pcf	g/m²	oz/sq.ft²
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) - refer also to **paragraph 3.5 *Processing by vacuum bagging***. 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 post-cure the bond at higher temperature, the table below gives the maximum temperature for post-curing.

Foam	**R63.50**	**R63.80**	**R82**	**C51**	**C70**	**C71**	**T90/92**
Temp. °C	40	50	160	110	100	130	150
°F	100	120	320	230	210	265	300

Maximum temperature for post-curing 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 depending on the pressure applied.

Important note!

Air bubbles must be avoided at any cost when bonding parts together, otherwise the bond will be dramatically weakened. Grooved sheets are helpful to allow volatiles and air bubbles to be evacuated when gluing under vacuum.

2.5.2 Thermoplastic hot-melt adhesives

General

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 make it possible to easily bond skins made from polyolefins or polyamide to foams.
Due to the thermal insulation nature of the foam, they cannot be used to join sheets.
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.

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 aluminium skins.

Ethyl-Vinyl Acetates (EVA)

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

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.

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

AIREX®	R63	R82	C51	C70/C71	T90/T92/T10
Metals	PE, PP	PE, PP	PE, PP	PE, PP	PE, PP
FRP cured	TPU	TPU	TPU	TPU	TPU
Plastics (Thermo-plastics)	PE, PP, EVA, TPE	PE, PP, EVA, TPE	PE, PP, EVA, TPE	PE, PP, EVA, TPE	PE, PP, EVA, TPE
	PE: Polyethylene; PP: Polypropylene; TPU: Thermoplastic Polyurethane; EVA: Ethyl-Vinyl-Acetate; PA: Polyamide; TPE: Thermoplastic Polyester				

Bonding procedure

There are three separate steps in bonding adhesive films:

- preparation of the surfaces
- applying the adhesive
- pressing the parts together

Equipment

Generally a press, preferably equipped with heating and cooling arrangement is used when using adhesive films

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

Depending 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 may be grooved to get out entrapped air.

Pressing the parts together

It is recommended to apply 1 to 5 bar pressure depending on the foam density and treatment temperature. The foam thickness may be selected to be 1 to 2 mm thicker with respect to the final core thickness to increase the bonding strength. This additional thickness compensates manufacturing tolerances of the thickness, makes a constant high pressure reliable and takes creep into account. Spacers will allow controlling the final thickness.

Important note!

If the total handling cycle is shorter than 40 seconds and spacers are used to prevent excessive compression of the foam, the following surface temperatures are allowable:

Foam type	R63	R82	C51	C70	C71	T90/T92/T10
Temp. °C	150	250	180	150	180	200
°F	300	480	360	300	360	390

Maximum temperature for bonding with hot melt adhesives using spacer bars.

Important note!

Air bubbles must be avoided at any cost when bonding parts together, otherwise the bond will be dramatically weakened. Grooved sheets are helpful to allow volatiles and air bubbles to be evacuated.

3 Sandwich manufacturing

Introduction

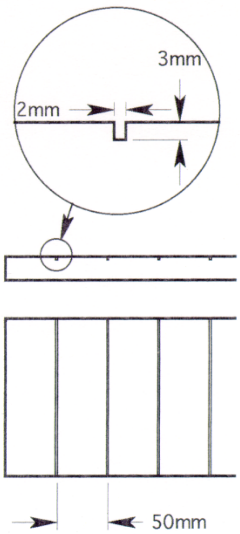
A sandwich product consists of a rigid core bonded to two tensile/compression stiff faces. This lightweight and stiff design keeps its structural rigidity only if the bonding between skin and core does not fail. The correct installation of the foam core is therefore mandatory and the most critical part of the sandwich manufacturing process.
Fibre reinforced plastics with a polymeric matrix 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:

- Wet lay up (Hand and Spraying methods) (**chapter 3.4.1**)
- Resin transfer methods (**chapter 3.4.2**)
- Prepregs (**chapter 3.4.3**)

3.1 Core preparation

Grooving and perforation

Before installation, foam sheets should be either grooved or perforated. Grooving helps to evacuate air and - in the case of infusion processes – allows also the resin to flow.
Perforation is used to equalize resin flow in vacuum infusion and to evacuate trapped air from the mould side.



A typical grooving pattern is shown in the picture on the left.

Cross-wise grooving is an additional option mostly used for vacuum infusion to prevent dry spots.

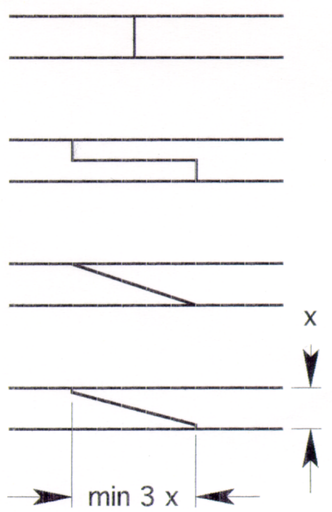
For perforation, holes of approx. 2 to 3 mm diameter (1/16 to 1/8 in) at equal distance of 50 mm (2 in) or less are recommended. To get an accurate distribution of holes, it is highly recommended to use a pattern made of cardboard or plywood.

Cores can be ordered with premade finishing options such as grooving and perforations.
(refer to http://www.airexbaltekbanova.com/downloads.html)

Important note!

Before installation, the surface of the foam sheets must be cleaned properly 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 on the left. Recommendations for adhesives to be used can be found in **chapter 2.5**

Kit manufacturing

For complex 2- or 3-dimensional parts (boat hulls, wind mill blades, etc.) it is useful to have foam kits available that can be put into the mould very quickly and conveniently. When the kit manufacturing is done the first time, the foam sheets are cut to size directly in the mould. From these first cut foam kit, templates can be made from plywood which can be used to cut additional foam kits.

In prepreg and vacuum infusion processes the sheets must perfectly fit to each other. In order to reduce the risk of building a gap between two foam parts one of the butt joints options mentioned above is recommended.

Gaps should be avoided for following reason:

- print-through effect leading to additional rework operations
- exothermal reaction during curing leading to hot spots in areas of accumulated resin, which may eventually degrade the foam
- race tracking leading to dry areas

It is recommended to bond the foam sheets together during the dry lay-up process. In **chapter 2.5** possible foam bonding adhesives are listed.

When using vacuum infusion techniques (**chapter 3.4.2**) it is important to have neighbouring sheets cut in a way that the grooves are continued so that the flow front is not interrupted.

Important note!

In the transition area 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.

3.2 Installation of foam in a curved mould

General

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

- cold bending
- thermoforming (see **chapter 2.4**)
- use of scrim clothed cores (ContourKore)
- Flexicut

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.

Cold bending

Especially for AIREX® R63 cold bending is a very well suited method, but also other AIREX® foam types may be formed by this process.

The minimum bending radius depends on the type of foam, the thickness of the sheet and 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	R63	R82	C70	C51	T92	T10 T	T10 L
Multiplication factor	15	35	25	25	20	10	35

Multiplication factor to determine the minimum cold bending radius

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

If the desired bending radius falls short of the calculated minimum value it is possible to laminate several thinner foam core sheets together over a male mould.
Alternatively the part can also be thermoformed (see **chapter 2.4**) or cut.

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.

Scrim cloth cores

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

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 sandwich panels with scrim cloth cores becomes considerably higher than for bended or thermoformed ones. This is a factor not only concerning costs but can also affect the structural integrity of sandwich composites in case of voids.

Calculation

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

$$\boxed{V \approx d^2 * 29 * \arcsin(3/r)}$$

V: Volume of gaps per square meter [cm³]
d: Thickness of foam core [cm]
r: bending radius [cm]
arcsin has to be used in degree (not rad)

Example

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

This volume does not include the amount of resin taken up by the grooves themselves (i.e. without bending).

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*

Other options

In order to enable cores to adapt to curved moulds other finishing options providing flexible cores without the help of scrim cloths are available. For further information please contact AIREX® technical services directly.

3.3 Resin systems

General

The most common resins used for sandwich manufacturing are the following thermosetting resins: Unsaturated Polyester (UP), Vinylester (VE), Epoxy (EP).
Other resins include Phenolic (PF), Bismaleimide (BMI), Polyurthane thermosets (PUR) and thermoplastic resins such as Thermoplastic Polyurethane (TPU), Polyamide (PA), Polypropylene (PP).

3.3.1 Epoxy

EP

Epoxy (EP) - resin systems are frequently used in preference to unsaturated polyester systems for structural applications because of their long-term stability, low shrinkage on cure, their suitability for vacuum bagging and availability in form of prepregs (see **chapter 3.4.3**). Epoxy resins are normally solvent-free systems, therefore solvent migration issues do not occur. Thus protective sealing of the foam is not necessary.

Curing

To obtain the maximum mechanical strength of epoxy laminates, 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 depending on the dwell time and pressure. This should however be verified by experiments.

Foam type	Temperature			
	Cure		Post-cure	
	°C	°F	°C	°F
R63	40	100	60 - 80	140 - 180
R82	80 - 130	180 - 270	130 - 180	270 - 360
C51	80 - 100	180 - 210	100 - 120	210 - 250
C70	60	140	60 - 90	140 - 190
C71	60 - 80	140 - 180	100 - 140	210 - 280
T90/T92/T10	150	300	150	300

Maximum curing temperatures

3.3.2 Polyester and Vinylester

UP/VE

For use in moulding, unsaturated polyester or a vinylester resins require the addition of several ancillary products. These products are generally:
- Catalyst (e.g. Peroxide)
- Accelerator or Promoter (e.g. Cobalt)
- Additives: Thixotropic; Pigment; Filler; Chemical/fire resistance

Important note!

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

Styrene sensitivity

Of the AIREX® foam cores, particularly the linear PVC material R63 and the lower densities of the C70 range may show, under certain working conditions, sensitivity towards styrene. Conditions 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
Peak temperature of exothermic reaction	as low as possible
Resin gel time ◆ below 20 °C ◆ below 25 °C	 60 min. 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

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 temperature
- increased creep of the foam

To avoid this, the foam core should be sealed before the lamination process.

Sealing

A sealing layer helps to protect the foam surface from the effects of migrating styrene monomer and exothermic heat released by the application of additional layers of laminate. Sealing of foam surfaces is accomplished by applying a thin layer of catalysed 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 styrene 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

A priming operation may be used in addition or as alternative to sealing as described in the overview below. Priming is described in detail in **chapter 3.4.1.**

Overview

Following priming and sealing operations are recommended for use with UP/VE resins:

Foam type	Sealing	Priming
R63	✹	✹
R82	✹*	○
C51		○
C70.40, C70.55	○	✹
C70.75 - C70.200		✹
C71		✹
T90/T92/T10		○

Necessity of priming and sealing

✹ Operation essential
○ Operation recommended
* Operation recommended for RTM and resin infusion

Composition

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.

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.

CSM barrier

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

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 uncatalysed resin spread on a flat surface. The progress of softening is noted.

3.4 Lamination processes

3.4.1 Hand lamination

General

Wet lay-up and spraying methods are still quite popular and widely used, particularly in boat building. 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 to 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 prior to lamination. Especially with UP/VE, a chopped strand mat (CSM) should be applied next to the foam - preferably 300 g/m^2 (1 oz/sq.ft.) to 450 g/m^2 (1½ oz./sq.ft.^{2}) with a resin to glass ratio of 2. 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 may be implemented (see the paragraph ***Styrene sensitivity*** in **chapter 3.3**).

Common resins such as Unsaturated Polyester, Vinylester and Epoxy based are typically used for hand lamination.

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, resin or a putty (see also **chapter 3.4.1**)

All the above methods have the same objectives:
- to ensure a perfect and strong bond between the FRP laminate and the core

Choice of Resin system

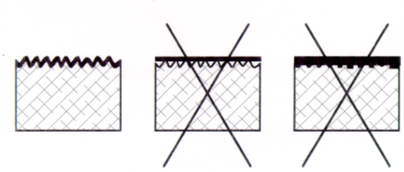
There is wide range of resins systems suitable for hand lay-up.
In general most resins are compatible with AIREX® foams however it is recommended to do small scale trials prior manufacturing.
For more information refer to **chapter 3.3**.

Priming (Pre-wetting)

Priming the core is a step of the lamination process providing optimum bond of laminate and core. This applies particularly to the bonding of laminates with high fibre content and correspondingly low resin fractions.
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 reacting 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, therefore adequate catalization of the priming resin is essential.
The priming resin has to be compatible with the laminating resin, the easiest is to use the same one. Often the resin manufacturer offers special resin formulations to bond the foam core to the laminates. It is advisable to take note of such recommendations.

Application of first resin layer

The application of the 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 in order to obtain a rough and not smooth surface.



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 pre-wetting the following amount of resin is recommended:

Foam type	Resin amount	
	g/m²	oz/sq.ft
R63.50	100 - 200	0.33 - 0.65
R63.80, R63.140	50 - 150	0.16 - 0.50
R82	200 - 300	0.65 - 1.00
C51	200 - 300	0.65 - 1.00
C70.40 - C70.90	200 - 300	0.65 - 1.00
C70.130 - C70.200	100 - 200	0.33 - 0.65
C71	150 - 200	0.50 - 0.65
T90/92 < 130 kg/m3	200 - 300	0.65 - 1.00
T90/92 > 130 kg/m3	150 - 250	0.50 - 0.82
T10	200 - 300	0.65 - 1.00

Amount of resin recommended for priming and sealing of foam cores

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.

Roller application

If the first resin layer has to be applied manually it is best done with a bristle roller. A sufficient amount of resin should be allowed extra for wetting of the roller. To avoid an uneven resin distribution or local styrene migration, the resin should not be poured directly onto the foam surface.

Installation

Core installation into uncured (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 for instance with sandbags or vacuum bag pressure.

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 2.5**.

Air entrapment

To ensure complete removal of entrapped air particularly from larger flat areas or shaped parts, it is essential to perforate and or groove the foam sheets (see **chapter 3.1**).
Grooving is not required for installation of scrim cloth core (Contour-Kore) types. However, the increased consumption of resin required to fill the slits between the foam cubes should be taken into account (refer to ***Scrim cloth cores*** in **chapter 3.2**).

Core installation with a bonding compound (putty)

This method is particularly recommended for the "contoured" and "scrim-cloth" variety of AIREX® core materials (see **chapter 3.2**). It can also be applied 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 resin with lightweight fillers, such as micro balloons, a thickening agent, such as kieselgur and sometimes also short chopped glass fibres. The cured compounds may range in density from 400 kg/m^3 (25 pcf) to 800 kg/m^3 (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 entrapped air and insufficient bond between laminate and core material.

Putties are ideally suited for the vacuum bagging method (see **chapter 3.5**). It is also possible to cure them in a press.

3.4.2 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 complete curing of the resin, the whole part can be de-moulded.

Advantages versus hand lay-up

All vacuum infusion processes have lower VOC emissions during production of sandwich parts than hand lay-up, in particular if polyester- or vinylester-resins are used. 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 defects and imperfections 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 production.

Process variants

Infusion and Injection processes differ in the way the resin is transported through the dry laminate and the applied 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 stronger the more pressure is applied on the resin. Moulds for RTM processing are therefore mainly 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 heatable as well.

Vacuum infusion with flexible bag

This method is well suited when switching from hand lay-up to vacuum infusion, as well as for single pieces, prototypes or very large parts (e.g. windmill blades and boat hulls). Existing moulds from hand lay-up can still be used. Some modifications have to be done at the flanges in order to be able to fix 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 3.5**, 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 vacuum bags are usually disposable however; reusable silicon vacuum bags exist to reduce the amount of waste. This may require a modification the mould frame.

Resin distribution

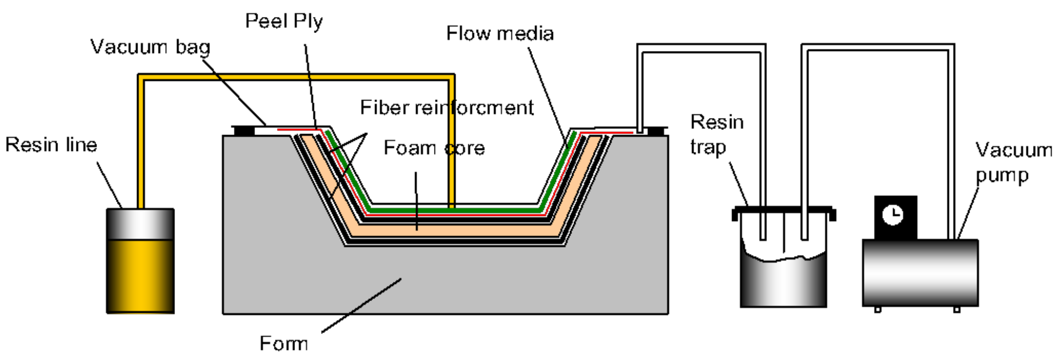
The distribution of the resin in the laminate can be done in three different methods: Infusion mesh, flow mat, grooved core.
They differ in the way the resin is transported.

Mesh infusion process (originally SCRIMP)

The infusion process with mesh (originally SCRIMP, Seemann Composites Resin Infusion Molding Process) is characterized by an additional infusion mesh placed outside of the sandwich part. During the infusion process this resin flow media is distributing the resin quickly over the surface of the part from where it then infuses into the sandwich component.
Because the infusion mesh shall not be part of the sandwich construction, a peel ply or a perforated foil is placed between them. Both foils are designed for one way use.

Good to know

If the part needs a surface treatment it is advisable to remove the peel ply only shortly before this process step to keep the surface clean.
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.
The example below needs a perforated foam core because the infusion mesh is only applied on the upper side. The perforations are required for the transfer of the resin flow to the bottom side.

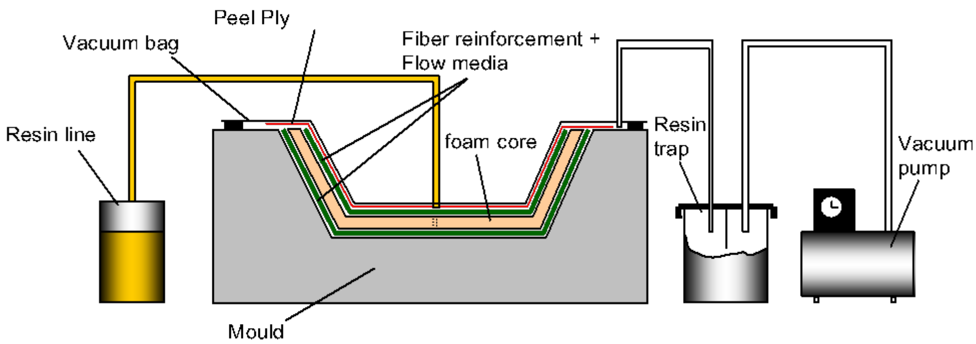


Disadvantages of the SCRIMP process are increased waste by use of disposable materials and additional resin consumption by the infusion mesh.

Flow mats

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 and remains in the skin. Continuous fibre mats, e.g. Unifilo® 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. They 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. A perforated foam core allows wetting uniformly both sides of the sandwich.

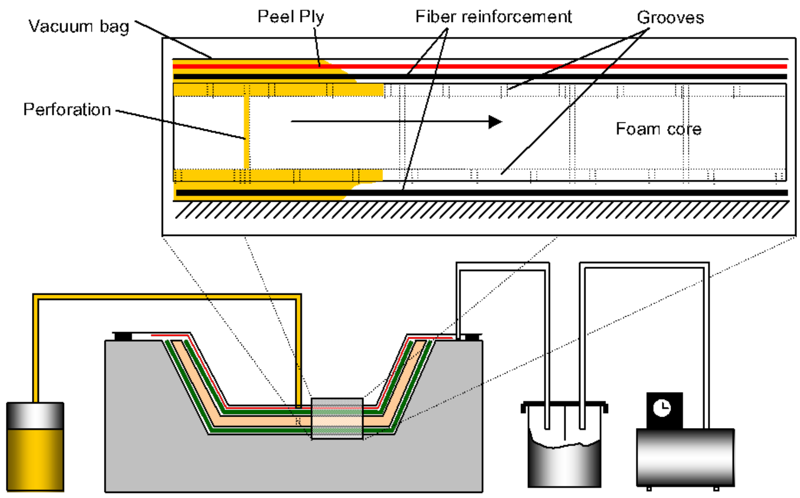


The disadvantage of flow mats is that resin rich skins are produced. The fibre content is reduced to 20% or even less in these layers.

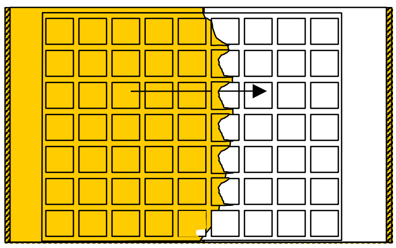
Grooved Foam

Grooved foams enable the resin to flow easily and quickly over the surface. With grooved foam there is no need for additional flow mats or flow media.
Generally, a square pattern of grooves are mill cut into one or both surfaces of the foam. The distance between the grooves shall be designed to avoid dry parts, i.e. areas with insufficient resin impregnation. The thinner the grooves the lower is the print-through effect on the gel-coat.
In addition the foam can be perforated for example with holes of about 2.5 mm in diameter in a distance of approximately 32 mm. The perforation will ensure the resin transport across the foam core.
This helps to equalize the flow on both sides.

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

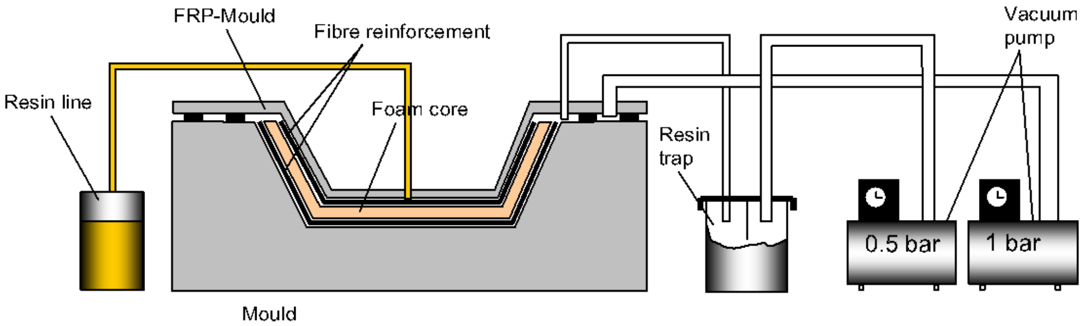


Top view



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). Similarly to the infusions with flexible bags, the compression on the laminate is induced by the vacuum only.
The applied vacuum pulls and distributes the resin in the mould. The resin flow can be checked easily through the thin semi-transparent FRP skin.
If the vacuum level is too high, the FRP mould may press too much onto the laminate and the resin flow will be drastically reduced (risk of incomplete impragnation). This is the reason why the vacuum level for this process should not exceed 0.5 bar (7 psi) depending on the type of fibres. 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 usually high temperature and pressure applied with this process requires higher mechanical and thermal properties of the foam. For suitable core materials in combination with the RTM process the AIREX® technical service can be contacted.

Requirements for the infusion process

The vacuum infusion technique requires different properties of resin, fibre mats or fabrics and foam core than e.g. hand lamination processes.

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	typically 50 – 90 min, depending on the part dimensions

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

Reinforcements

CSM (Chopped strand mats), woven fabrics, and stitched mats (non wovens) used for hand lay-up can also be used for infusion techniques. However, the resin flow through these mats is quite slow.
Therefore the use of flow mats or infusion meshes or core grooving is required as mentioned above.

Strategies for the infusion

One of the most important questions considering vacuum infusion is the strategy of guiding the flow to achieve a complete wet out of fibres. Where should the resin inlet be located and where should the vacuum be applied? The selection of the strategy depends on the geometry and size of the part. The following strategies are known:

Foam core

General requirements to the foam for vacuum infusion and injection technologies are:

- Closed cell structure
- Styrene resistant (if UP and VE resins are in use)
- Resistant to the maximum acting pressure and temperature

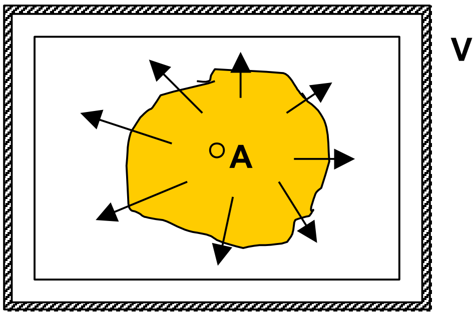
Note: AIREX® R82 has variable closed cell content especially at low density and may require a surface sealing process. AIREX® R63 has limited styrene resistance and requires either low styrene content resins or a surface sealing process.

3A Composites provides standard finishing options for vacuum infusion such as grooves and perforations, which provide good results in most cases.

Your AIREX® distributor, converter or the AIREX® technical service can give you advice if you have any questions.

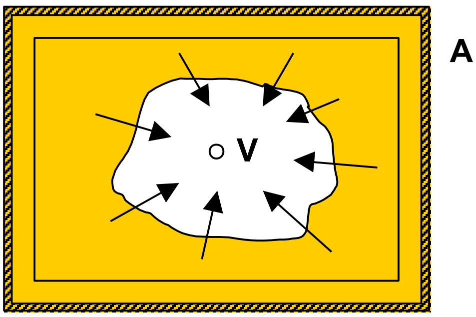
Point feeding

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



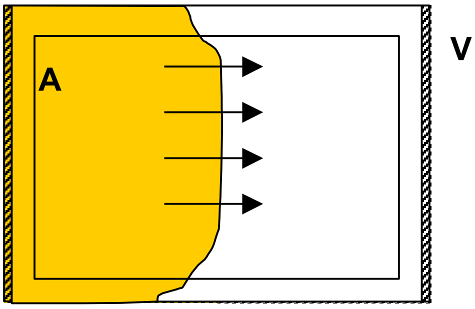
Edge feeding

The vacuum line is placed in the centre of 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.



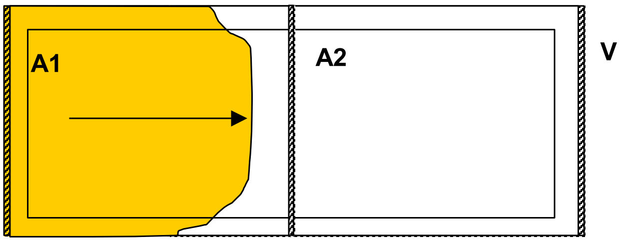
Line feeding

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 line. 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 line.



Multiple feeding

Especially for larger parts it is useful to have more then one feeding line 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.



Note

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

Further guidelines

For vacuum infusion following additional important points need to be considered:

Fibre lay-up in the mould

The lay-up of the mould with dry fabrics and foam core is difficult. It 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 to use spray adhesive for the fixation of the different layers.

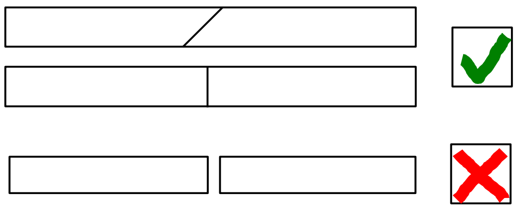
Assembling of foam

The assembly of foam in the mould needs to be done carefully. No gaps between the foam sheets are allowed. Such empty volumes would act as resin race tracks reaching prematurely the vacuum line and stop the infusion prior complete wet out.
In addition, such resin rich area develops higher temperatures during curing reaction – due to high exotherm.

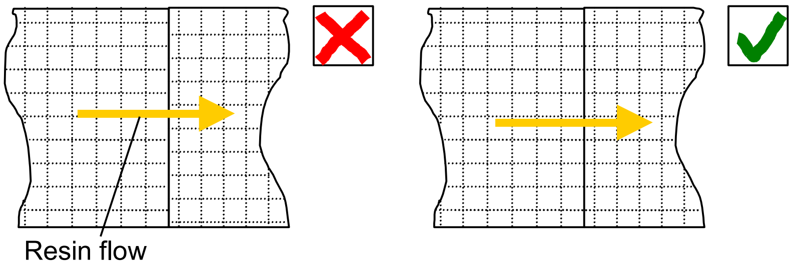
Qualified techniques for assembling foam sheets are:

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

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

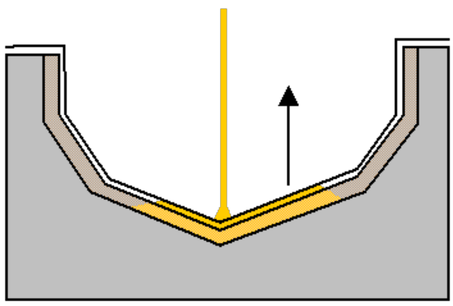


In the resin flow direction, the groove pattern of the sheet must match that of the next sheet.



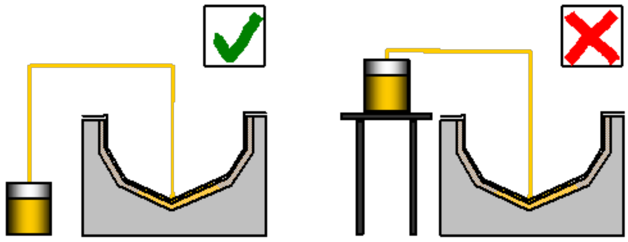
Resin flow upwards

With three-dimensional sandwich parts the resin should flow always upwards.



Resin tank below feeding point

The resin reservoir must be placed below the feeding point otherwise resin rich area will be generated.

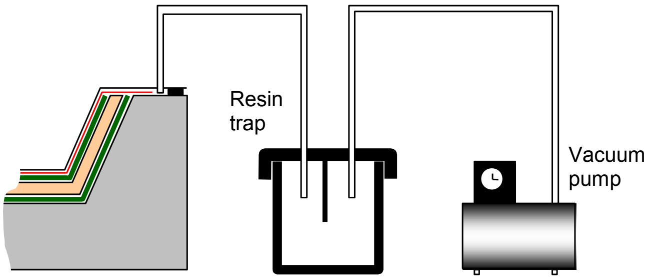


Temperature control

To define 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.

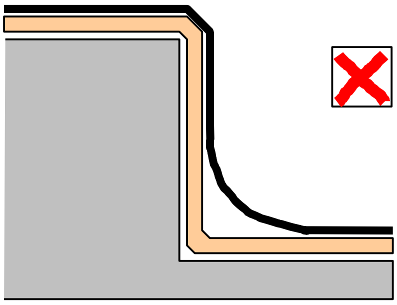


Number of feeding points

It is recommended to have as many feeding points as possible including some extra to be ready in case of unforeseen situations.

No bridge-building with 3D parts

The vacuum bag must be placed over 3D 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 intended resin front will be destroyed and dry spots may form in the part.



Chamfering the foam provides smooth transitions between single skins and sandwich or between different core thicknesses.

Additional Information

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 processes.
Vacuum consumables needed for vacuum infusion technology can be bought from different dealers which offer a large range of products.

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

3.4.3 Processing with prepregs

General

The use of prepregs - normally pre-impregnated fabrics - has a number of advantages over wet lamination processes: by their use, laminates with higher fibre contents within closer weight tolerances can be achieved. This results in higher and more constant mechanical properties and eventually 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
- autoclave curing
- compression moulding

Vacuum bagging

For processing at low pressures, vacuum bagging (**paragraph 3.5**) 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.

Autoclave curing and compression moulding

For optimum laminate properties, higher pressures are recommended by the prepreg suppliers and 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. In order to evacuate the entrapped air prior to consolidation a vacuum bag needs to be applied in combination with the autoclave process. This means that the foam is subject to the sum of the vacuum plus autoclave pressure.
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, they often specify relative high pressures in order to achieve void-free laminates, in particular for thick laminates. 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, pressures can be lowered without reduction of the mechanical properties. The pressure needs to be below the compressive strength of the foam at the curing temperature. Details can be obtained at AIREX® Technical Services.

Foam preparation

For vacuum bagging and autoclave processing, the foam normally does not require a special surface treatment. However, depending on temperature and foam type, a thermal conditioning may be required (refer to **paragraph 2.2 - *Conditioning of cross-linked PVC foam***). To take air entrapments and excessive resin out of the laminate, vacuum is applied and perforated release films combined with bleeder fabrics are placed on top of the prepreg lay-up.

By compression moulding excessive resin cannot 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 3.1***. Punched or drilled holes in a regular pattern can also be done. However in case of punching 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 punching and further processing.

Interface layer

As prepregs are supplied in a weight optimized form, they do not contain much excessive resin. On the other hand, the surface of a foam consists of cut-open cells and needs a certain minimum amount of resin. For proper bonding it may be necessary to apply a special interface layer such as prepreg with increased resin content or an adhesive film.

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 prepreg, the peel strength of the sandwich structure can be 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 cut-open surface cells.

Compatibility of foam and prepreg

Before manufacturing a sandwich part, the compatibility of foam and prepreg needs to be verified.

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 there are signs of incompatibility, 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.

3.5 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 can be used for thermoforming (**chapter 2.4**), simple bonding of foam (**chapter 2.5**), cold bending (**chapter 3.2**), vacuum infusion (**chapter 3.4.2**) as well as for prepreg processing (**chapter 3.4.3**). 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

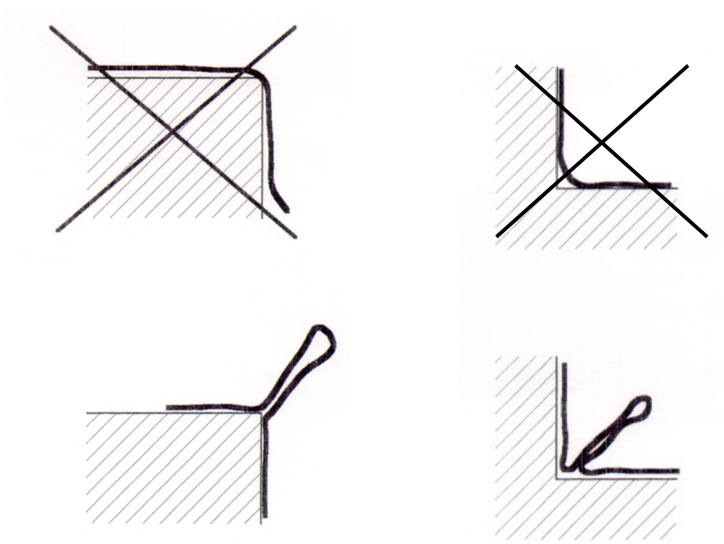
Bagging film

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 materials (silicone, natural or synthetic rubbers), disposable vacuum film bags usually are made of polyethylene (PE) or nylon (PA). 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 elastomer materials 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 the bagging film and the tool surface. During the resin curing process they may 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 / (Perforated) release film

Peel plies or bleeding plies help to extract excessive resin in prepreg processing and result in a higher fibre content of the laminate. They further lead to a rough surface ready for further bonding or coating operations. If a smooth surface is desired a release film should be used instead, which is usually perforated. For the vacuum infusion process a peel ply or a (perforated) release film is required if a flow medium is used.
For simple sandwich structures it is not necessary to use special peel and bleed plies. Instead it is sufficient to use directly the vacuum bag. 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. It has to be used in combination with a peel ply or release film for sandwich manufacturing. Bubble plastic film or fleece may be used as easily 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

A non-disposable vacuum valve may consist 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 amount of valves depends on the area of the part to be manufactured. The following table provides a rough estimation of valves needed per area to be processed:

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 processing a certain core area

Note: For infusion processes disposable connectors are used.

Vacuum source

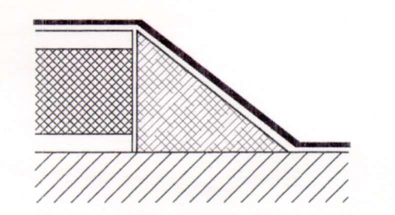
An electrically operated vacuum pump is the most common source of vacuum. Instead of a vacuum pump a venturi block may serve the same purpose, particularly for minor work.

Fabrication of sandwich structures

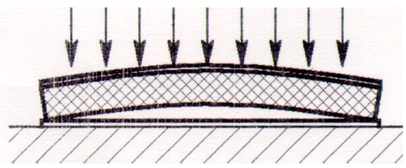
The manufacture of flat, two or three-dimensionally shaped sandwich panels with two fibre-reinforced plastic skins follows to a great extent the working practise outlined in the foregoing chapters.

Bonding

Bonding both faces simultaneously usually causes problems with entrapped air between the faces and the core. Single or cross-wise grooved cores are recommended to avoid bubbles (see **chapter 3.1**). Further information is given in **chapter 2.5**.



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 dimensions 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.

A warped thick foam core panel may not be pressed flat under full vacuum pressure. The bending stiffness of a thick foam panel is often sufficient to withstand such 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.
Warped 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 by the vacuum bagging process are not as straight forward as simple bonding. Additional details have to be taken into account such as the surface texture of the finished laminate and the quality of the bond between faces and foam core. These items are further explained in **chapter 3.4.**