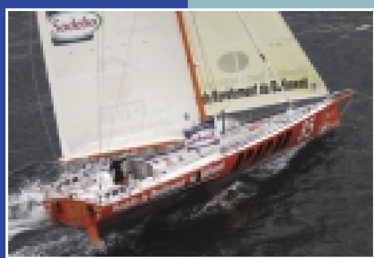
Prepreg Technology

HEXCEL



Prepregs have had a considerable impact on the evolution of man in the late 20th century. Used in all aerospace programmes worldwide, they are also enabling a new generation of high speed trains and fast ships to become reality rather than a designer's dream.

Many industries are just discovering the benefits of these fibre-reinforced composites over conventional materials. This guide sets out to remove some of the mystification surrounding prepregs, by explaining the technology involved.

We have pioneered the development of prepregs for over 60 years. The trademark HexPly® is renowned in aerospace and other high performance industries.

March 2005
Publication No. FGU 017b

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INTRODUCTION

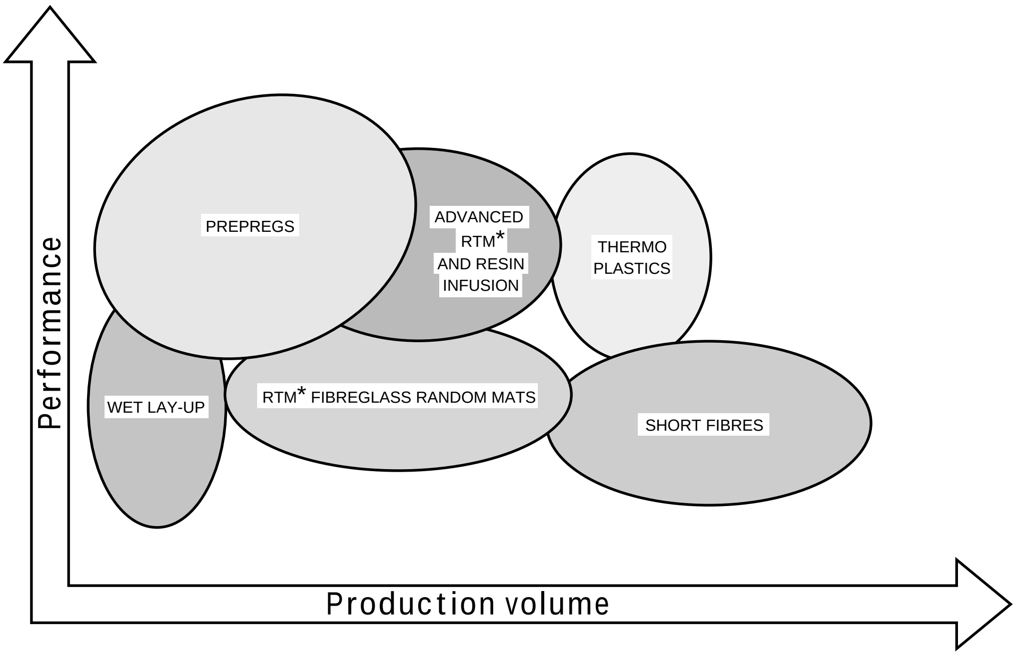
The benefits of composite materials are well documented and the great variety of applications for composites ranging from "industrial" and "sports and leisure" to high performance aerospace components indicates that composite materials have a promising future.

This guide has been written to provide a greater understanding of PREPREGS, how they are manufactured, processed, their properties and varied applications.

Information is provided to assist with the choice of the most suitable prepreg and processing method for an application. To assist with product selection Hexcel has produced the PREPREG MATRIX SELECTOR GUIDE which is available on request. For more information on our product range, prepreg selection or processing techniques please contact Hexcel.

A - Main technologies for high performance composites

The position of prepreg technology in terms of performance and production volumes is compared below with other fabrication processes.

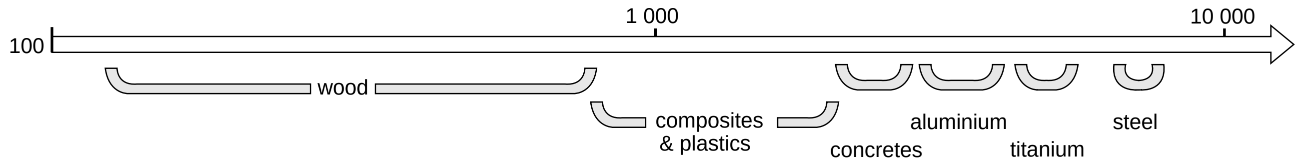


* RTM : Resin Transfer Moulding

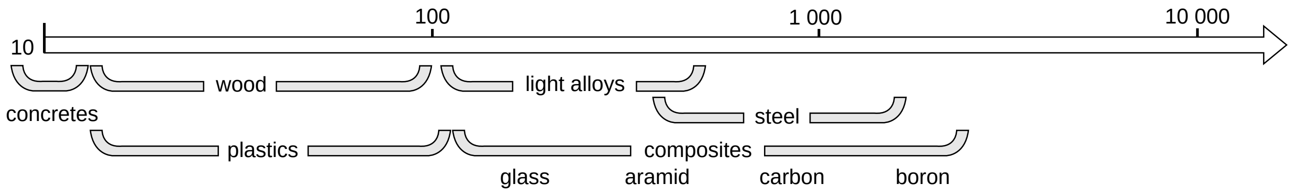
B - Why use composites ?

Comparison of different material characteristics :

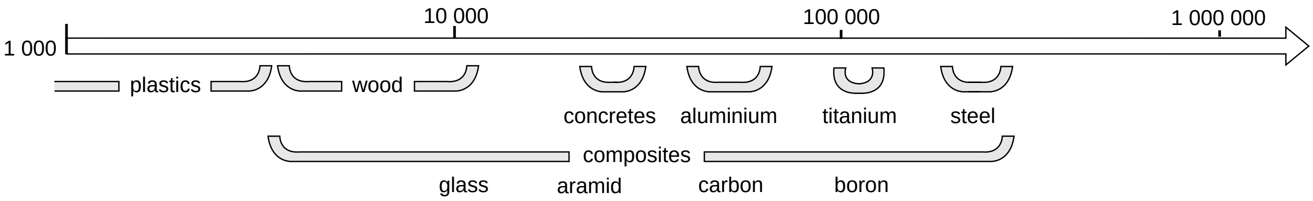
Volume weight (kg/m^3)



Tensile strength (Mpa)



Tensile modulus (Mpa)



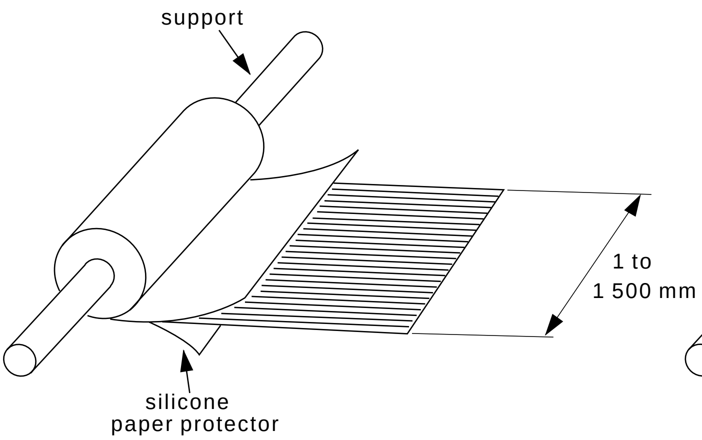
Composites provide the advantages of lower weight, greater strength and higher stiffness.

C - What is a prepreg ?

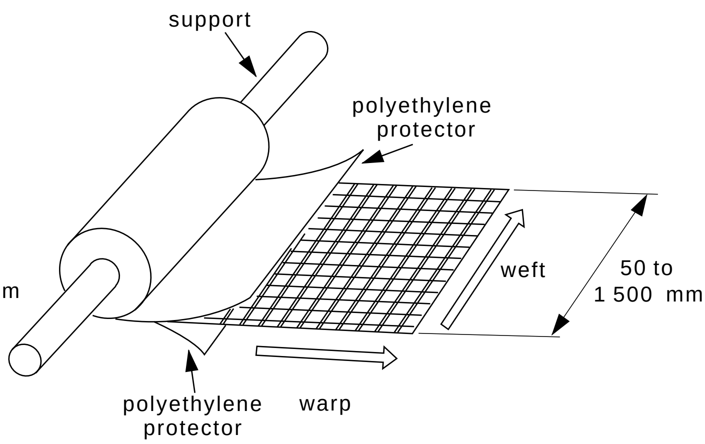
A prepreg consists of a combination of a matrix (or resin) and fibre reinforcement. It is ready to use in the component manufacturing process.

It is available in :

- UNIDIRECTIONAL (UD) form (one direction of reinforcement)
- FABRIC form (several directions of reinforcement).



■ Unidirectional reinforcement



■ Fabric reinforcement

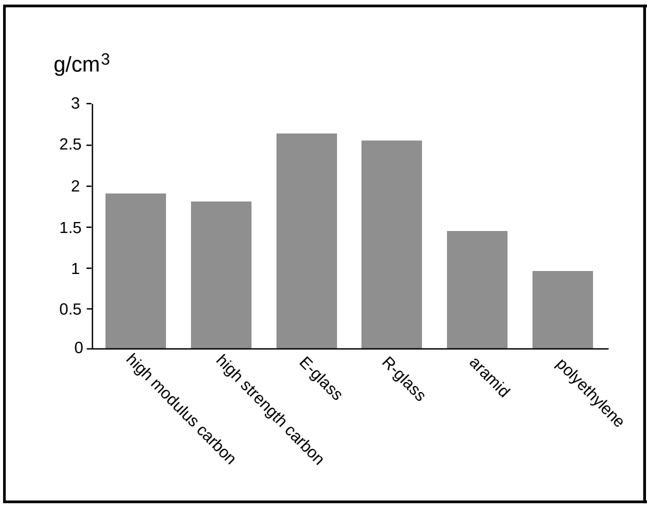
FIBRE AND FABRIC PROPERTIES

A - What are the fibre properties ?

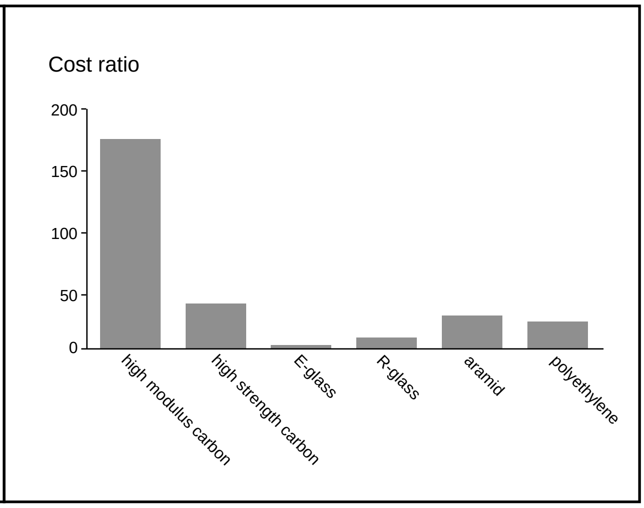
Reinforcement materials provide composites with mechanical performance : excellent stiffness and strength, as well as good thermal, electric and chemical properties, while offering significant weight savings over metals.

The range of fibres is extensive. The graphs below highlight the main criteria for fibre selection.

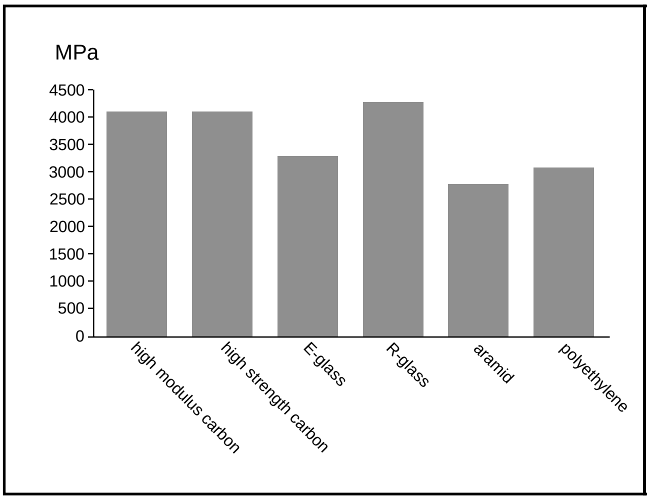
DENSITY



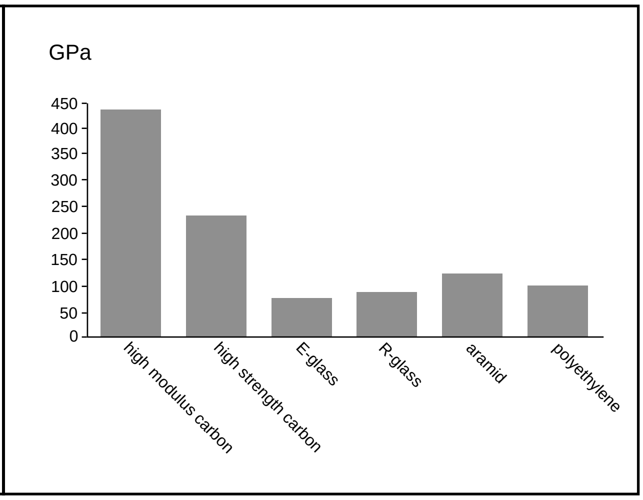
COST



TENSILE STRENGTH



TENSILE MODULUS



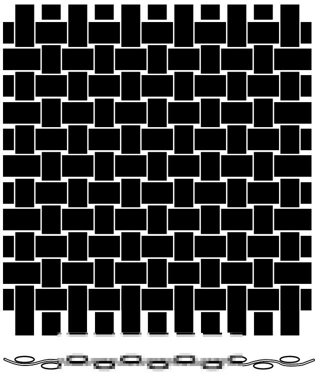
B - What are the different styles of fabrics ?

The fabrics consist of at least two threads which are woven together : the warp and the weft.

The weave style can be varied according to crimp and drapeability. Low crimp gives better mechanical performance because straighter fibres carry greater loads ; a drapeable fabric is easier to lay up over complex forms.

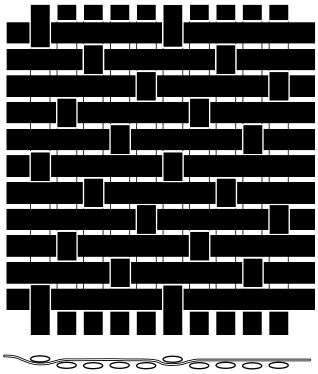
There are four main weave styles :

PLAIN WEAVE



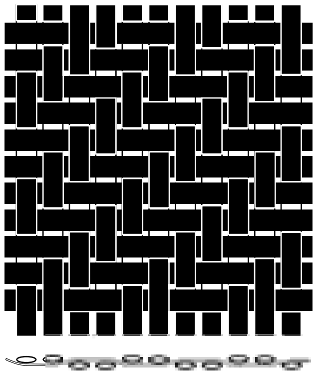
Low drapeability/high crimp

SATIN WEAVE
(4, 5, 8, 11)



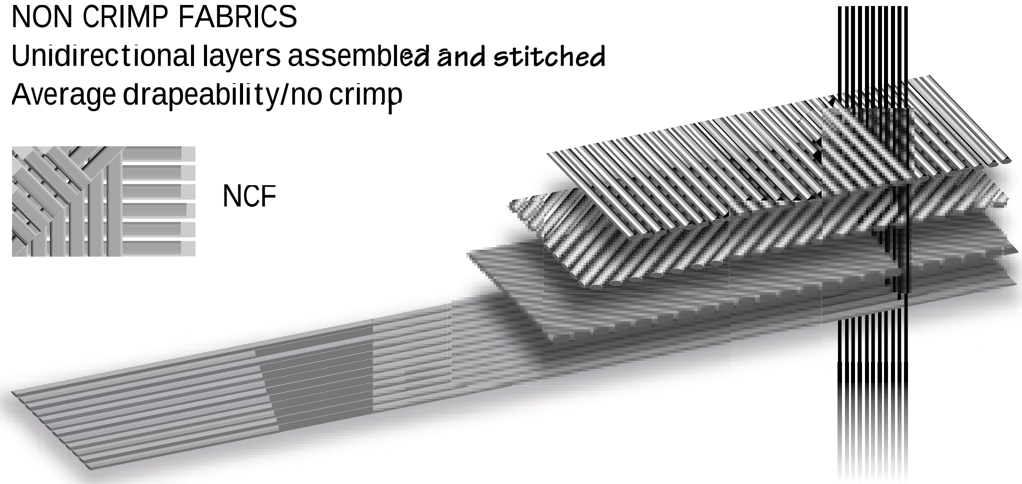
Good drapeability/low crimp

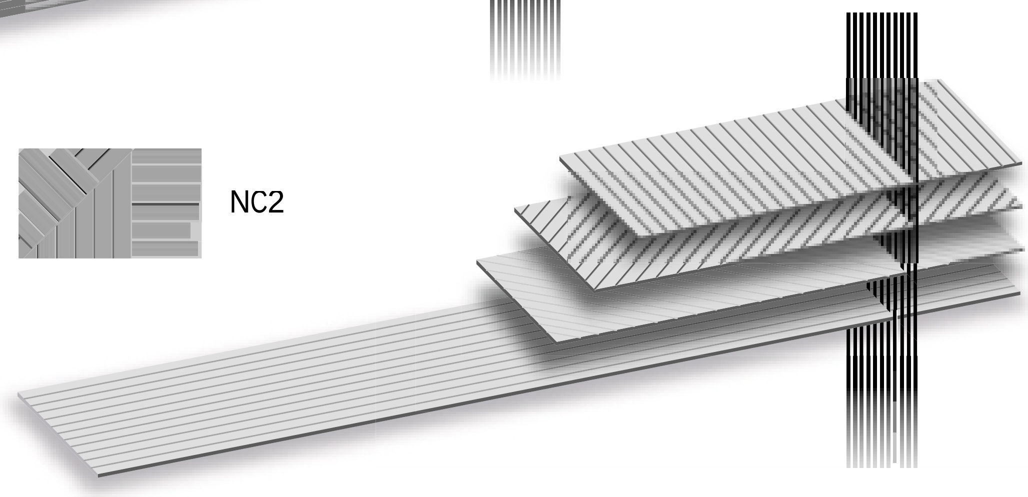
TWILL WEAVE
(2/1, 3/1, 2/2)



Average drapeability/average crimp

NON CRIMP FABRICS
Unidirectional layers assembled and stitched
Average drapeability/no crimp





C - What are the main factors affecting the choice of reinforcement ?

Reinforcement come in various forms, and each type offers particular advantages, as shown below.

Reinforcement		Advantages	Applications
Unidirectional	Tape	• High strength and stiffness in one direction • Low fibre weights ≈ 100 g/m²	Sports goods Aircraft primary structures
Unidirectional	Single tow	• Suitable for filament winding • Very narrow width for accurate fibre placement (1 mm)	Pressure vessels Drive shafts Tubes
Unidirectional	Strips	• High strength and stiffness in one direction • High fibre weights ≈ 500 - 1,500 g/m² • Economic processing	Yacht masts Leaf springs Skis Windmill blades
Unidirectional	Fabrics > 80 % warp	• For components requiring predominant strength and stiffness in one direction • Good handling characteristics • Weights from 160 to 1,000 g/m²	Aerospace Industrial Sport and leisure
Woven fabrics	Balanced fabrics	• Strength and stiffness in two directions • Very good handling characteristics • Good drape • Choice of weave styles • Possible to mix fibres • Weights from 20 to 1,000 g/m²	Aerospace Industrial Sport and leisure
Multiaxials	NCF	• Time-saving, cost-effective technology • Strength and stiffness in multiple directions • Unlimited ply orientation • Ability to optimise weight distribution in fabric • No crimp • Less waste for complex lay-ups (cross plies) • Reduced processing cost • Heavy weights achievable	Large Advanced Structures Aerospace Floor Beams Industrial

Multiaxials	NC2	• As NCF, plus
		• Gap free construction
		• Suitable for heavy tows and high modulus fibre
		• Homogenous filament distribution in the matrix yielding:
		  • Improved mechanical properties (compression)
		  • Enhanced resin flow effect (capillarity)	

MATRIX PROPERTIES

A - What is the role of the matrix ?

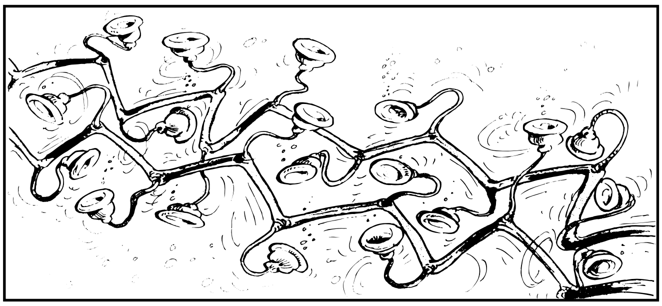
The role of the matrix is to support the fibres and bond them together in the composite material. It transfers any applied loads to the fibres, keeps the fibres in their position and chosen orientation. The matrix also gives the composite environmental resistance and determines the maximum service temperature of a prepreg. When selecting prepregs the maximum service temperature is one of the key selection criteria for choosing the best prepreg matrix.

The thermoset cure mechanism and the role of the different components of a matrix are represented below.

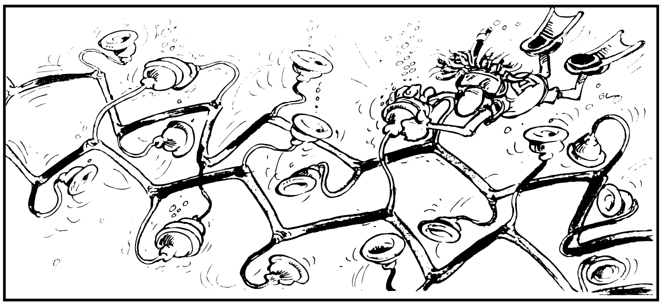
The cure can be simply represented by pre-polymers whose reactive sites join together forming chains and cross linking. In practice, there are more constituents and the cure process is more complex. Once this process has taken place the polymer is fully cured.

CURING THE MATRIX
(under temperature and pressure)

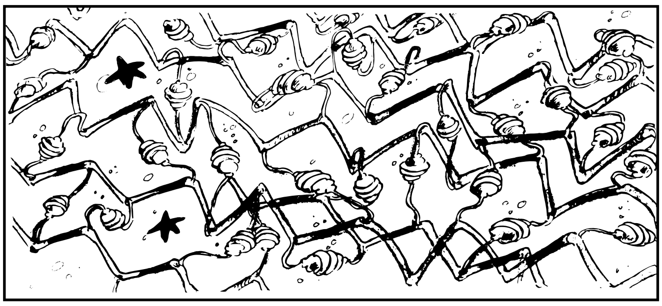
Pre-polymers (with free reactive sites)



Cure (joining of reactive sites)

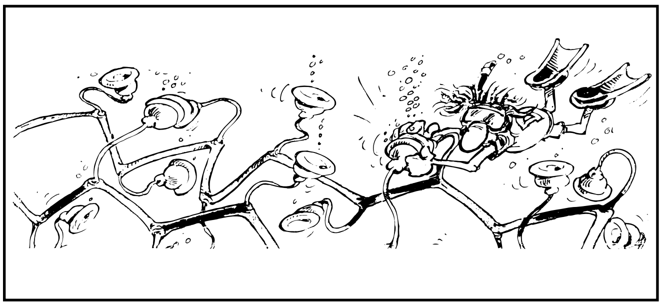


Cured polymer

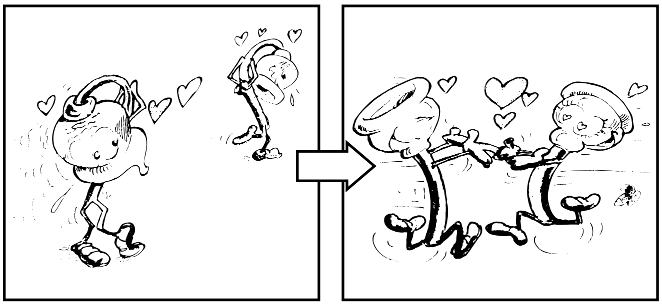


ROLE OF THE DIFFERENT CONSTITUENTS
OF A MATRIX

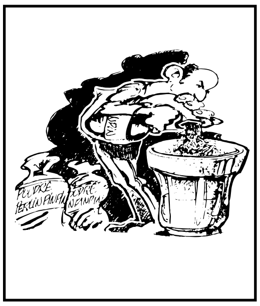
Hardener



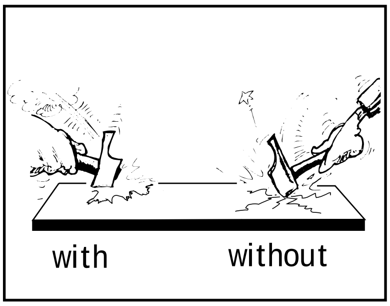
Accelerator



Fillers



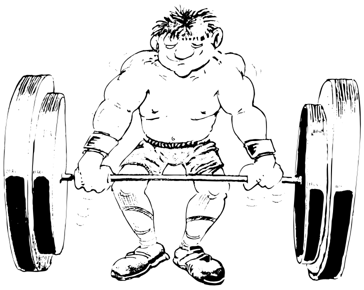
Thermoplastic resins



There are a wide range of matrices available.

B - What are the properties of different thermoset matrices ?

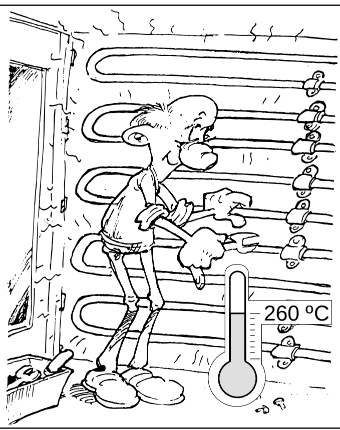
There are three main matrix types : epoxy, phenolic and bismaleimide. The table below indicates the advantages of each type and typical applications.

EPOXY	Advantages	Applications
	Excellent mechanical performance • Good environmental resistance and high toughness • Easy processing	**120 °C cure:** Aerospace Sport Leisure Marine Automotive Railways Transport **180 °C cure:** Aerospace Military

PHENOLIC

	Excellent fire resistance • Good temperature resistance • Low smoke and toxic emissions • Rapid cure • Economic processing	Aerospace (interior components) Marine Railways

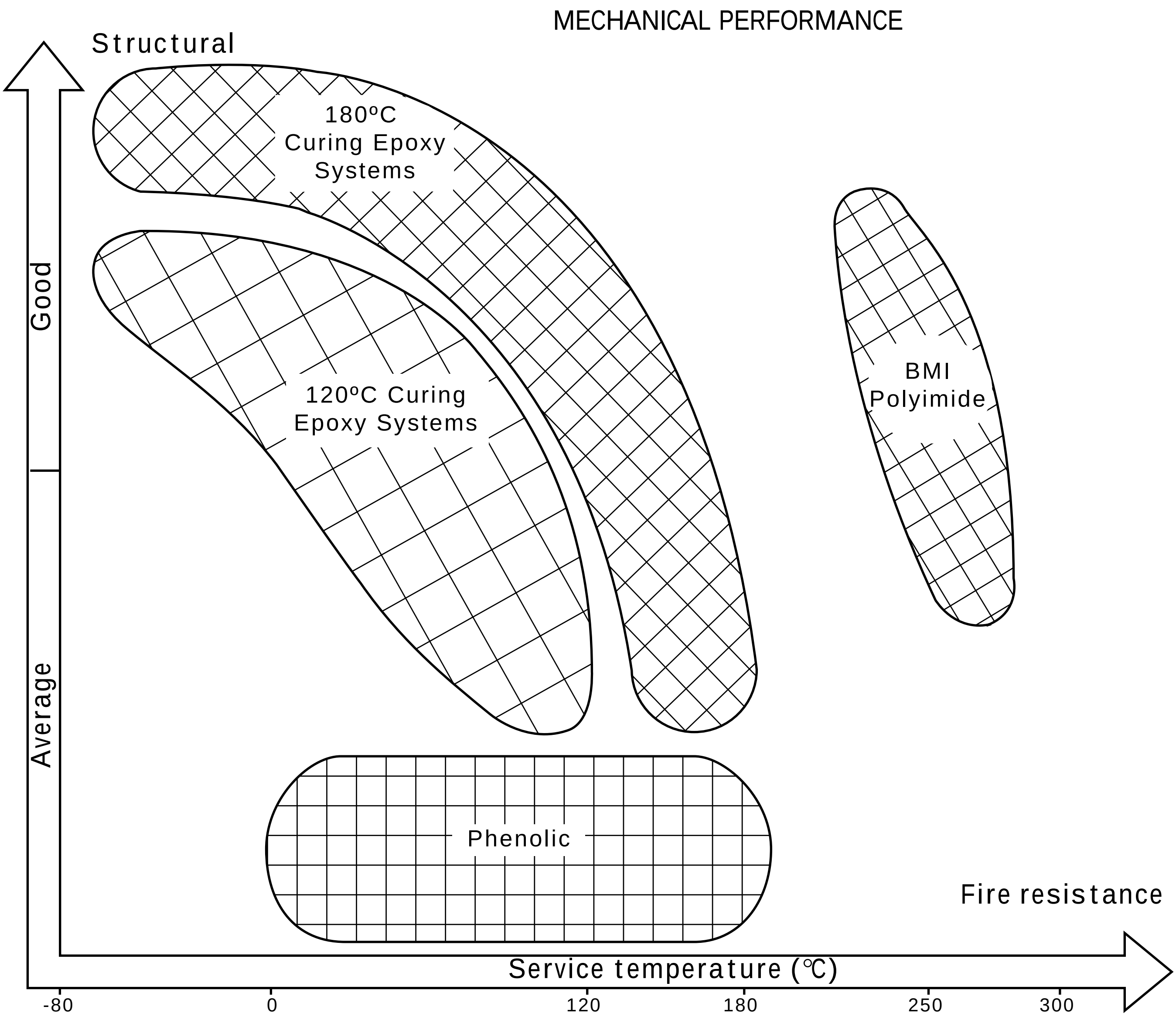
BISMALEIMIDE (AND POLYIMIDE)

	Excellent resistance to high temperatures • Service temperature up to 260 °C • Good mechanical characteristics • Good resistance to chemical agents, fire and radiation	Aeroengines High temperature components

C - How do different matrices compare in terms of temperature/mechanical performance ?

Matrices can be conveniently classified according to service temperature as follows :

Type	Service Temperature	Characteristics
Phenolic	80-100°C	Excellent fire, smoke and toxicity properties (FST).
Epoxy	100°C	Highly toughened epoxy systems usually exhibit good adhesion for honeycomb bonding.
Epoxy	130-155°C	Toughened epoxy systems aiming for maximum hot wet properties.
Bismaleimides (BMI) and polyimides	260°C	Long cure cycles needed to obtain best properties. Temperature resistance main priority, while preserving handling and toughness qualities.

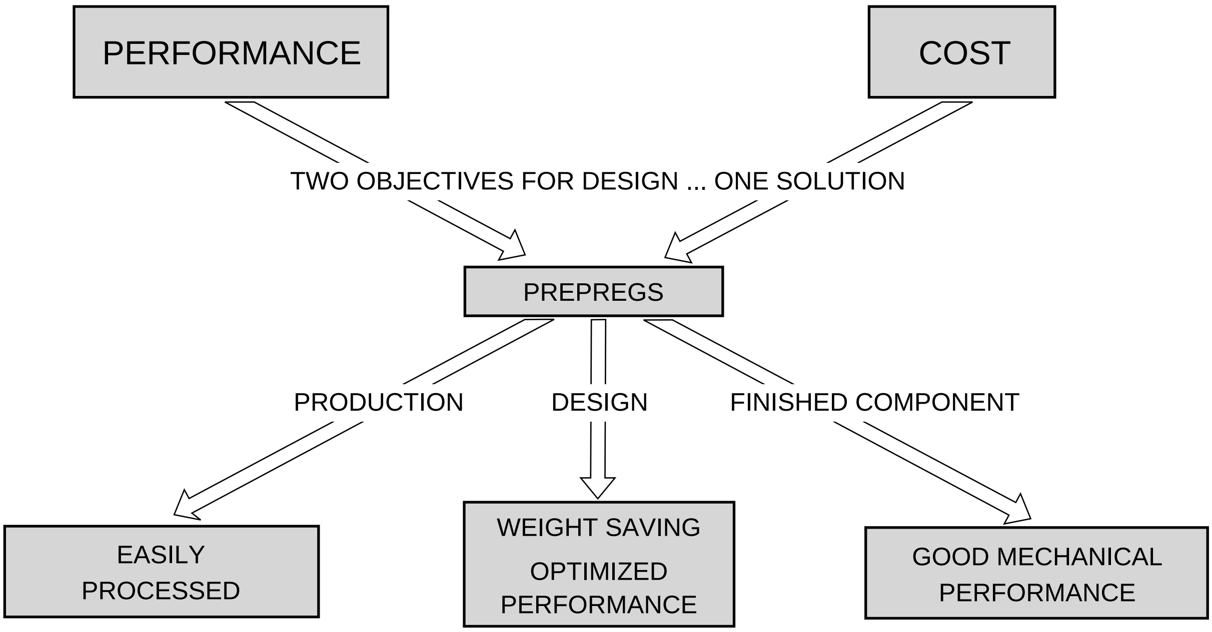


To select the matrix best suited to your application, refer to the PREPREG MATRIX SELECTOR GUIDE available from HEXCEL.

PREPREG PROPERTIES

A - Why use prepregs ?

Two main criteria influence the selection of prepregs for a particular application : performance and cost. The diagram below shows the advantages of using prepregs.



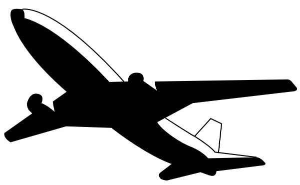
- Lower fabrication cost
- Reduced energy consumption
- Reduced number of parts
- Control of fibre content

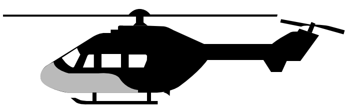
- Optimized weight/ performance ratio

- Fatigue, tensile, stiffness
- Corrosion
- Good ageing
- Repair

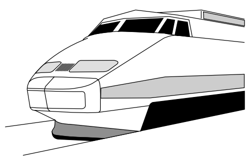
B - Where are prepregs used ?

Aerospace

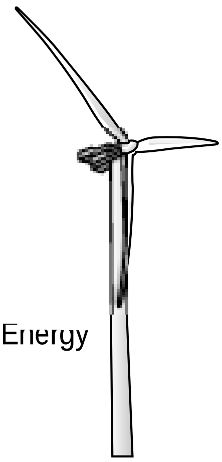




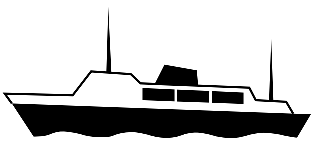
Railway

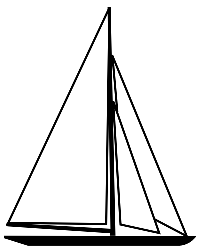


Energy



Marine





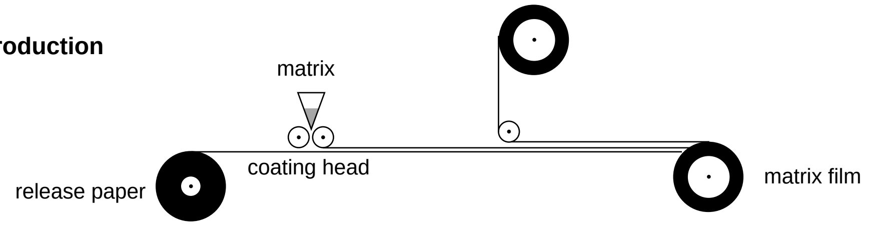
Sport and leisure

C - How are prepregs made ?

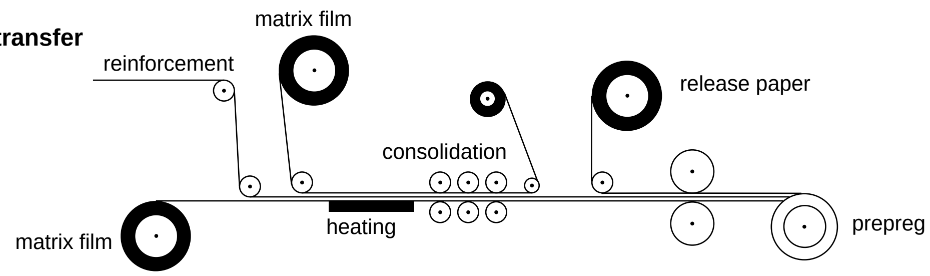
MANUFACTURING TECHNIQUES

Film transfer route : 2 steps process

Step 1 - Film production

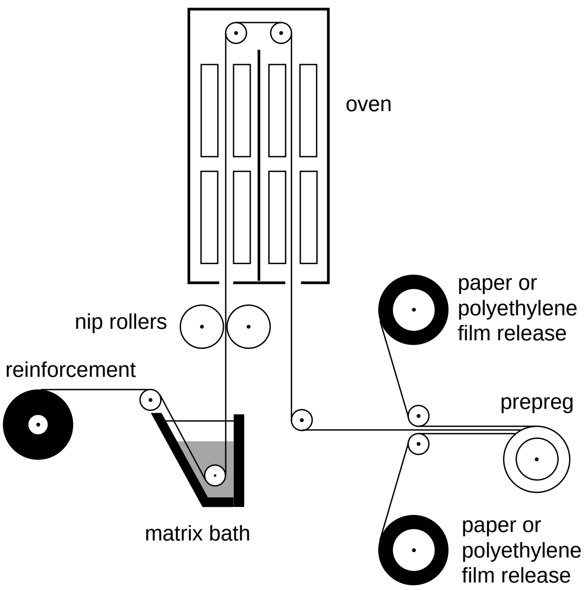


Step 2 - Film transfer

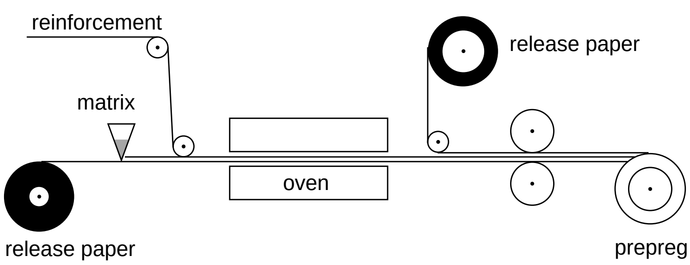


Solution route

VERTICAL (TOWER)



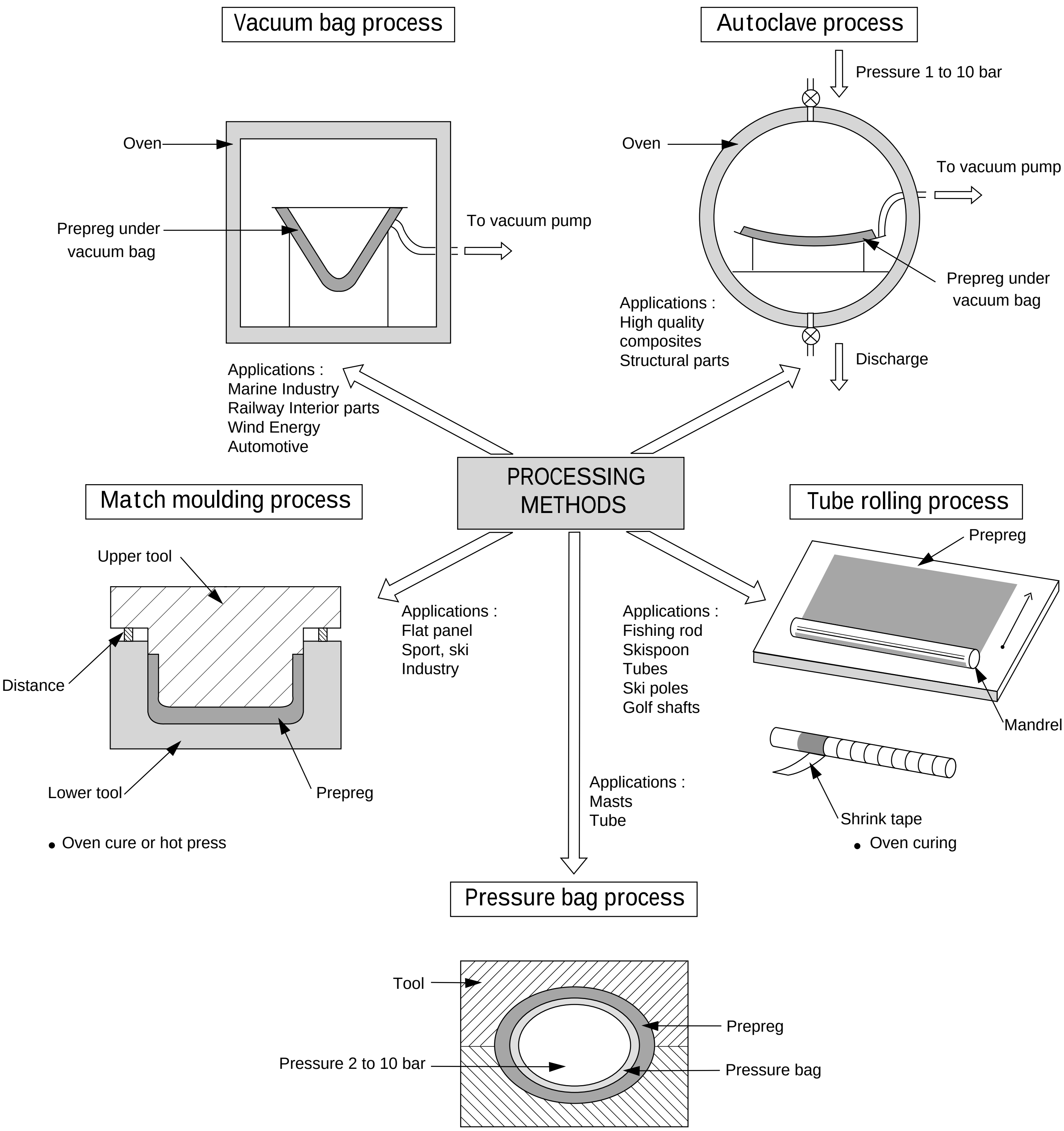
HORIZONTAL



PREPREG PROCESSING

A - What are the different prepreg processing techniques ?

Prepregs can be processed in different ways. The diagram below enables the most appropriate method to be chosen for a particular application.

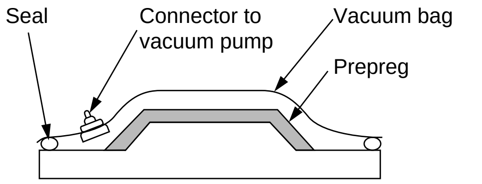


B - Vacuum bag or autoclave - which process ?

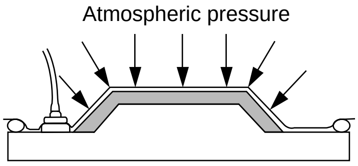
Vacuum bag and autoclave processing are the two main methods for the manufacture of components from prepreg. The processing method is determined by the quality, cost and type of component being manufactured.

	Component		Processing costs	
Processing method	Quality	Section thickness	Equipment cost	Cure cycle time
• Vacuum bag	Good	Thin	Moderate	Short
• Autoclave	Excellent	Thick	High	Long

Vacuum bag processing is suited to components with thin sections and large sandwich structures. The vacuum bag technique involves the placing and sealing of a flexible bag over a composite lay-up (fig. 1) and evacuating all the air from under the bag (fig. 2).



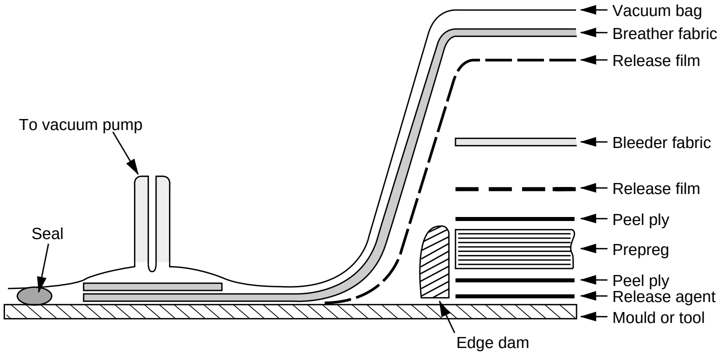
■ Fig. 1 : sealing flexible bag over lay-up



■ Fig. 2 : applying vacuum to the system

The removal of air forces the bag down onto the lay-up with a consolidation pressure of 1 atmosphere (1 bar). The completed assembly, with vacuum still applied, is placed inside an oven with good air circulation, and the composite is produced after a relatively short cure cycle.

Autoclave processing is used for the manufacture of superior quality structural components containing high fibre volume and low void contents. The autoclave technique requires a similar vacuum bag (fig. 3) but the oven is replaced by an autoclave. The autoclave is a pressure vessel which provides the curing conditions for the composite where the application of vacuum, pressure, heat up rate and cure temperature are controlled. High processing pressures allow the moulding of thicker sections of complex shapes. Honeycomb sandwich structures can also be made to a high standard. Long cure cycles are required because the large autoclave mass takes a long time to heat up and cool down. Sometimes slow heat up rates are required to guarantee even temperature distribution on the tooling and composite components.



■ Fig. 3 : detail of vacuum bag lay-up

All the components of a vacuum bag lay-up are shown in the diagram above. This lay-up is ideal for high quality aerospace components, however alternative lay-ups are possible for industrial applications.

C - What is the role of each layer in vacuum bag assembly ?

Consumables for vacuum bag processing :

• Release agent	Allows release of the cured prepreg component from the tool.
• Peel ply (optional)	Allows free passage of volatiles and excess matrix during the cure. Can be removed easily after cure to provide a bondable or paintable surface.
• Bleeder fabric	Usually made of felt of glass fabric and absorbs the excess matrix. The matrix flow can be regulated by the quantity of bleeder, to produce composites of known fibre volume (see calculation).
• Release film	This layer prevents further flow of matrix and can be slightly porous (with pin pricks) to allow the passage of only air and volatiles into the breather layer above.
• Breather fabric	Provides the means to apply the vacuum and assists removal of air and volatiles from the whole assembly. Thicker breathers are needed when high autoclave pressures are used.
• Edge dam	Contains resin flow and component shape.
• Vacuum bag/sealant tape	Provides a sealed bag to allow removal of air to form the vacuum bag.

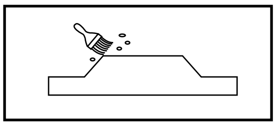
NOTE : it is recommended that new consumables are used each time to ensure the manufacture of good quality components.
Some vacuum bags are moulded to produce production components and are reusable.

D - How is vacuum bag and autoclave processing carried out ?

The information below on vacuum bag and autoclave processing techniques compares these production methods. This enables the most appropriate method to be chosen for a particular application considering the corresponding advantages and disadvantages.

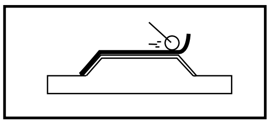
LAY-UP	CURING

1



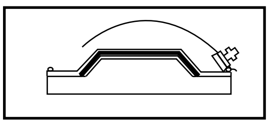
APPLY MOULD RELEASE

2



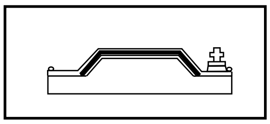
LAY-UP PREPREG

3

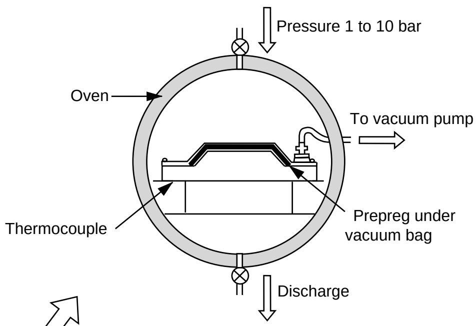


ASSEMBLE VACUUM BAG

4



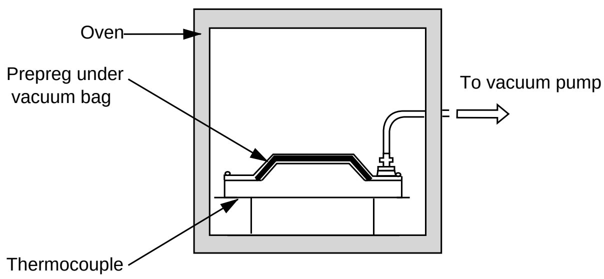
Autoclave process



Application of vacuum
+
heat

Application of vacuum
+
heat

Vacuum bag process



1 **Apply mould release**

- with a brush or cellulose pad
- with an aerosol in a specially prepared room (vapour, deposit of mould release on the prepreg, etc.)

NOTE : comply with instructions for use.

2 **Lay-up prepreg**

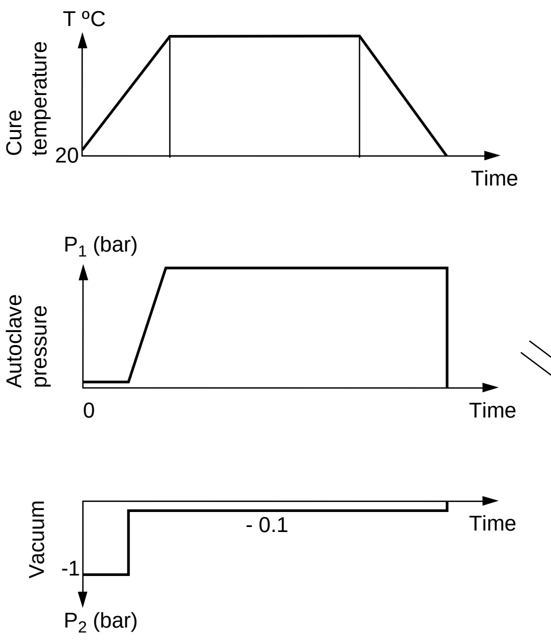
- Easy to cut with a sharp tool (cutter, etc.).
- Wear protective clothing (gloves, etc.).
- The prepreg can be high, medium or low tack.

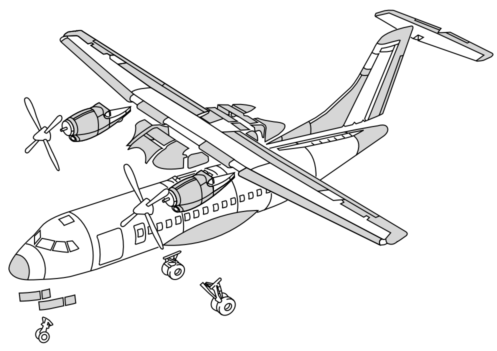
CAUTION : make sure that the prepreg protective film is removed before laying-up.

3 **Ensure the vacuum bag is tightly sealed and leak free.**

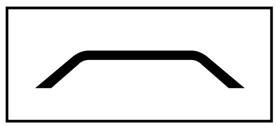
STANDARD CURE CYCLE	FINISHED PARTS

Autoclave process

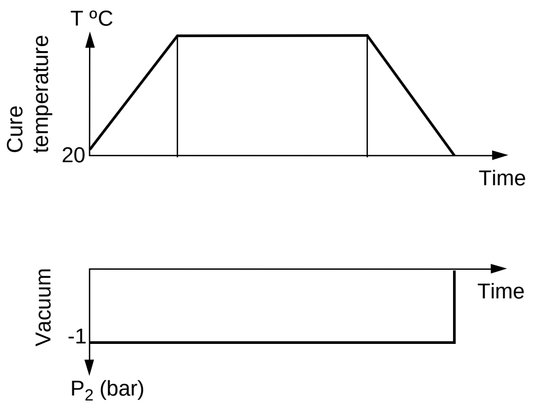


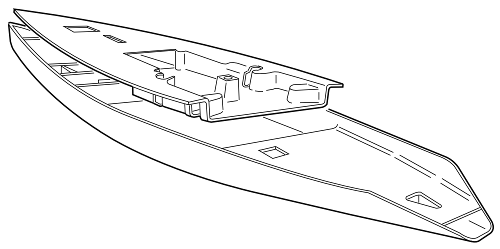


Finished parts



Vacuum bag process (oven cure)





E - What are the main autoclave and vacuum bag processing parameters ?

Vacuum

Used to remove air from the prepreg lay-up and provide a consolidating pressure for oven curing. It is common practice in autoclave cure cycles to reduce the applied vacuum to a low level and this acts as a very effective vacuum bag leak detector, for the duration of the cure cycle.

Consolidation

Large quantities of air are inevitably trapped between each prepreg layer and can be removed by covering the prepreg with a release film, a breather layer and applying a vacuum bag. The vacuum should be applied for 10-15 minutes at Room Temperature. The first ply attached to the tool face is generally consolidated and this can be repeated after every 3 or 5 layers depending on the prepreg thickness and component shape. Consolidation can be carried out overnight or during a natural break in the lay-up process.

Heat up rate

The matrix, viscosity, flow, reaction rates and component surface quality are all effected by the chosen heat up rates. Most prepregs can be processed by a range of heat up rates. Generally, fast heating rates are possible for thin components and slow heating rates are used for large and thick components. The heat up rate selected should avoid large temperature differentials between the component and the heat source.

Temperature tolerances

The oven/autoclave, component and tooling, should all reach and remain above the minimum cure temperature throughout the cure cycle. Thermocouples used to monitor the temperature should be placed carefully to ensure accurate information is received for the whole system and to operate at the cure temperature ± 5 ºC. With large components a "heat search" may be necessary to indicate the heating characteristics of the component and tooling.

Cure time

Each prepreg has a recommended cure time which starts when the lowest thermocouple reading reaches the minimum cure temperature. Extended cure times at the recommended cure temperature do not normally have an adverse effect on the component quality.

Cooling rates

Cooling cycles should be controlled to avoid a sudden temperature drop which may induce high thermal stresses in the component. Pressure and/or vacuum should be maintained throughout the cooling period.

F - What are the best processing methods for thicker industrial components ?

For components up to 10 mm thick, it is recommended to use internal bleed layers of dry fabric. These absorb excess resin and become an integral part of the cured composite. This procedure has the following advantages :

- Vacuum is easily distributed, eliminating any void content in the composite.
- Excess matrix accumulating between the layers is absorbed.
- Fibre volume is controlled.

Notes **:**

- For monolithic structures, any dry fabric plies must be evenly distributed throughout the thickness of the component.
- For sandwich structures, any dry fabric plies must only be placed in the outer 2/3 of the skin.
- The dry fabric layers must always overlap the prepreg stack to allow connection to the vacuum system.

G - What is the best cure cycle for thicker components ?

To avoid exotherms it is advisable to incorporate a **dwell** and a **controlled heat up rate.**

Dwell - used to equalise tool and component temperatures and to initiate a controlled prepreg cure.

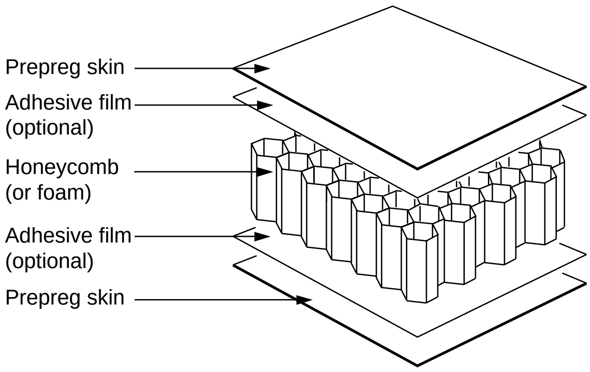
Controlled heat up rate - avoids a large temperature differential between the air temperature and the component. Any accumulations of resin are prone to exotherm under these conditions.

H - What is a prepreg sandwich construction ?

A sandwich contruction consists of thin high strength prepreg skins bonded to a thicker honeycomb, foam or balsa core.

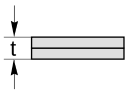
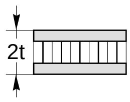
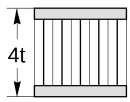
A "self-adhesive" prepreg does not require additional adhesive layers and enables the production of light structures at reduced fabrication costs.

HONEYCOMB SANDWICH WITH PREPREG SKINS

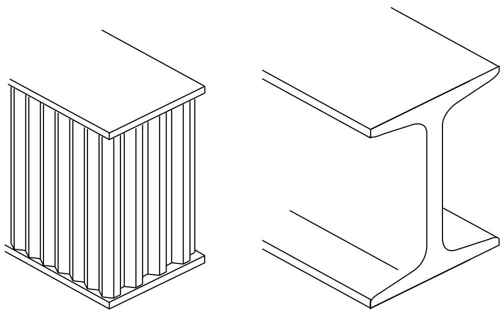


Advantages : very low weight, high stiffness, durable, design freedom, reduced production costs.

I - What are the properties of a sandwich construction ?

	Solid material	**Core thickness t**	**Core thickness 3t**
			
Stiffness	1.0	7.0	37.0
Flexural strength	1.0	3.5	9.2
Weight	1.0	1.03	1.06

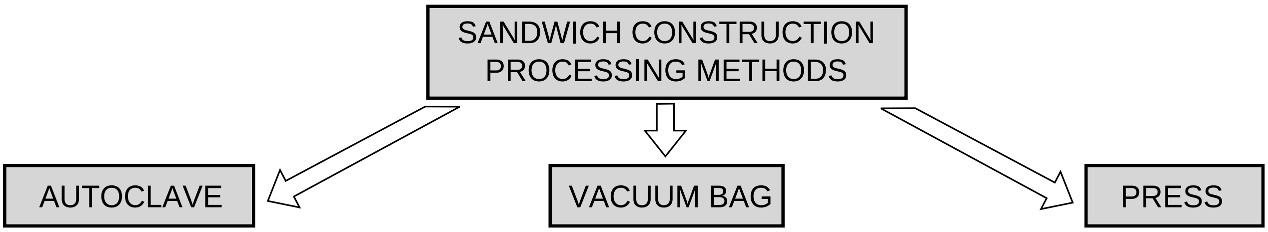
ANALOGY BETWEEN AN I-BEAM AND A HONEYCOMB SANDWICH CONSTRUCTION

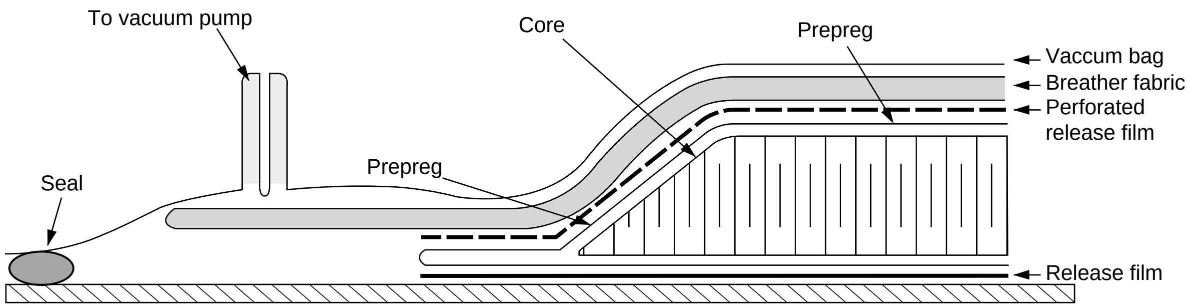


Benefits of honeycomb sandwich :

- Tensile and compression stresses are supported by the skins
- Shearing stress is supported by the honeycomb
- The skins are stable across their whole length
- Rigidity in several directions
- Exellent weight saving

J - How is a sandwich construction produced ?





RECOMMENDATIONS FOR THE MANUFACTURE OF SANDWICH CONSTRUCTIONS

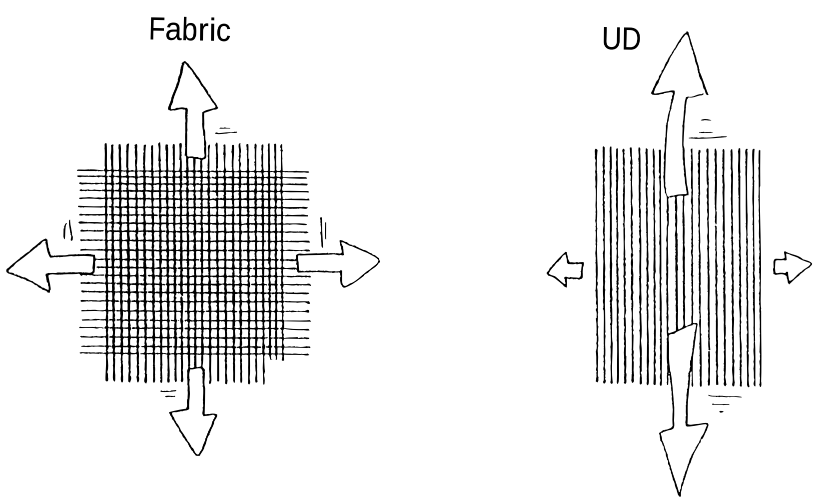
Sandwich constructions can be manufactured by autoclave, press or vacuum bag moulding. For autoclave or press processing sandwich constructions can usually be laid up and cured as a single shot process. However, for the vacuum bag curing of large components it may be necessary to lay-up and cure in two or more stages. This will improve the quality of the component, ensuring against voids and telegraphing (where honeycomb cells are visible through the composite skins). Avoid excessive pressures which can lead to movement of the core.

PROPERTIES OF FIBRE-REINFORCED COMPOSITES

A - What are the characteristics of a composite material ?

The fibres in a composite are strong and stiff and support most of the applied loads. The matrix contributes mainly to the service temperature, toughness, and environmental resistance of the composite. As a result unidirectional composites (UD) have predominant mechanical properties in one direction and are said to be anisotropic. Isotropic materials (most metals) have equal properties in all directions.

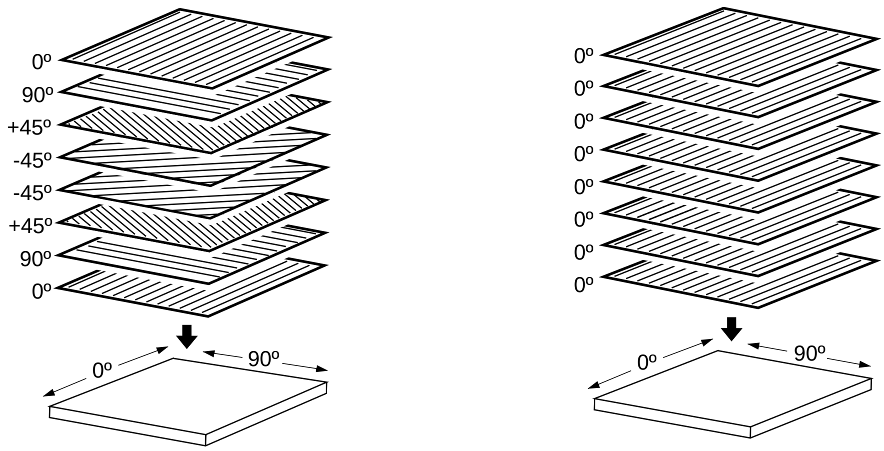
Components made from fibre-reinforced composites can be designed so that the fibre orientation produces optimum mechanical properties, but they can only approach the true isotropic nature of metals.



■ Equal properties ■ Unequal properties

Orientation

The fibre directions can be arranged to meet specific mechanical performance requirements of the composite by varying the orientation.



■ Quasi-isotropic lay-up ■ Unidirectional lay-up

B - What physio/chemical tests are made on prepregs before and after cure ?

The following tests can be made to assess the quality of manufacture and suitability of prepregs for the composite manufacturing processes.

Uncured prepregs

• Gel time	The time, at a given temperature, when the matrix progresses from liquid to solid. Indicated by a rapid increase in matrix viscosity.
• Viscosity	Measurement of the flow characteristics of matrices, which are influenced by temperature and heat up rates.
• Volatiles	Percentage weight loss of gaseous material from a weighed prepreg specimen, after conditioning at a selected temperature and time.
• Flow	Percentage weight loss of matrix from a weighed test specimen under agreed conditions of temperature and pressure.
• Tack	A measurement of the capability of an uncured prepreg to adhere to itself and to mould surfaces.
• Resin content	Weight percentage of resin per unit area.
• Formulation	Verification of the correct quantity of formulation components. (physicochemical test)

Cured prepregs

• Glass transition temperature (Tg)	Tg is the temperature which marks a physical phase change in the matrix properties and gives an indication of its maximum service temperature.
• Fibre volume	Percentage of fibre by volume in the composite.
• Composite density	Mass per unit volume g/cm^3.
• Cure	Assessment of prepreg advancement and cure characteristics.
• Cpt	Cured ply thickness.

See pages 28 and 29 for calculations.

C - How are composites tested ?

MECHANICAL TESTS ON MONOLITHIC STRUCTURES

Each group shows the general specimen test configuration and formula.

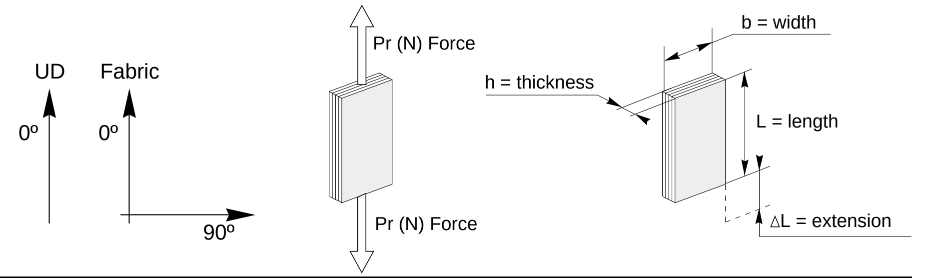
Tensile

- Tensile strength σ

$$\sigma\ (\text{MPa}) = \frac{Pr}{b\ .\ h}$$

- Tensile modulus *E*

$$E\ (\text{MPa}) = \frac{Pr\ .\ L}{b\ .\ h\ .\ \Delta L}$$



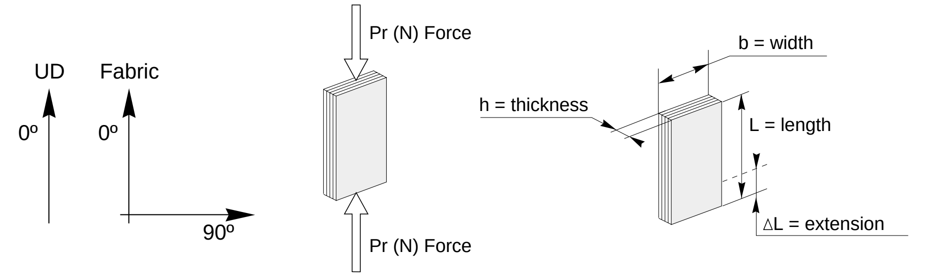
Compression

- Compression strength σ

$$\sigma\ (\text{MPa}) = \frac{Pr}{b\ .\ h}$$

- Compression modulus *E*

$$E\ (\text{MPa}) = \frac{Pr\ .\ L}{b\ .\ h\ .\ \Delta L}$$



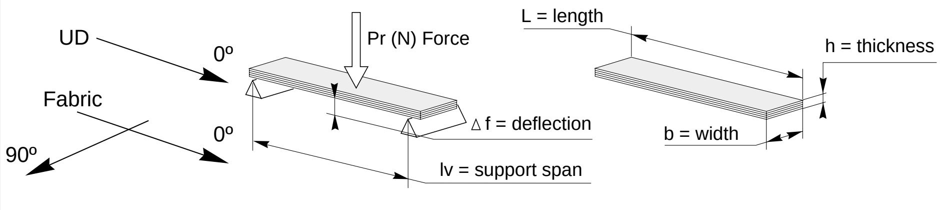
Flexural

- Flexural strength σ

$$\sigma\ (\text{MPa}) = \frac{3\ Pr\ .\ lv}{2\ b\ .\ h^2}$$

- Flexural modulus *E*

$$E\ (\text{MPa}) = \frac{Pr\ .\ lv^3}{4\ .\ b\ .\ h^3\ .\ \Delta f}$$

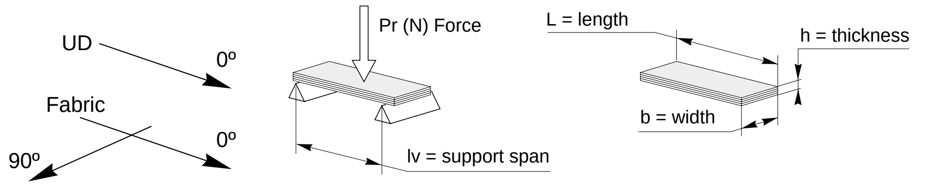


Span to thickness ratio 40 : 1 carbon ; 20 : 1 aramid ; 16 : 1 glass

Shear (short beam)

- Interlaminar shear strength σ

$$\sigma\ (\text{MPa}) = \frac{3\ Pr}{4\ .\ b\ .\ h}$$



Span to thickness ratio 5 : 1

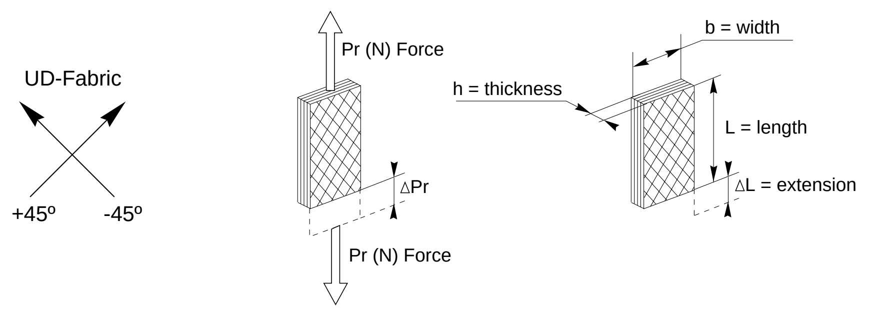
In-plane shear

- In-plane shear strength σ

$$\sigma\ (\text{MPa}) = 0.5 \times \frac{Pr}{b\ .\ h}$$

- In-plane shear stress modulus G

$$G\ (\text{MPa}) = \frac{0.5}{(1 + \upsilon)} \times \frac{\Delta Pr}{b\ .\ h\ \ \Delta L}$$

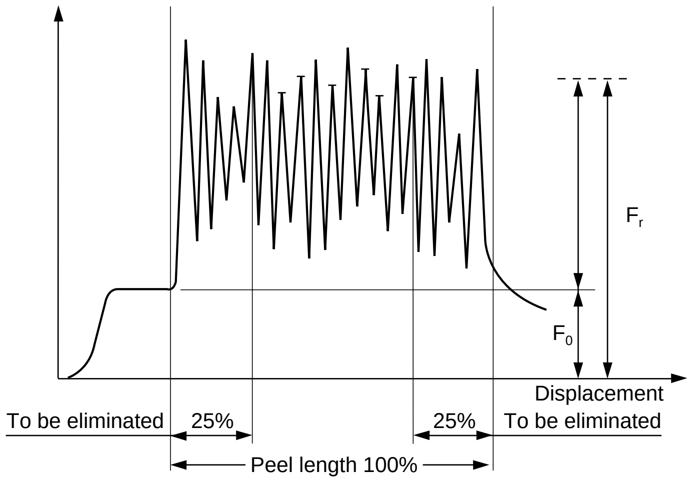


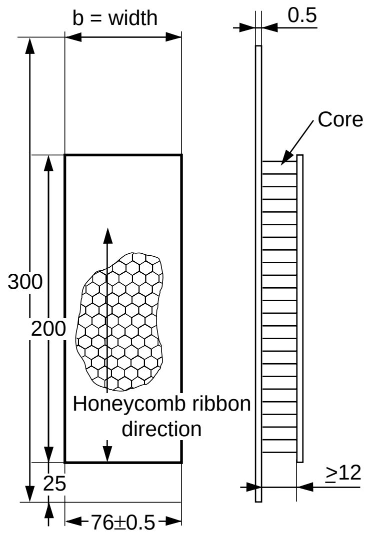
υ = Poisson's ratio

Climbing drum peel test

Peel strength F_p

F_p (N) = $F_r - F_0$





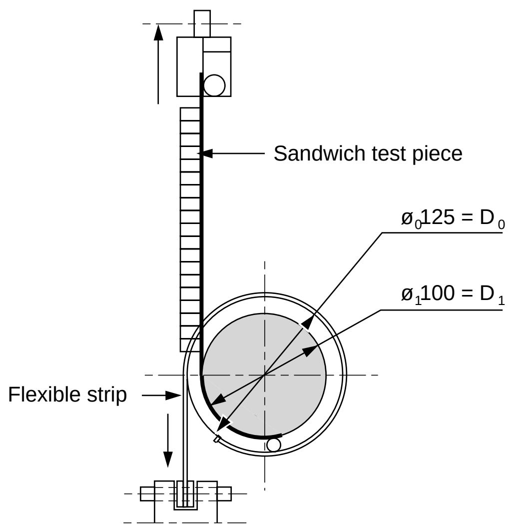
Dimensions in mm

Peel torque C_p

$$C_p \text{ (Nmm/mm)} = \frac{F_p (D_0 - D_1)}{2\,b}$$

Conversion factors :

1 Newton per 76 mm width
= 0.0127 Nm/76 mm
= 0.1671 Nm/m
= 0.01671 daNcm/cm
= 0.2248 lbf/3 in
= 0.1124 lbf-in/3 in
= 0.03747 lbf-in/in



The climbing drum peel test measures the peel resistance of the bond between the flexible skin and the core of a sandwich structure.

The test is commonly used as a practical process control method in sandwich manufacturing, to monitor the cure and the bond quality.

TYPICAL MECHANICAL VALUES ON EPOXY PREPREG LAMINATES

Volume content of fibres : ≈ 60 % (Carbon), ≈ 50 % (E-glass - Aramid). Directions: ℓ 0°, t 90°

			UNITS	FIBRES: E-GLASS UD	E-GLASS Fabric	ARAMID UD	ARAMID Fabric	HIGH STRENGTH CARBON UD	HIGH STRENGTH CARBON Fabric	INTERMEDIATE MODULUS CARBON UD	INTERMEDIATE MODULUS CARBON Fabric
Tensile	$\sigma \ell$	|||	MPa	1100	600	1100	500	2000	800	2400	900
	σt	≡	MPa	35	550	35	450	80	750	80	850
	$E \ell$	|||	GPa	43	20	60	30	130	70	170	90
	$E t$	≡	GPa	8	19	8	30	9	65	9	90
	Poisson's ratio $\upsilon \ell t$			0.28	0.13	0.34	0.2	0.25	0.05	0.27	0.05
Compression	$\sigma \ell$	|||	MPa	900	550	250	150	1300	700	1600	800
	σt	≡	MPa	150	500	150	150	250	650	250	750
	$E \ell$	|||	GPa	42	17	75	31	115	60	150	80
	$E t$	≡	GPa	10	16	5.5	30	10	55	11	75
Flexural	$\sigma \ell$	|||	MPa	1200	700	550	400	1800	1000	1400	1200
	$E \ell$	|||	GPa	42	20	40	25	120	65	140	75
In-plane shear	$\sigma \ell t$		MPa	60	55	45	40	95	80	95	80
	$G \ell t$		GPa	4	4.2	2.1	4	4.4	5.5	4.4	5
Interlaminar shear	σ	|||	MPa	75	50	60	50	80	70	80	70

TYPICAL THERMAL PROPERTIES OF PREPREG LAMINATES

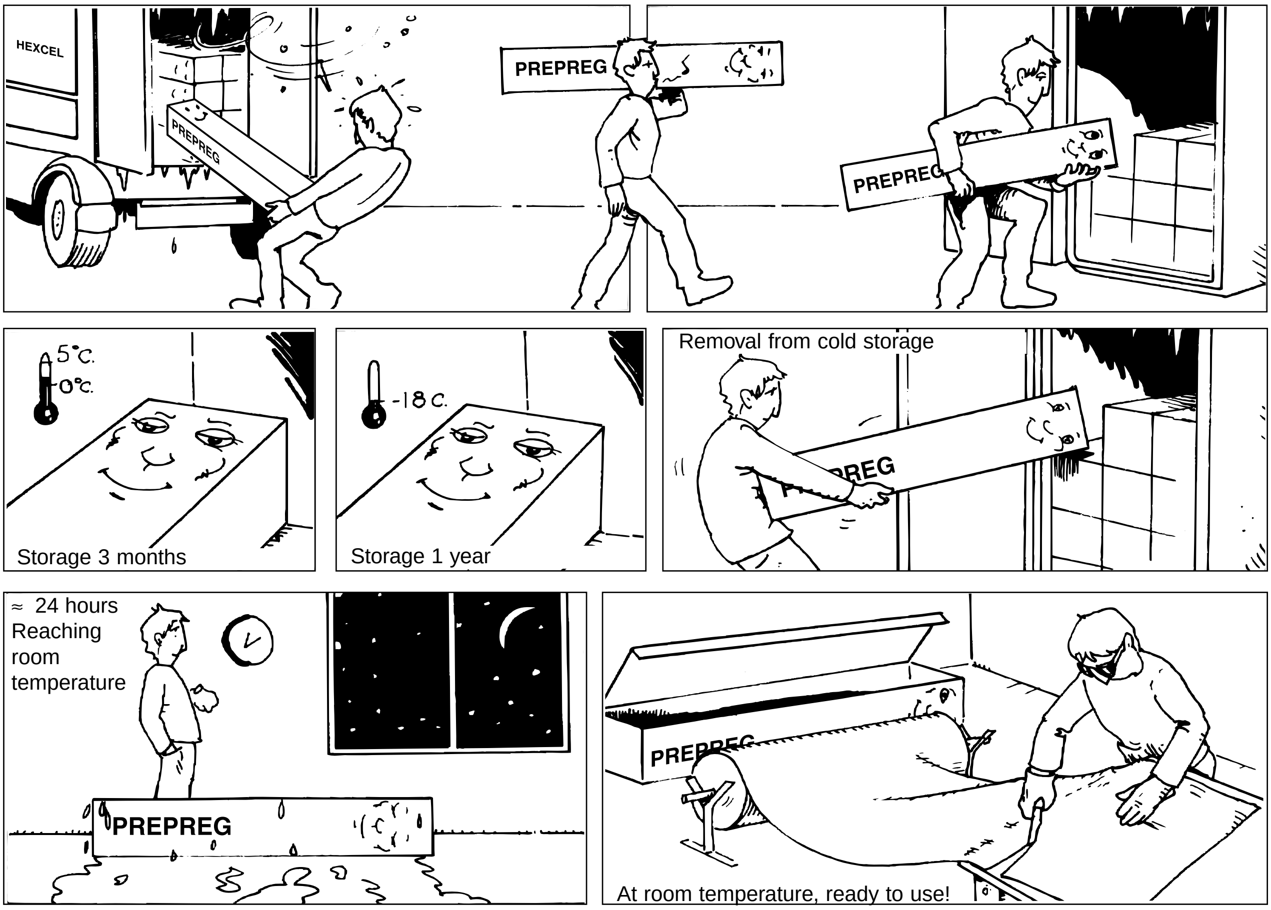
	Units	Glass UD	Glass Fabric	Aramid UD	Aramid Fabric	High strength carbon UD	High strength carbon Fabric
Coefficient of expansion	10^{-6} / °K	11	14	- 0.4	- 5.2	0.3 - 0.7	2 - 3
Thermal conductivity	W/m . °K	0.4	0.16 - 0.33	0.4	0.21	1	0.86 - 1.44

PREPREG STORAGE AND SAFETY PRECAUTIONS

A - How should prepregs be stored ?

Prepregs should be stored as received in a cool dry place or in a refrigerator. After removal from refrigerator storage, prepreg should be allowed to reach room temperature before opening the polyethylene bag, thus preventing condensation (a full reel in its packaging can take up to 48 hours).

Typically prepregs have a guaranteed shelf life at - 18 ºC of 12 months. Tack life at 23 ºC depends on the matrix, and is clearly defined on the relevant Product Data Sheet.



B - What health and safety precautions should be taken when handling prepregs ?

Hexcel prepregs are particularly low-risk in terms of handling hazards for the following reasons :

- Prepreg is covered on both sides by protective coverings which are not removed until assembly lay-up. It should be cut to shape before removing the protective coverings and virtually no handling of the prepreg is necessary.
- Unlike wet lay-up methods of fibre reinforced composite manufacture, where dry fibre and liquid resin are used, uncured prepregs have no loose fibrous dust and are splash-free, leak-free and spillage free.
- Prepregs are volatile-free at normal room temperature.
- Prepregs have a moderate/low tack level at normal room temperature.

However, the usual precautions when handling synthetic resins should be observed, ie. always wear gloves and ensure arms are covered, thus avoiding skin contact with the product. Repeated unprotected touching of prepreg can cause an allergic reaction.

Dust from machining cured product will contain fibrous material, inhalation of which should be avoided. Provide positive dust extraction and collection from the cutting zone. Protect against fire and explosion by avoiding dust formation and ignition sources when machining cured product. Dust from products containing carbon fibre is electrically conductive.

Hexcel has prepared Safety Data Sheets for each product. These are available to company safety officers on request. The Safety Data Sheet should always be read and understood before the product is removed from its packaging.

APPENDIX I - CALCULATIONS

A - Theoretical calculations of bleeder plies to make a composite laminate of selected fibre volume

This method applies to carbon, glass or kevlar composite laminates made from either unidirectional or woven prepregs and uses any available bleed material.

Stage 1 — Measure the absorbency of the bleed material : "A"

- Make a series of bleed-out tests where each test has the same prepreg stack (checked by weight).
- Individual tests should have an increasing number of bleed layers (also weighed g/m^2) to absorb the resin.
- Cure the prepreg using recommended cure cycle.
- Examine the bleed packs and select the bleed pack with the optimum resin absorption from the test series.
- Weigh the best bleed pack and calculate the resin weight absorbed by each layer. *120 style glass fabric typically absorbs 50g/m² of epoxy resin (density ≈ 1.3).*

Stage 2 — Determine the resin and fibre areal weights of the prepreg (g/m^2)

Stage 3 — Calculate the number of bleed plies

$$= \frac{\left[wr - \left(\frac{wf \times \rho r \times Vr}{\rho f \times Vf} \right) \right]}{A} Np$$

Parameters :

A : Absorbency of bleed layer (g/m^2)
wr : Resin areal weight in prepreg (g/m^2)
wf : Fibre areal weight in prepreg (g/m^2)
Vf : % fibre volume (selected)
Vr : % resin volume (= 100 - %Vf)
ρr : Resin density (g/cm^3)
ρf : Fibre density (g/cm^3)
Np : Number of plies of prepreg in stack

B - Calculations for cured ply thickness, fibre volume and composite density

Cured ply thickness (calculated) = cpt

Parameters :

wf : Fibre areal weight in prepreg (g/m^2)
ρf : Fibre density (g/cm^3)
Vf : Fibre volume (%)

$$cpt = \frac{wf}{\rho f \times 10 \times Vf}$$

Resin bleed required to achieve a cpt at a high fibre volume see calculation (A)
No bleed will give the natural fibre volume - see calculation below for fibre volume (method 1)

Fibre volume % = Vf

Parameters :

wf : Fibre areal weight in prepreg (g/m^2)
wr : Resin areal weight in prepreg (g/m^2)
ρf : Fibre density (g/cm^3)
ρr : Resin density (g/cm^3)

method 1
no bleed

$$Vf = \left(\frac{wf/\rho f}{wr/\rho r + wf/\rho f} \right) \times 100$$

method 2
from measured laminate thickness

$$Vf = \frac{\text{calculated cpt x fibre volume (used to calculate cpt)}}{\text{measured cpt}}$$

Composite density = ρc

Parameters :

ρl : Liquid density (g/cm^3)
Archimedes principle

$$\rho c = \frac{\text{composite weight (air)}}{\text{composite weight (air) - composite weight (liquid)}} \times \rho l$$

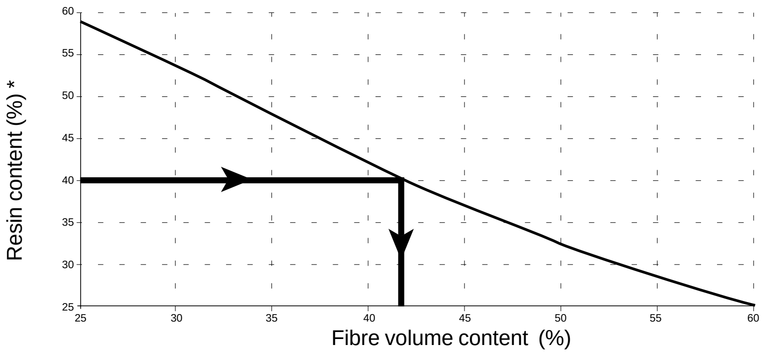
AID TO PREPREG SELECTION

C - Choice of prepreg resin content to achieve required fibre volume/cured ply thickness

Having chosen the ideal fibre and matrix for your application, the following diagrams assist with the selection of resin content and fibre weight in a prepreg to obtain the desired fibre volumes and cured ply thicknesses.

Fibre volumes

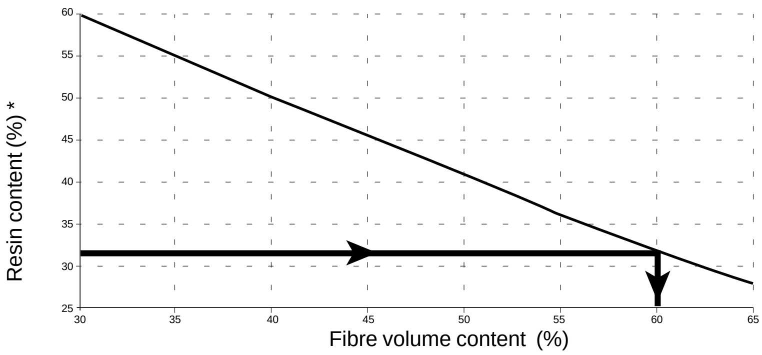
EPOXY/E-GLASS



Matrix density ➪ 1.2
Fibre density ➪ 2.6

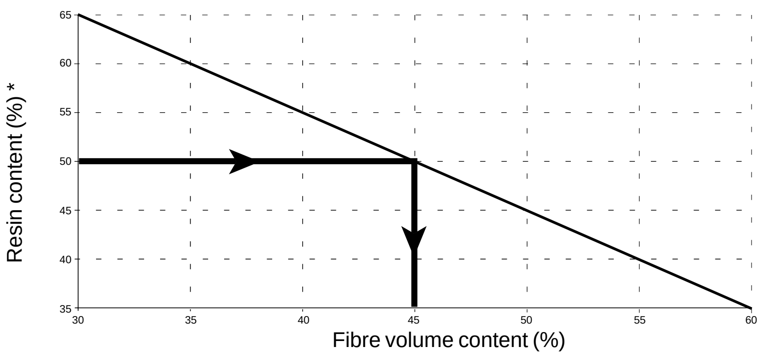
Bold lines demonstrate for a 40% resin content you have a fibre volume content of 42%

EPOXY/HS CARBON



Matrix density ➪ 1.2
Fibre density ➪ 1.8

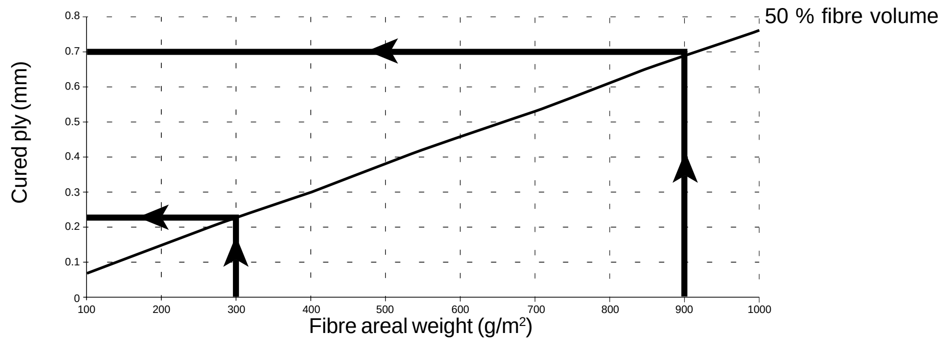
EPOXY/ARAMID



Matrix density ➪ 1.2
Fibre density ➪ 1.45

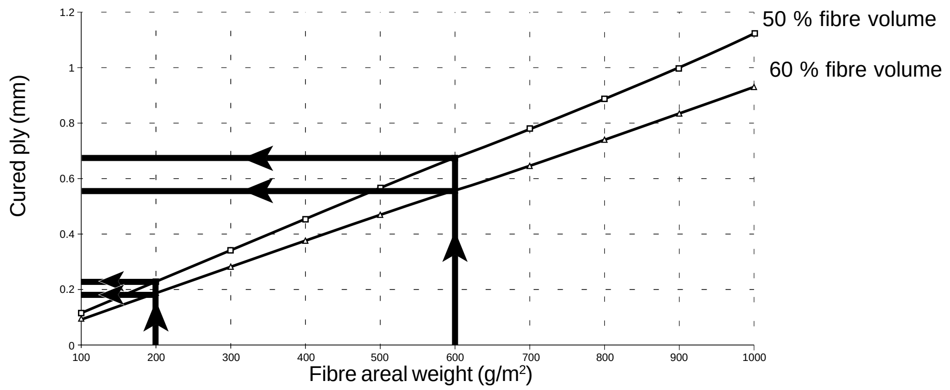
Cured ply thickness

EPOXY/E-GLASS

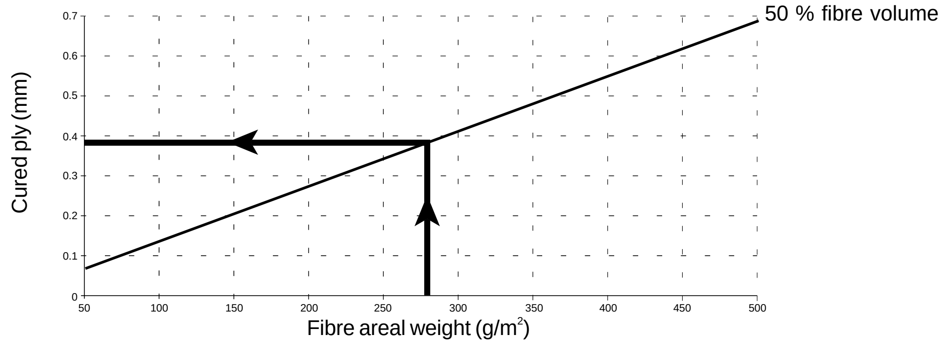


Bold lines demonstrate for a 900g/m² fibre areal weight you have a cured ply thickness of 0.7mm

EPOXY/HS CARBON



EPOXY/ARAMID



APPENDIX II - HEXCEL PRODUCT RANGE

HexPly® is Hexcel's trademark for high performance prepregs.

Hexcel manufactures a comprehensive range of composite materials, including :

TowFlex® continuous fibre-reinforced thermoplastic composites

Resins and reinforcements for RTM, RFI and LRI

Redux® structural film adhesives

HexWeb® aluminium and aramid honeycombs

Hexlite® and Fibrelam® honeycomb sandwich boards

Polyspeed® laminates

Modipur® polyurethanes

Fabrics, multiaxials and braids in carbon, glass, aramid and hybrids