HexPly® Prepreg Technology

HEXCEL®

Prepregs are specially formulated resin matrix systems that are reinforced with man-made fibres such as carbon, glass and aramid. Hexcel has its own in-house supply of carbon fibre and world class weaving facilities for the development of optimum reinforcement technologies to complement the prepreg resin formulations.

Prepreg is the ultimate composite material. The thermoset resin cures at elevated temperature, undergoing a chemical reaction that transforms the prepreg into a solid structural material that is highly durable, temperature resistant, exceptionally stiff and extremely lightweight.

In the early 1980's prepregs were considered speciality materials, accounting for around 5% of an aircraft design and used only for non-critical secondary structures. Today prepregs are baseline for aircraft primary structures and constitute more than 50% of the airframe of the Airbus A350 XWB and Boeing 787. The growth in aerospace and other industries including wind energy, automotive, sports goods and industrial machinery has followed. More recent applications benefitting from prepreg include subsea tubes for oil and gas exploitation and high pressure vessels. This growth in the use of prepreg composites over metal has been driven by higher strength to weight performance, better fatigue strength and potential to offer greater freedom of design.

Hexcel is a world leader in prepreg technology and Hexcel prepregs are marketed using the HexPly® registered trademark.

January 2013
Publication No. FGU 017c

CONTENTS

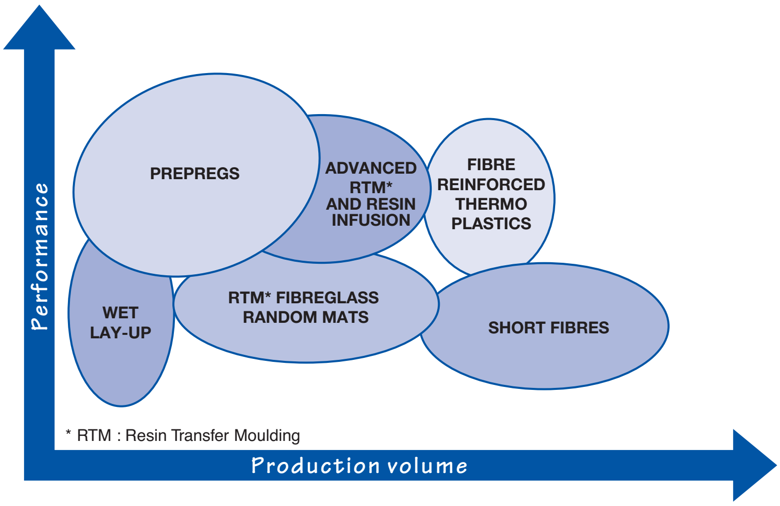
INTRODUCTION

Prepregs are fibre-reinforced resins that cure under heat and pressure to form exceptionally strong yet lightweight components. Hexcel is a world leader in prepreg technology and 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 guide you through the choice of the most suitable prepreg and processing method for an application. To assist with product selection Hexcel has produced PREPREG MATRIX SELECTOR GUIDES for Aerospace and Industrial applications which are available on request. For more information on our product range, prepreg selection or processing techniques please contact Hexcel or visit www.hexcel.com.

A - Main technologies for high performance composites

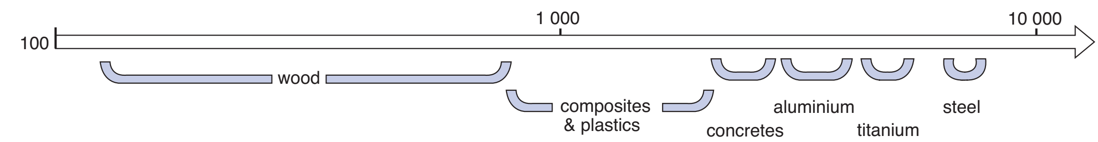
The position of prepreg technology in terms of performance and production volumes is compared below with other fabrication processes.



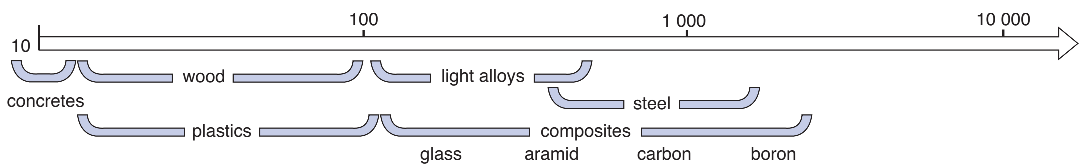
B - Why use composites ?

Comparison of different material characteristics :

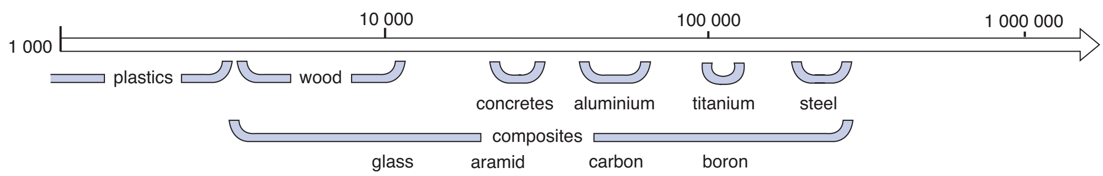
Density (kg/m^3)



Tensile strength (MPa)



Tensile modulus (MPa)



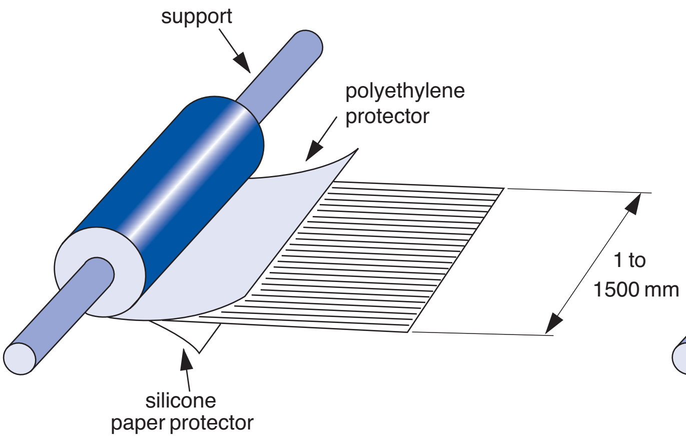
Composites provide the advantages of lower weight, greater strength and higher stiffness.

C - What is a prepreg ?

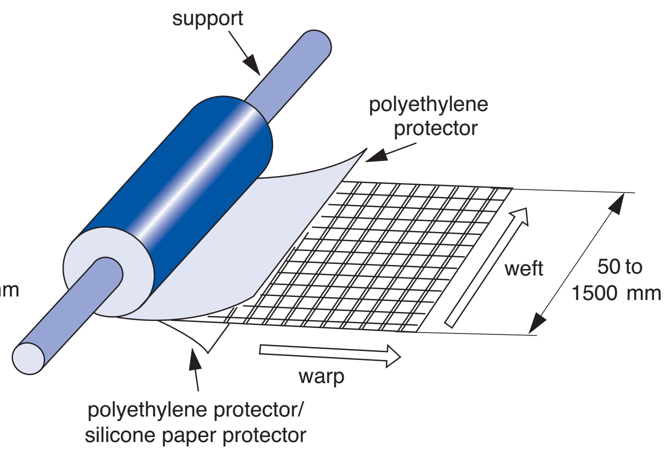
A prepreg consists of a combination of a matrix (or resin) and fibre reinforcement. It is ready to use in the component manufacturing process.

It is available in :

Unidirectional (UD) form
(one direction of reinforcement)



Fabric form
(WOVEN, NCF, NC2®)



D - Where are prepregs used ?

Aerospace
- Civil Aircraft
- Primary Structures
- Interiors
- Aero-engines
- Defence Aircraft
- Helicopters
- Space

Industrial
- Wind Energy
- Sports Equipment
- Transport
- Machinery
- Tooling

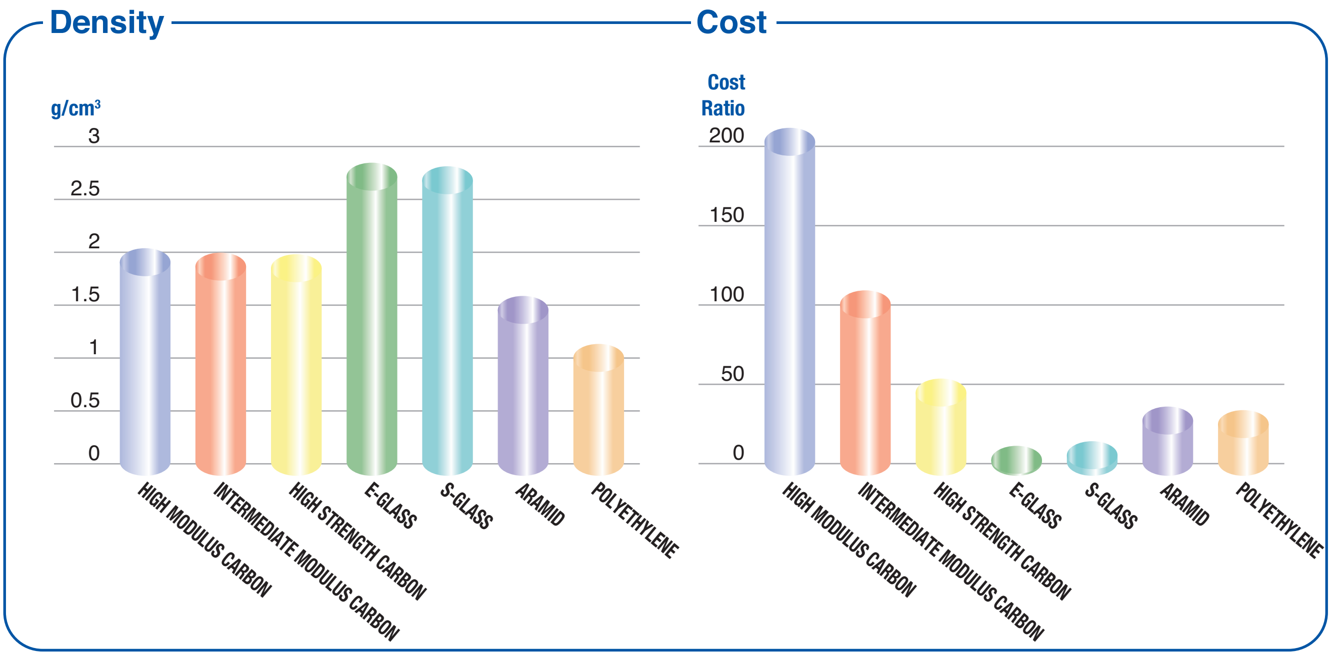
HEXCEL®

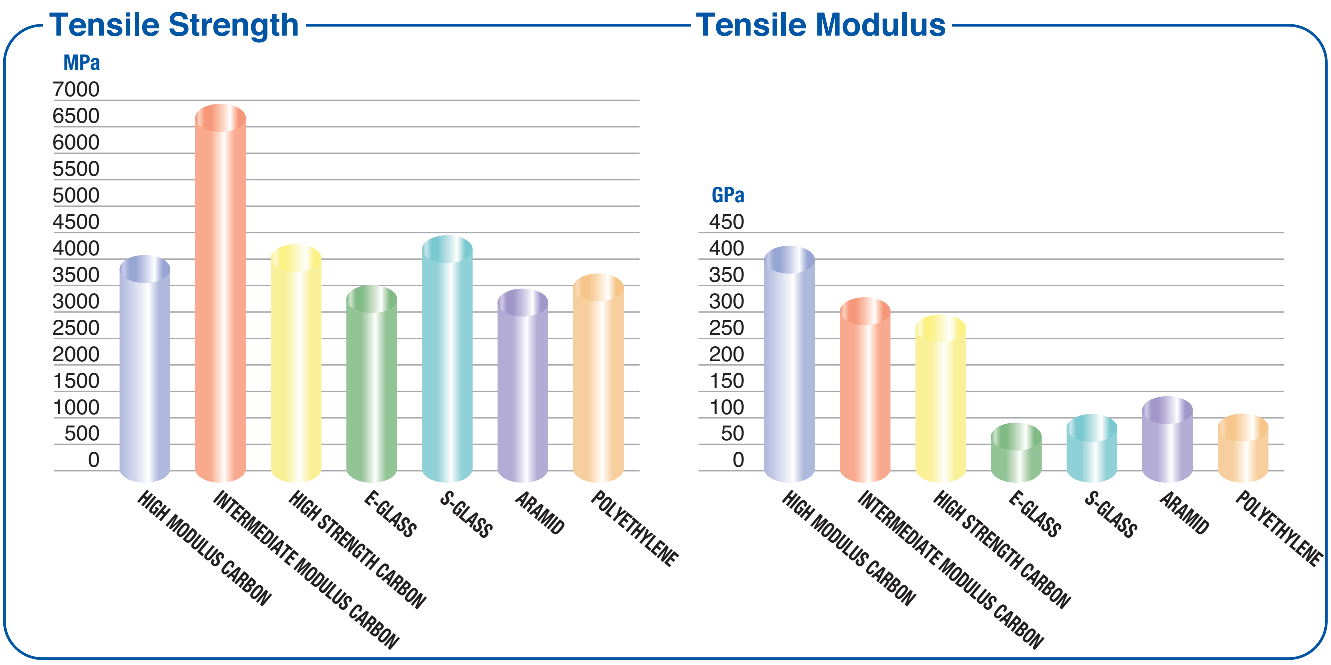
FIBRE AND FABRIC PROPERTIES

A - What are the fibre properties ?

Reinforcement materials provide composites with mechanical performance: excellent stiffness and strength, as well as good thermal, electrical 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.





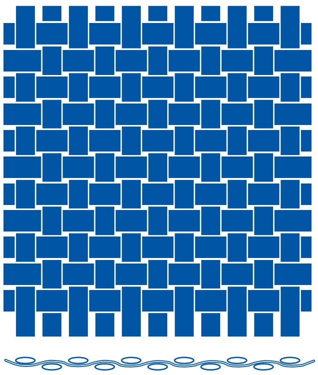
B - What are the different weave styles of fabrics ?

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.

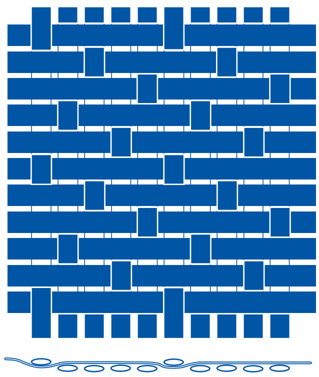
There are three main weave styles:

PLAIN WEAVE



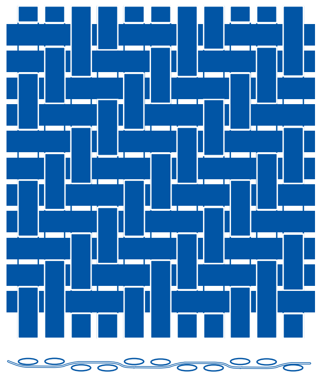
Low drapeability/high crimp

SATIN WEAVE
(4, 5, 8, 11)



Good drapeability/low crimp

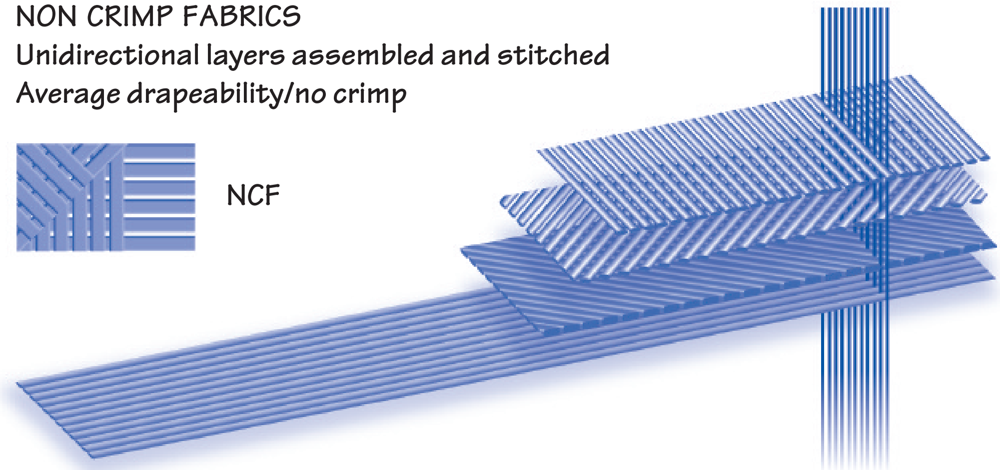
TWILL WEAVE
(2/1, 3/1, 2/2)



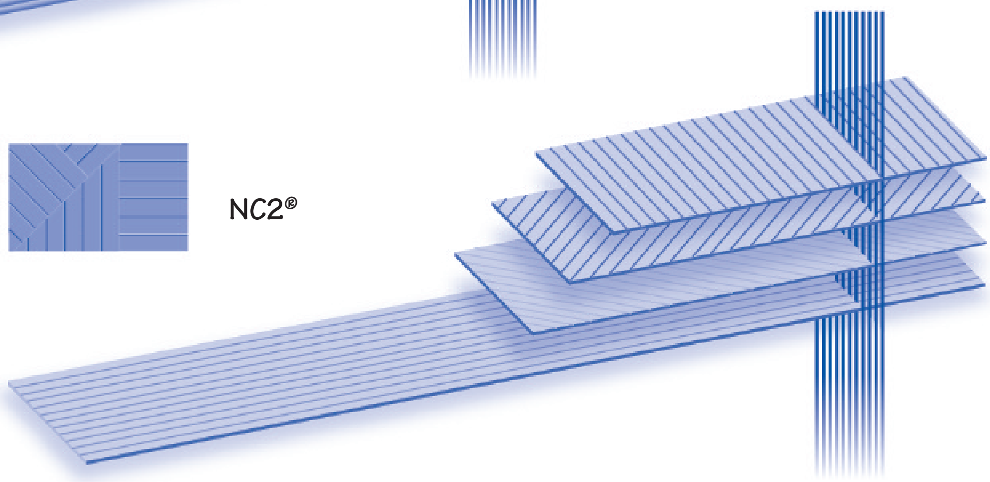
Average drapeability/average crimp

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

NCF



NC2®



See selector guides for industrial and aerospace product ranges http://www.hexcel.com/resources/selector-guides

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

Reinforcements come in various forms, with each type offering particular advantages, as shown below.

Reinforcement		Advantages	Applications
Unidirectional	UD prepreg Tape	• High strength and stiffness in one direction • Low fibre weights ≈ 100 g/m² • High fibre weights ≈ 3000 g/m² for glass and ≈ 800 g/m² for carbon	Sports goods Aircraft Primary structures Wind energy Load carrying structures
	Single tow	• Suitable for filament winding • Very narrow width for accurate fibre placement (1 mm)	Pressure vessels Drive shafts Tubes
	Slit tape	• High strength and stiffness in one direction • Low fibre weights ≈ 134 g/m² • Ideally suited for high deposition of complex parts	Aerospace primary structures
	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 • PrimeTex® smooth, closed weave fabrics for uniform cosmetic appearance, where fabric tows are flatly woven and/or spread in both warp and weft directions	Aerospace Industrial Sport and leisure Wind Energy
Multiaxials	NCF	• Time-saving, cost-effective technology • Strength and stiffness in multiple directions • Unlimited ply orientation • Ability to optimise weight distribution within a fabric • No crimp • Less waste for complex lay-ups (cross plies) • Reduced processing cost • Heavy weights achievable	Wind energy (blades)

	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)
			Automotive

MATRIX PROPERTIES

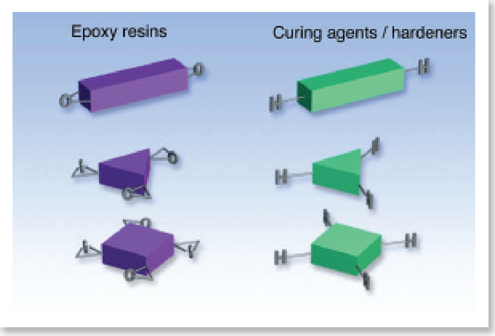
A - What is a matrix ?

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 determines environmental resistance and maximum service temperature of a prepreg. When selecting prepreg the maximum service temperature is one of the key criteria for choosing the appropriate prepreg matrix.

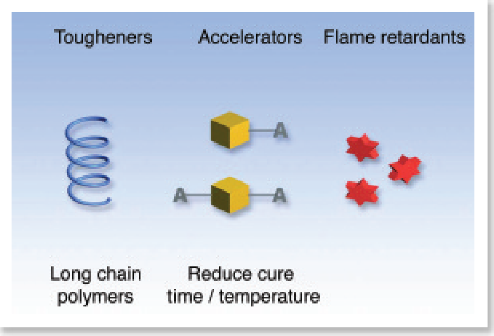
The thermoset cure mechanism (epoxy example) and the role of the different components of a matrix are represented below.

The cure can be simply represented by epoxy 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.

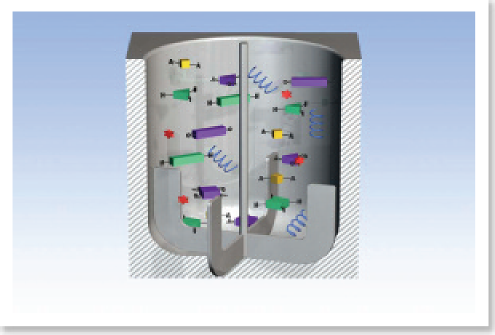
1. **Reactive Components**
   Many different types available



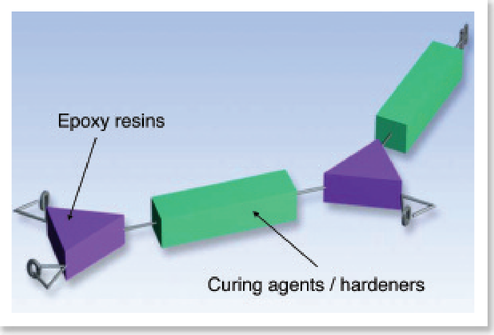
2. **Additives (reactive and non-reactive)**



3. **Choose formulation and mix together with heat and/or solvent**



4. **Reaction begins with heat, pressure and time**

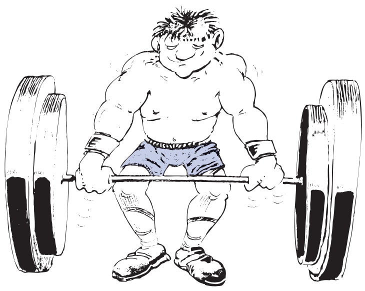


5. **Matrix gels and then hardens**
   3D network is formed

6. **Additives are held in the 3D network**
   Final properties dependent on formulation recipe

B - What are the properties of different thermoset matrices ?

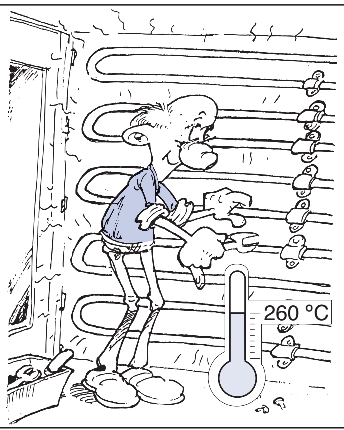
There are three main matrix types: epoxy, phenolic and bismaleimide. The table below indicates the advantages of each type and typical applications.

EPOXY	Advantages	Applications	
	**Excellent mechanical performance** • Good environmental resistance and high toughness • Easy processing	**120°C cure** Aerospace Sport Leisure Marine Automotive Rail Transport Wind Energy	**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 Rail

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 ?

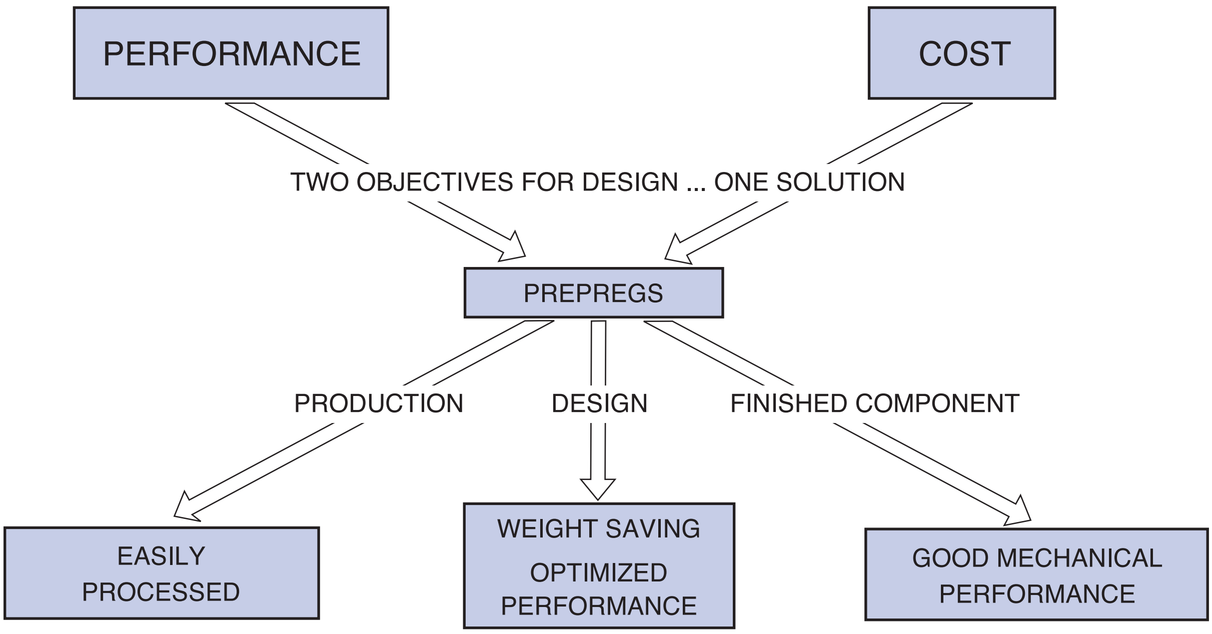
Matrices can be conveniently classified according to service temperature as follows:

Type	Maximum Service Temperature	Characteristics
Phenolic	80-100°C	Excellent fire, smoke and toxicity properties (FST).
120°C Curing Epoxy	100°C	Highly toughened epoxy systems usually exhibit good adhesion for honeycomb bonding.
180°C Curing 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.

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
- Consistent performance and processing characteristics

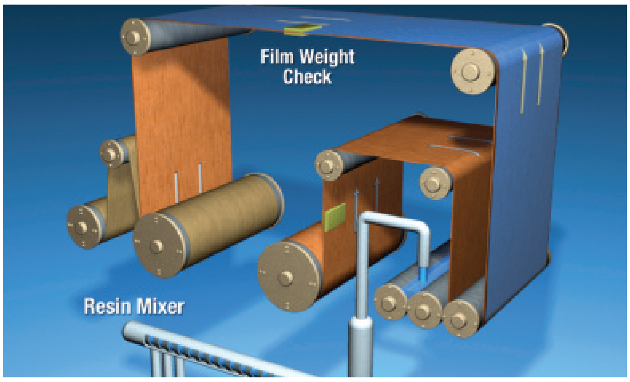
- Optimized weight/ performance ratio

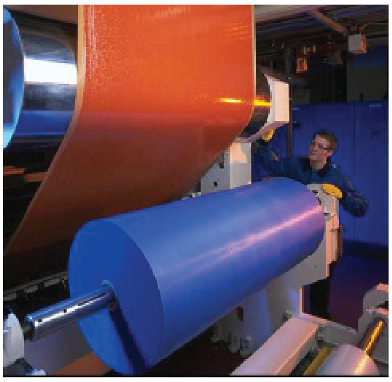
- Fatigue, tensile, stiffness
- Corrosion
- Good ageing
- Repair

B - How are prepregs made ?

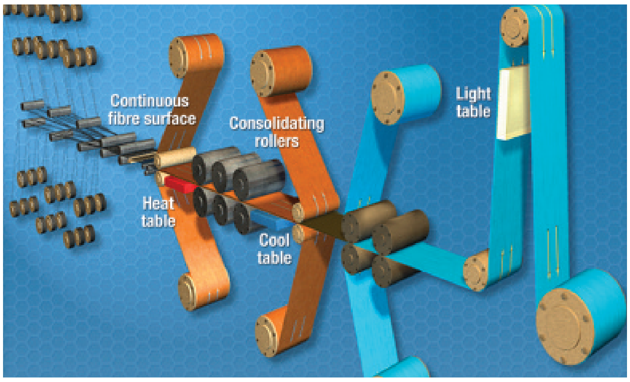
1 Film transfer route: 2 step process for UD and woven prepregs

Step 1 - Film manufacture

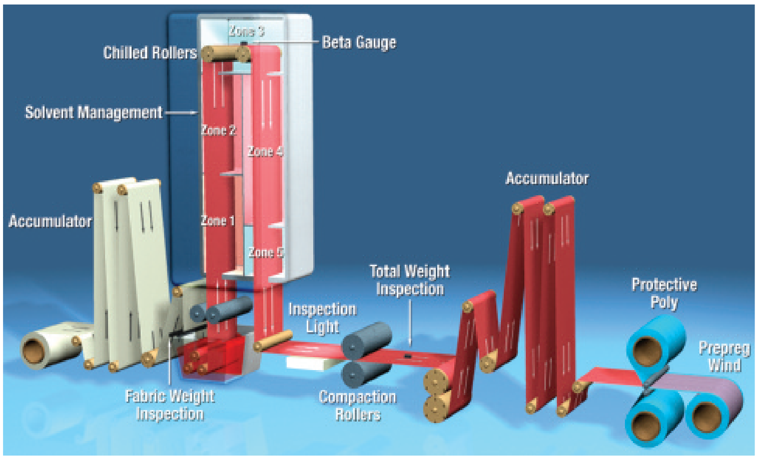




Step 2 - Film impregnation



2 Solution route: 1 step process for woven prepregs

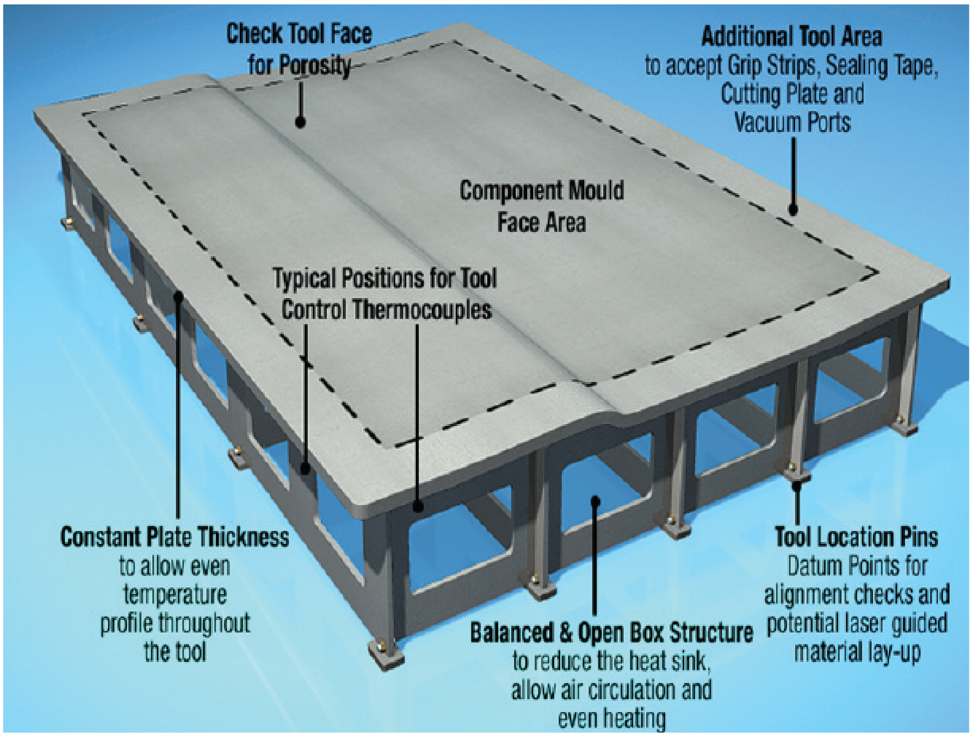


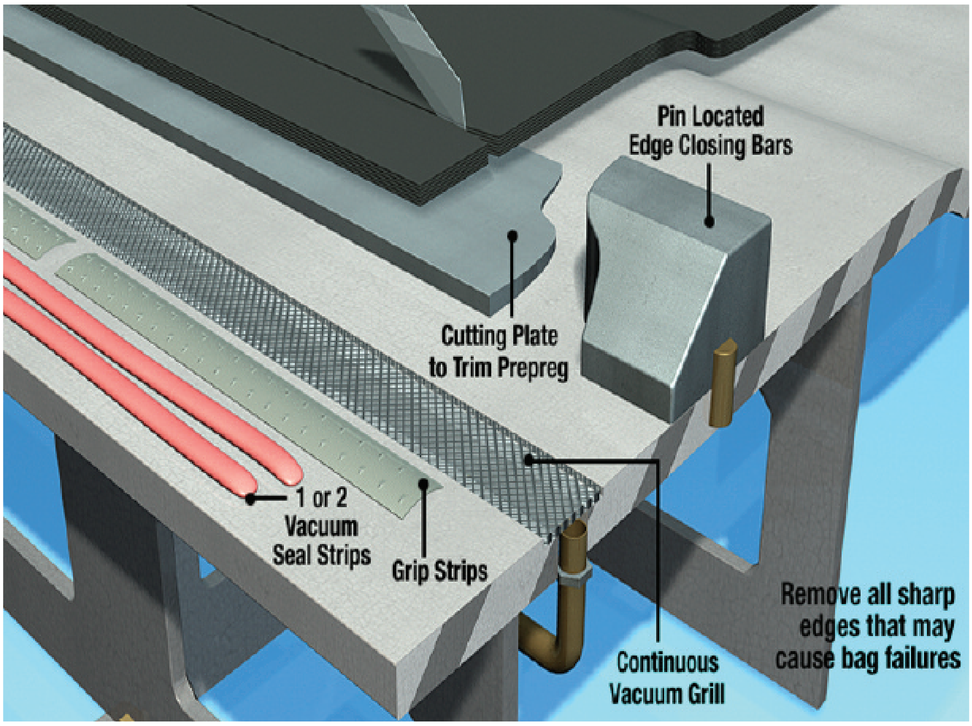
HEXCEL

PREPREG PROCESSING

A - How are prepregs laid up into a component ?

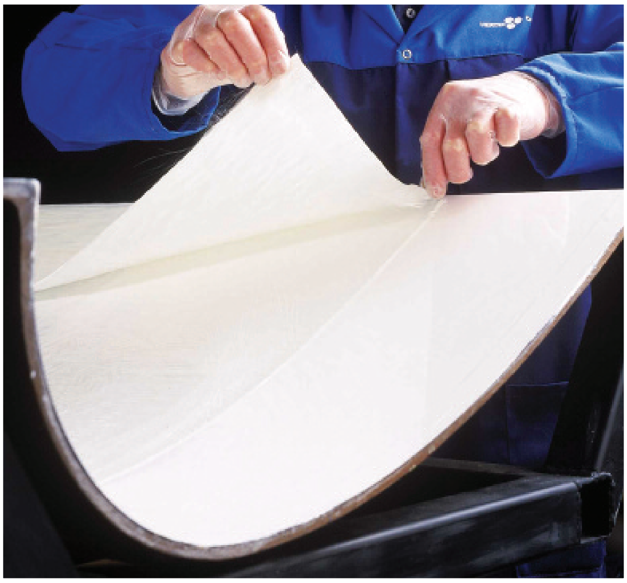
Tooling: Tool design plays an important role in component manufacture. Design a simple, stable tool so that uniform pressures can be applied to the component during cure. Heat cycle all new tools to release any stresses and complete a heat search to calibrate the tool. Here are some features to consider for tool design:





PREPREG PROCESSING

Layup:



Hand Lay-Up: Manual/non-automated lay-up process of prepreg. Available for all types of fibre reinforced prepregs (glass, carbon, kevlar) with unidirectional and woven reinforcements and at various widths. Prepreg supplied with polythene and/or paper protectors. Suitable for complex shaped parts, monolithic and sandwich panels, low to medium volume production.

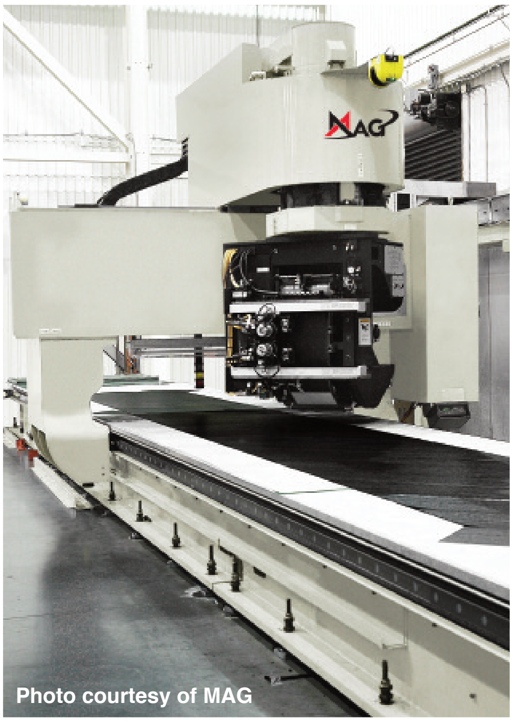


Photo courtesy of MAG

Automatic Tape Laying (ATL): Automated deposition of unidirectional prepreg tapes and also for some other reinforcement materials e.g. glass woven prepregs, wet peel plies and metallic mesh prepregs. Typically available at 150mm (5.9") or 300mm (11.8") widths. Other widths can be considered, dependant on ATL machine design. Prepreg is supplied with a single double-sided release paper. Suitable for large, low to medium curvature monolithic parts.

Automatic Fibre Placement (AFP): Automated deposition of narrow unidirectional prepreg tapes. Typically available at 3.175mm (1/8"), 6.35mm (1/4") or 12.7mm (1/2") width and various bobbin sizes. Prepreg is supplied with a single polythene protector. Suitable for medium to large complex curvature monolithic parts.

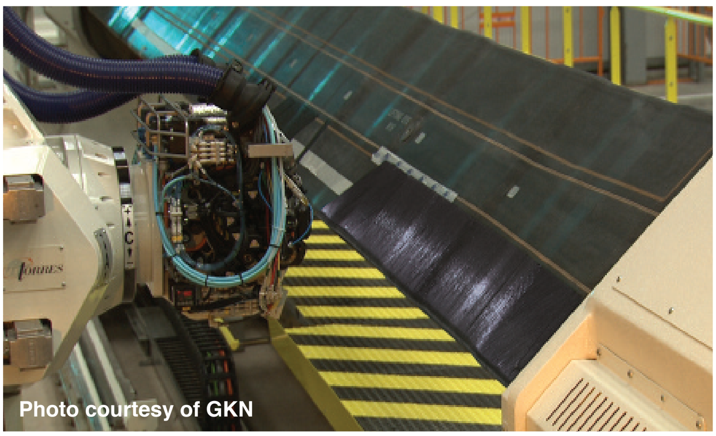
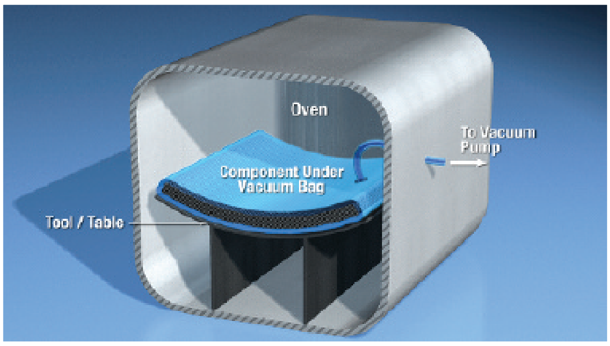


Photo courtesy of GKN

B - What are the different prepreg processing techniques ?

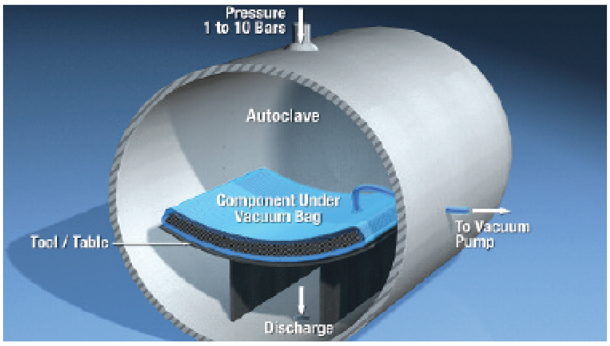
Prepregs can be processed in different ways. The drawings below demonstrate the most appropriate method to be chosen for a particular application. For large parts heated tools may be more appropriate than an oven.

Vacuum bag oven process



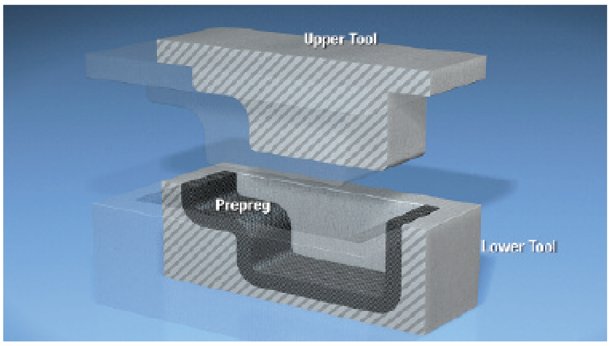
Applications:
- Aerospace
- Marine industry
- Railway interior
- Wind energy
- Automotive

Autoclave process



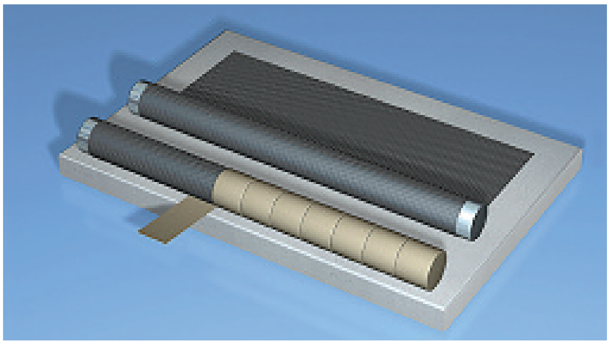
Applications:
- High quality composites
- Structural parts

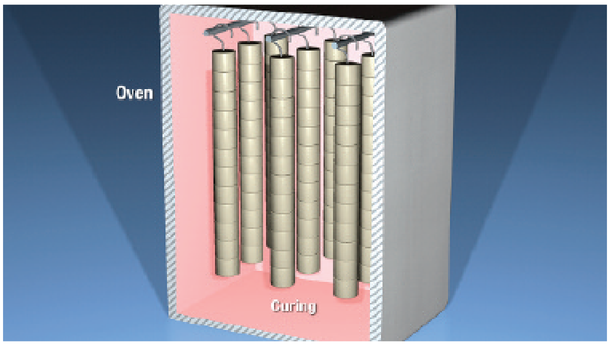
Match moulding process



Applications:
- Flat panels
- Sport equipment
- Industrial

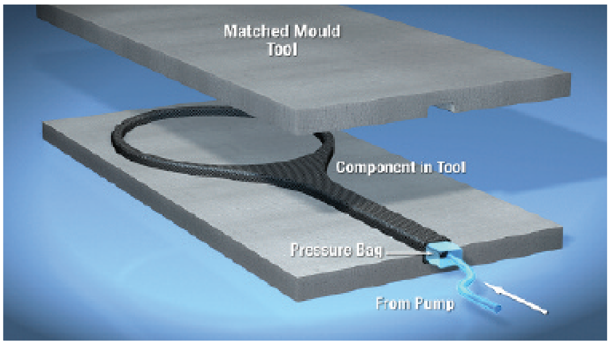
Tube rolling process





Applications:
- Fishing rods
- Tubes
- Ski poles
- Golf shafts
- Masts

Pressure bag process



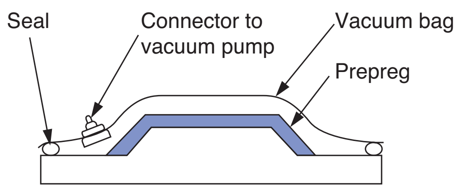
C - Vacuum bag/oven or autoclave - which process ?

Vacuum bag/oven 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.

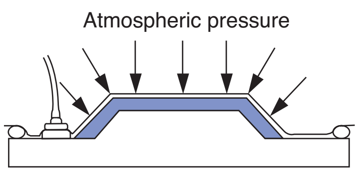
	Component		Processing costs	
Processing method	Quality	Section thickness	Equipment cost	Cure cycle energy
• Standard vacuum bag	Good - Excellent*	Thin to Thick	Moderate	Low
• Autoclave	Excellent	Thin to Thick	High	High

*dependent on prepreg definition and application.

- **Vacuum bag processing** is suited to monolithic components of varying thickness 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

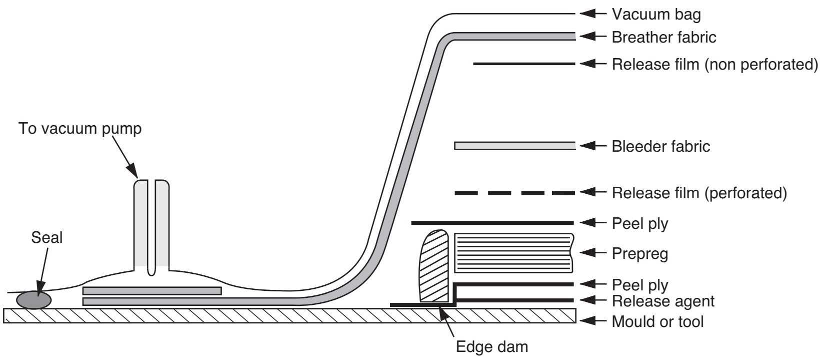


■ Fig. 2 : applying vacuum to the system

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

Some high performance prepregs can be cured using standard vacuum bag techniques and provide near autoclave quality components.

- **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, typically at lower pressures. 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 : example 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.

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

Consumables for vacuum bag processing :

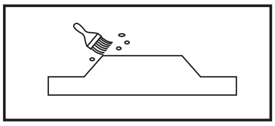
• Release agent	Allows release of the cured prepreg component from the tool.
• Peel ply (optional)	Allows free passage of volatiles and excess matrix during the cure. Can be removed easily after cure to provide a bondable or paintable surface.
• Bleeder fabric (optional)	Usually made of felt or glass 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.

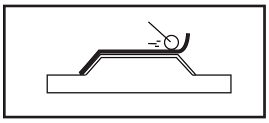
E - How is vacuum bag/oven and autoclave processing carried out ?

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.

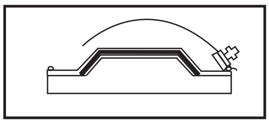
LAY-UP	CURING

1


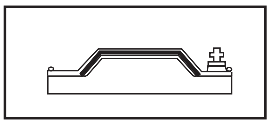
APPLY MOULD RELEASE

2


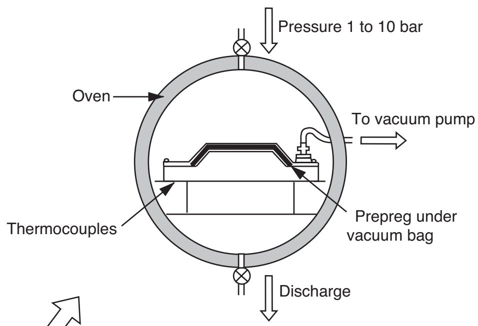
LAY-UP PREPREG (by hand, ATL or AFP)

3


ASSEMBLE VACUUM BAG

4


Autoclave process

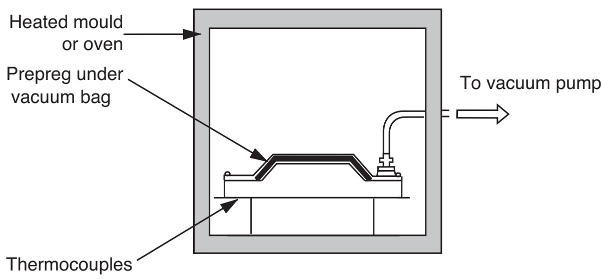


Application of vacuum
+
heat
+
pressure

Application of vacuum
+
heat

Vacuum bag/oven process

Large parts may use heated tools instead of an oven



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

NOTE : comply with instructions for use.

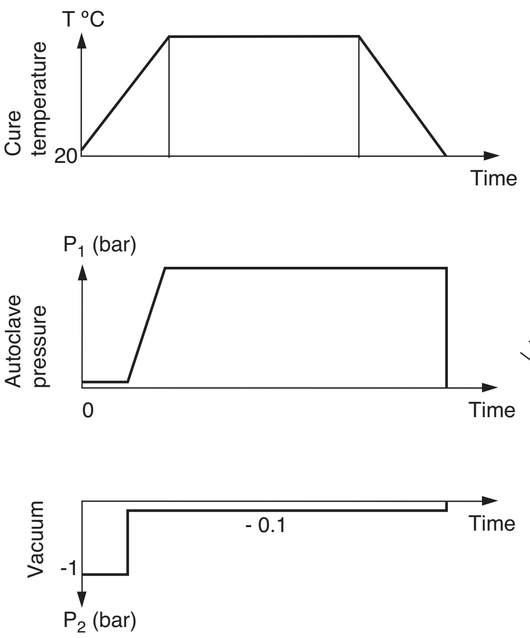
2 **Lay-up prepreg**
- Easy to cut with a sharp tool (cutter, etc.).
- Wear protective clothing (gloves, etc.).
- The prepreg can be high, medium or low tack.

CAUTION : make sure that the prepreg protective film is removed before laying-up.
- Automated lay-up used for increased productivity, reliability and accuracy of lay-up.

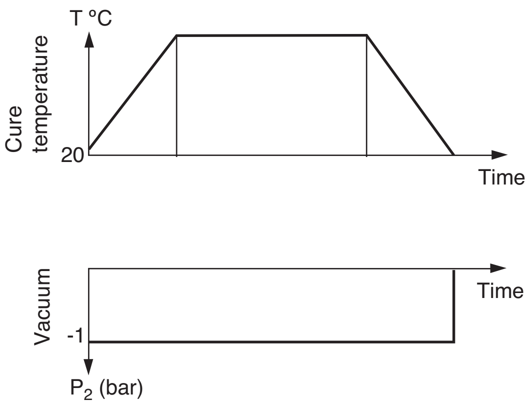
3 **Ensure the vacuum bag is tightly sealed and leak free.**

TYPICAL CURE CYCLE

Autoclave process



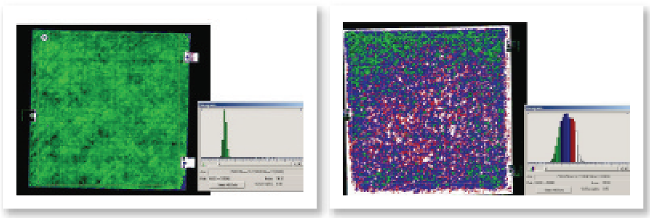
Vacuum/Oven process



FINISHED PARTS

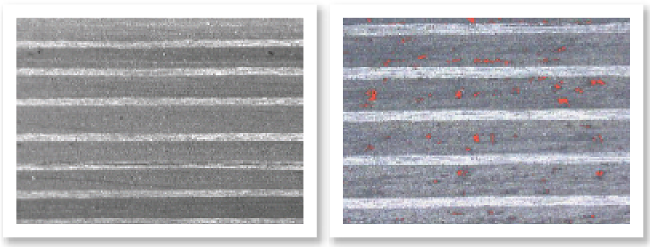
Inspection

Non Destructive Techniques	Information obtained
Visual inspection	Surface porosity
Ultrasound - C-scan & A-scan	Internal porosity, inclusions
Thermography	Internal porosity, inclusions



Example of a low porosity and high porosity panel assessed by C-scan.

Destructive Techniques	Information obtained
Mechanical testing	Extent of cure
Visual inspection	Internal porosity



Example of optical microscopy

Painting/Finishing

Example of aerospace panel, partly painted

F - What are the main autoclave and vacuum bag/oven processing parameters ?

Consolidation

During lay-up air can become 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.

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 once pressure has been applied and this acts as a very effective vacuum bag leak detector, for the duration of the cure cycle.

Heat up rate and intermediate dwell temperature

The matrix viscosity, flow, reaction rates and component surface quality are all affected 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, tool and the heat source.

For large components and tools, an intermediate dwell can also be introduced into the cure cycle. It will guarantee even temperature distribution throughout the tooling and component. Good temperature control will provide consistent and improved resin flow characteristics during cure.

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°C. 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 lagging 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.

Quality inspection of finished parts

Various methods can be used for quality inspection of the components after cure, ultrasonics, shearography, thermography.

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

For components above 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.

H - 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.**

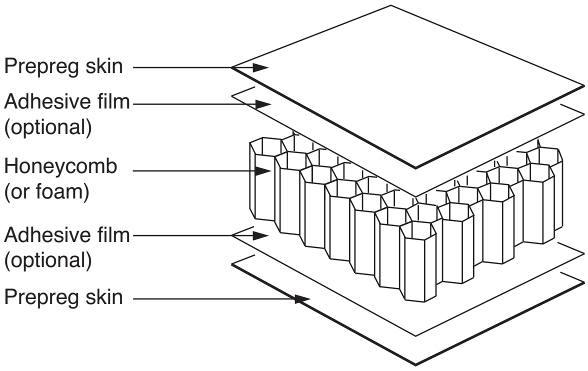
Dwell - used to equalise tool and component temperatures and to initiate a controlled prepreg cure.

Controlled slow 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.

I - What is a prepreg sandwich construction ?

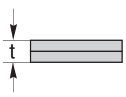
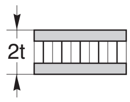
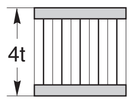
A sandwich contruction consists of thin high strength prepreg skins bonded to a thicker honeycomb, foam or balsa core.
A "self-adhesive" prepreg does not require additional adhesive layers and enables the production of light structures at reduced fabrication costs.

HONEYCOMB SANDWICH WITH PREPREG SKINS

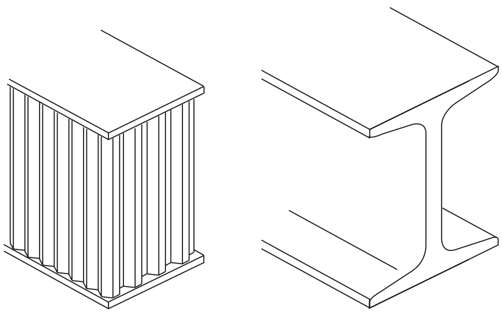


Advantages : very low weight, high stiffness, durable, design freedom, reduced production costs.

J - What are the properties of a sandwich construction ?

Properties	**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

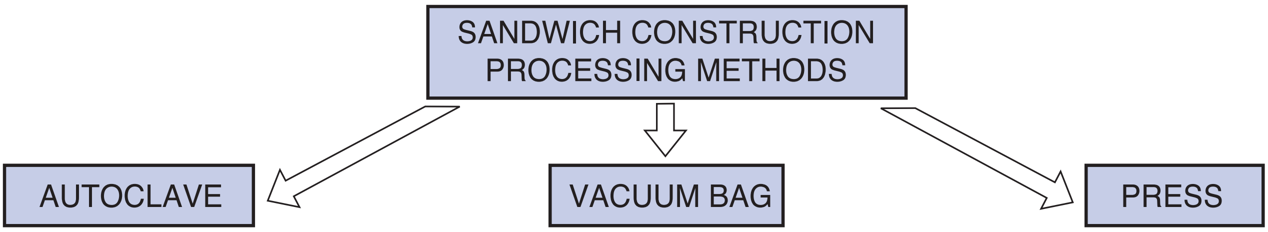
ANALOGY BETWEEN AN I-BEAM AND A HONEYCOMB SANDWICH CONSTRUCTION

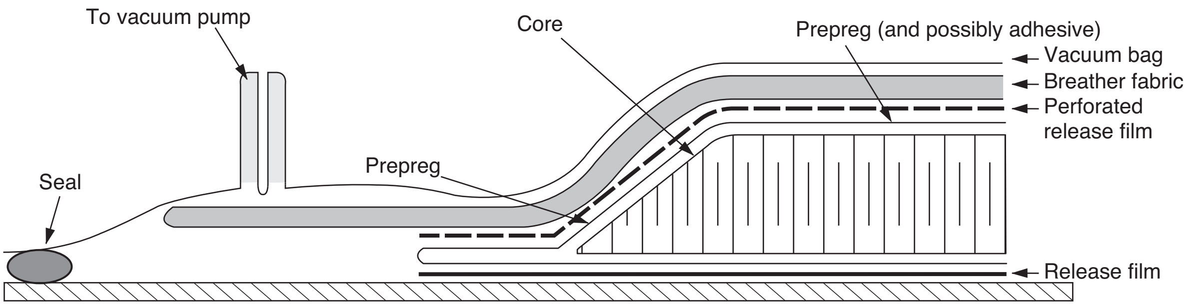


Benefits of honeycomb sandwich :

- 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

K - How is a sandwich construction produced ?





RECOMMENDATIONS FOR THE MANUFACTURE OF SANDWICH CONSTRUCTIONS

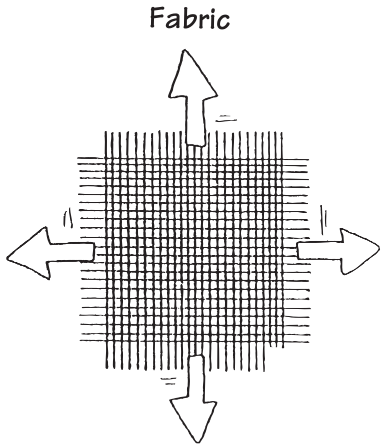
Sandwich constructions can be manufactured by autoclave, press or vacuum bag moulding. For autoclave or press processing sandwich constructions can usually be laid up and cured as a single shot process. However, for the vacuum bag curing of large components it may be necessary to lay-up and cure in two 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 or eventually core crush.

PROPERTIES OF FIBRE-REINFORCED COMPOSITES

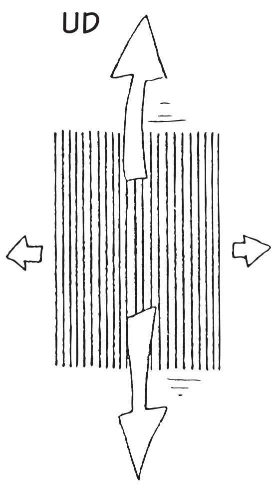
A - What are the characteristics of a composite material ?

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.



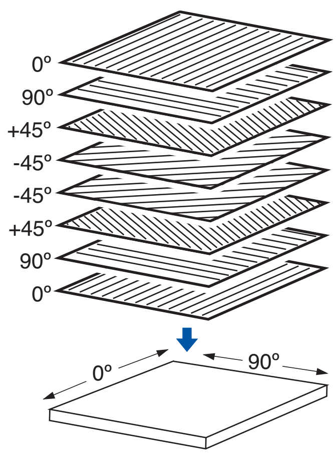
■ Equal properties



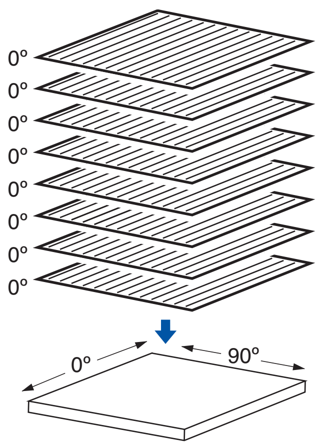
■ Unequal properties

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 physical/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 exposure to 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.

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.
• Degree of 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.

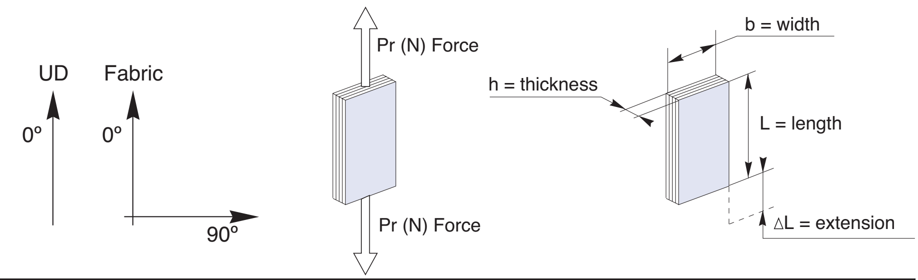
Tensile

- Tensile strength σ

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

- Tensile modulus E

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



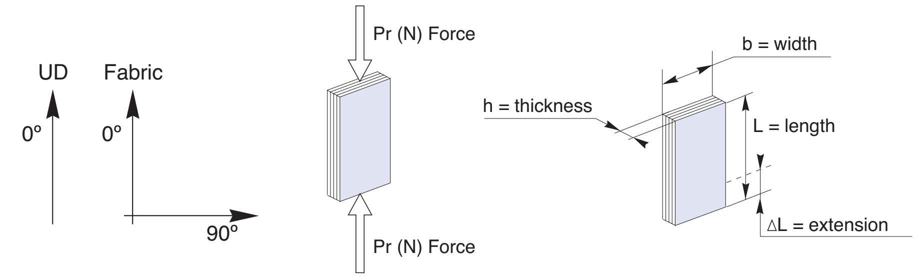
Compression

- Compression strength σ

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

- Compression modulus E

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



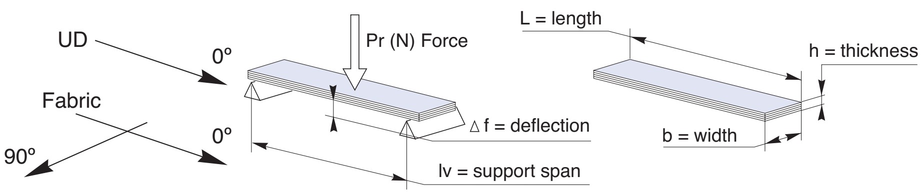
Flexural

- Flexural strength σ

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

- Flexural modulus E

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

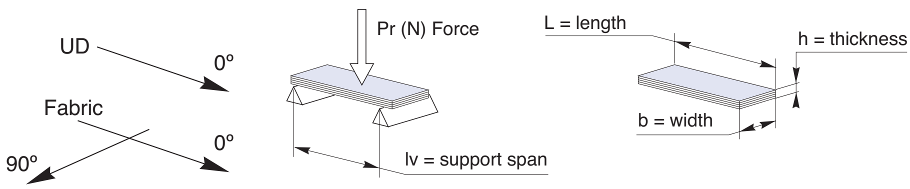


Typical span to thickness ratio 40 : 1 carbon ; 20 : 1 aramid ; 16 : 1 glass (dependent on specification and material)

Shear (short beam)

- Interlaminar shear strength σ

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



Typical span to thickness ratio 5 : 1 (dependent on specification)

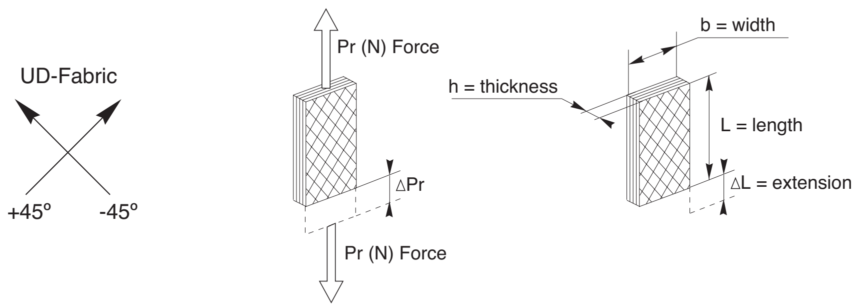
In-plane shear

- In-plane shear strength σ

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

- In-plane shear stress modulus G

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

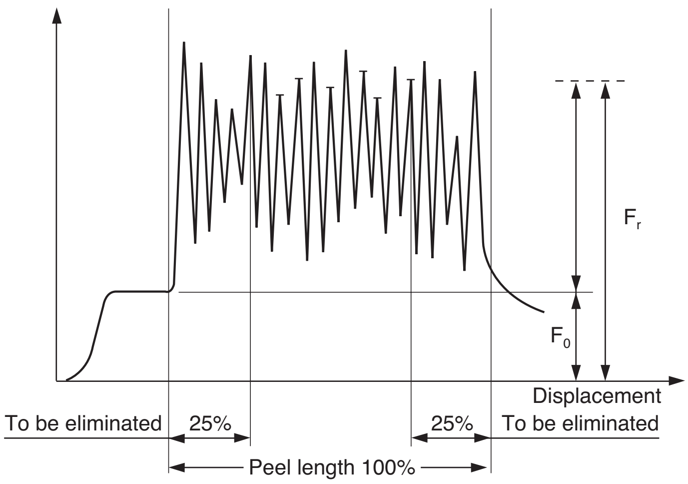


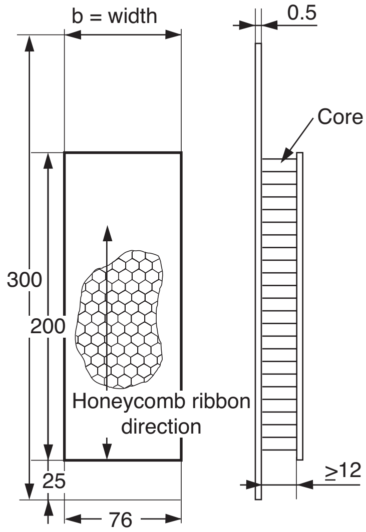
υ = Poisson's ratio

Climbing drum peel test

Peel strength F_p

F_p (N) = $F_r - F_0$





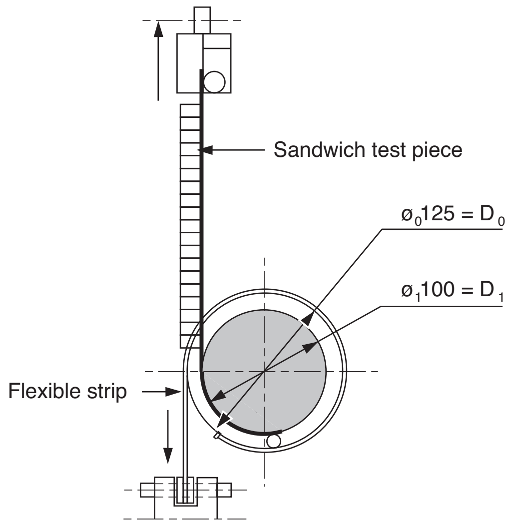
Dimensions in mm

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.

Refer to test method specifications for full details and procedures.

TYPICAL MECHANICAL VALUES ON EPOXY PREPREG LAMINATES

t 90°, ℓ 0°

Volume content of fibres :
≈ 60 % (Carbon)
≈ 50 % (E-glass - Aramid)

			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	σℓ	|||	MPa	1100	600	1100	500	2000	800	2400	900
	σt	≡	MPa	35	550	35	450	80	750	80	850
	Eℓ	|||	GPa	43	20	60	30	130	70	170	90
	Et	≡	GPa	8	19	8	30	9	65	9	90
	Poisson's ratio υℓt			0.28	0.13	0.34	0.2	0.25	0.05	0.27	0.05
Compression	σℓ	|||	MPa	900	550	250	150	1300	700	1600	800
	σt	≡	MPa	150	500	150	150	250	650	250	750
	Eℓ	|||	GPa	42	17	75	31	115	60	150	80
	Et	≡	GPa	10	16	5.5	30	10	55	11	75
Flexural	σℓ	|||	MPa	1200	700	550	400	1800	1000	1400	1200
	Eℓ	|||	GPa	42	20	40	25	120	65	140	75
In-plane shear	σℓt		MPa	60	55	45	40	95	80	95	80
	G ℓt		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^{-1}	11	14	- 0.4	- 5.2	0.3 - 0.7	2 - 3
Thermal conductivity	Wm^{-1} K^{-1}	0.4	0.16 - 0.33	0.4	0.21	1	0.86 - 1.44

HEXCEL®

PREPREG STORAGE AND SAFETY PRECAUTIONS

A - How should prepregs be stored ?

HexPly® prepregs should be stored, as received, in a freezer at -18°C.

To avoid moisture contamination, allow the prepreg to reach room temperature before opening the polythene bag. (A full reel in its packaging can take up to 48 hours).

Typically prepregs have a guaranteed shelf life at -18°C for 12 months from date of manufacture. The exact -18°C shelf life and room temperature life are printed on the prepreg box labels. Tack life and out life at 23°C are matrix dependant and are defined on the relevant Product Data Sheet.

Definitions:
Shelf life
The maximum storage life when stored continuously, in a sealed moisture-proof bag at -18°C. *The exact expiry date is on the box label.*

Tack Life
The time, at room temperature, during which the prepreg retains enough tack for easy component lay-up.

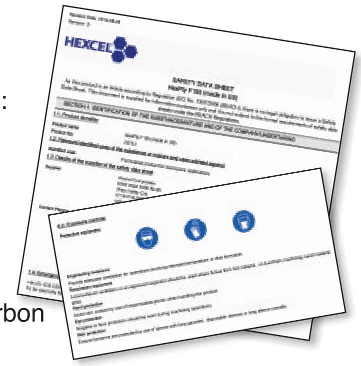
Out life
The maximum accumulated time allowed at room temperature between removal from the freezer and cure.

Similar definitions:	Shelf life	=	Storage life
	Tack life	=	Work life, Handling life
	Outlife	=	Cure by life, mechanical life

Handling:
- Always support the prepreg through the core.
- Record time out of the freezer.
- After use, tape up prepreg roll tightly to prevent wrinkles.
- Return the prepreg to the freezer in a sealed bag, supported in a box.

B – What health and safety precautions should be taken when handling prepreg?

Hexcel prepregs are particularly low-risk in terms of handling hazards for the following reasons:
- Prepreg is covered 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 minimum fibrous dust and are splash-free, leak-free and spillage free.
- Prepregs are volatile-free at normal room temperature.
- Prepregs tend to 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 should be avoided. It is recommended that positive dust extraction and collection from the cutting zone is provided. 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 on request at http://www.hexcel.com/ourcompany/prodsafety-overview
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/m^2 of epoxy resin (density ≈ 1.3g/cm^3).*

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

Stage 3 Calculate the number of bleed plies

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

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

A Resin Bleed Calculator can be found on our website at:
http://www.hexcel.com:82/calculators/src/bleederAidcalcs.aspx

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

Cured ply thickness (calculated) = CPT (mm)

Parameters :

wf : Fibre areal weight in prepreg (g/m²)
ρf : Fibre density (g/cm³)
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/m²)
wr : Resin areal weight in prepreg (g/m²)
ρf : Fibre density (g/cm³)
ρr : Resin density (g/cm³)

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 (g/cm³)

Parameters :

ρl : Liquid density (g/cm³)
Archimedes principle

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

The following calculation tools are available on our website:

Composite Properties:
http://www.hexcel.com:82/calculators/src/compositeProps2withbleed.aspx

Cured Ply Thickness Calculator:
http://www.hexcel.com:82/calculators/src/CPTcalculator.aspx

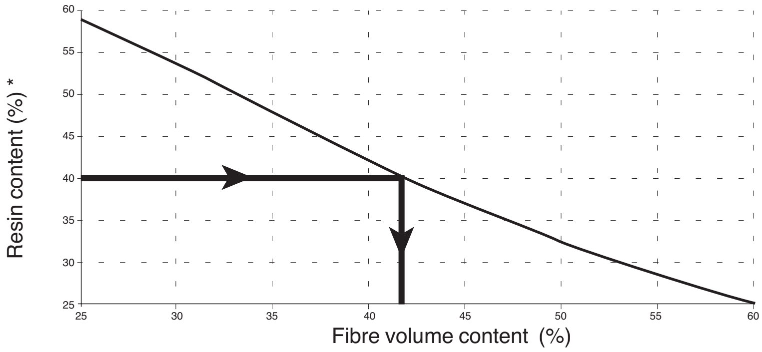
AID TO PREPREG SELECTION

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.

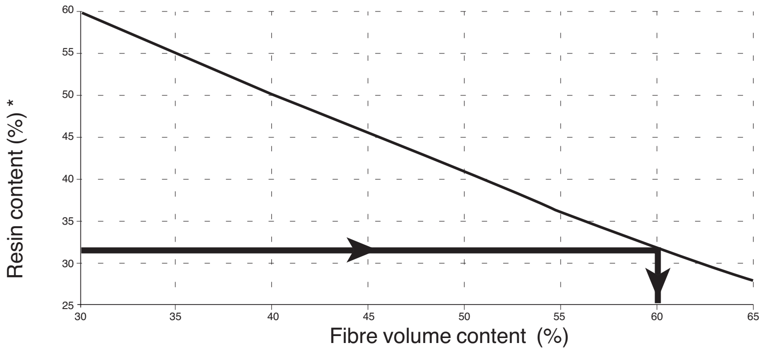
Fibre volumes

EPOXY/E-GLASS



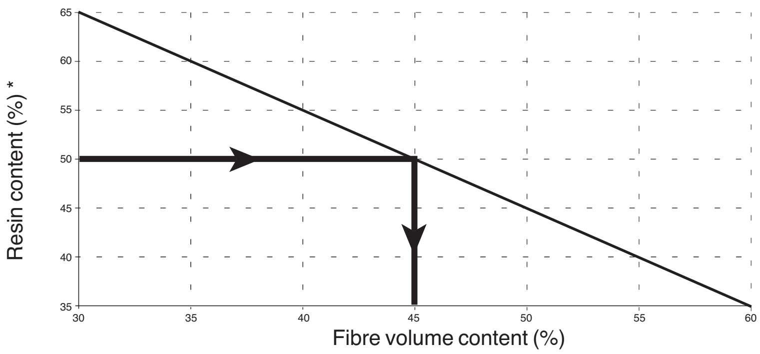
Matrix density ➪ 1.2 g/cm³
Fibre density ➪ 2.6 g/cm³

EPOXY/HS CARBON



Matrix density ➪ 1.2 g/cm³
Fibre density ➪ 1.8 g/cm³

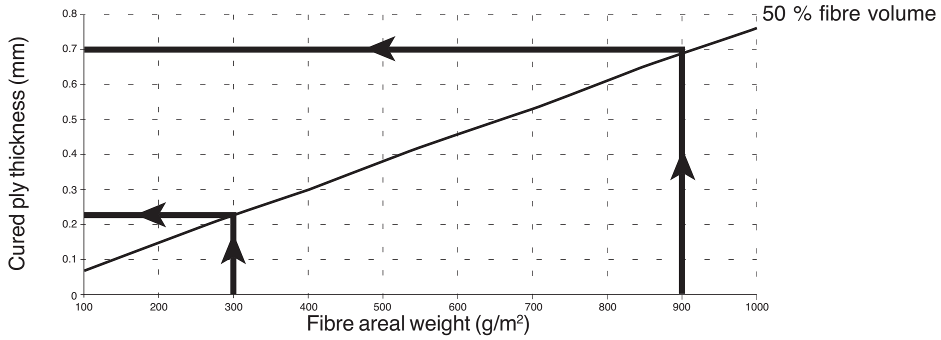
EPOXY/ARAMID



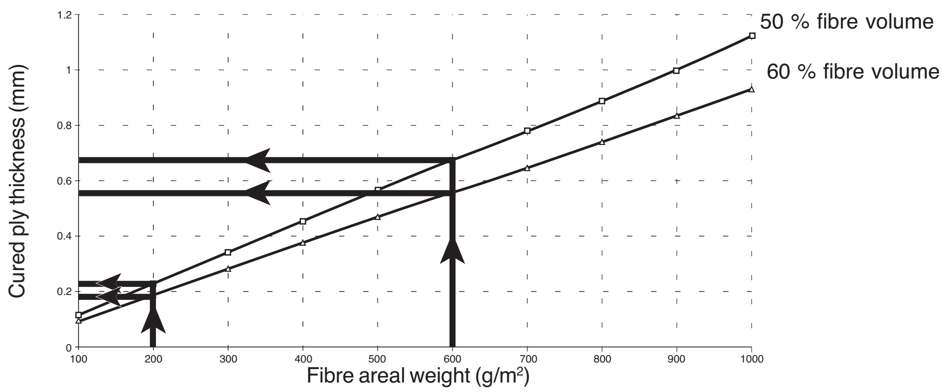
Matrix density ➪ 1.2 g/cm³
Fibre density ➪ 1.45 g/cm³

Cured ply thickness

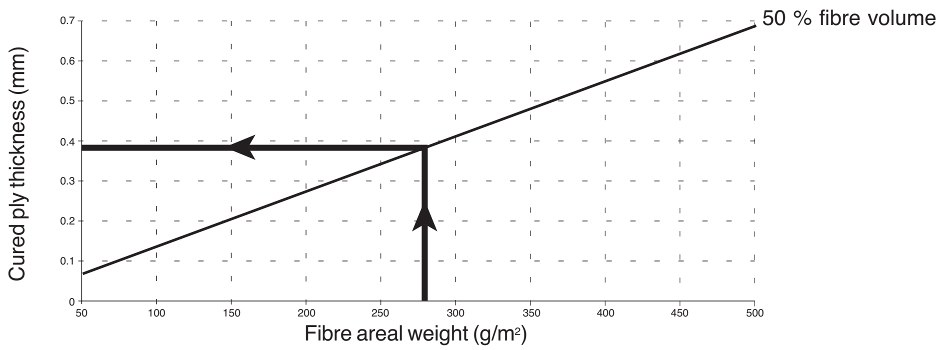
EPOXY/E-GLASS



EPOXY/HS CARBON



EPOXY/ARAMID



APPENDIX II - HEXCEL PRODUCT RANGE

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

Hexcel manufactures an unrivalled range of composite materials and engineered products. From carbon fibres and reinforcement fabrics that we convert into prepregs - to adhesives, honeycomb materials and HexTOOL® tooling system.

Hexcel also manufactures resins and reinforcements for RTM and infusion processing.

For full details on our complete range of products visit our website www.hexcel.com

Weblinks:

Product Selector Guides:
HexForce® Fabric and HexPly® Prepreg Selector Guides for Aerospace and Industrial:
http://www.hexcel.com/resources/selector-guides

HexPly® Prepreg Data Sheets:
http://www.hexcel.com/resources/datasheets

HexPly® Prepreg Selector Tool:
http://www.hexcel.com/resources/seltool-hexplyprepreg

Calculators:
http://www.hexcel.com/resources/calculator

Important

For More Information

Hexcel is a leading worldwide supplier of composite materials to aerospace and other demanding industries. Our comprehensive product range includes:

- Carbon Fibre
- RTM Materials
- Honeycomb Cores
- Carbon, glass, aramid and hybrid prepregs
- HexTOOL® composite tooling material
- Structural Film Adhesives
- Honeycomb Sandwich Panels
- Engineered Core
- Reinforcement Fabrics

For US quotes, orders and product information call toll-free 1-800-688-7734

For other worldwide sales office telephone numbers and a full address list please go to:

http://www.hexcel.com/contact/salesoffices