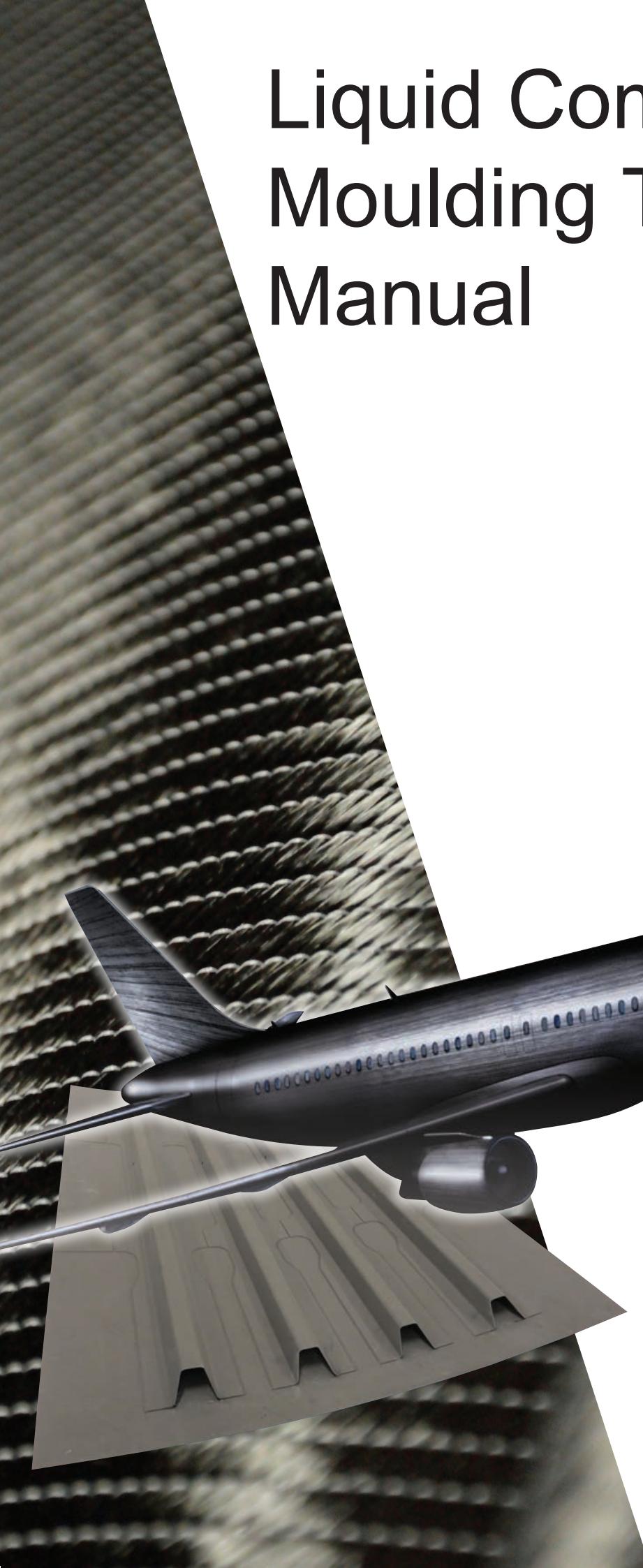
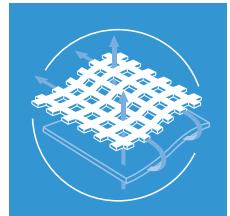


Liquid Composite Moulding Technology Manual



LIQUID COMPOSITE MOULDING TECHNOLOGY MANUAL

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REFERENCES

This document complements other Hexcel documents which are available on Hexcel.com:

- Data sheets HexFlow®RTM6, HexFlow®RTM6-2
- HexFlow®RTM6/RTM6-2 Safety & Processing Recommendations for Injection & Infusion
- Safety data sheets

For more information, please contact Hexcel Technical Support.

July 2020

Publication No. ITA 272c

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INTRODUCTION

Hexcel is a global leader in providing composite solutions for aerospace and other high performance applications. Hexcel pioneered the development of resin formulations for composites and is the premier global supplier of prepregs, RTM and infusion systems. Hexcel is also a major manufacturer of carbon fibre and technical reinforcements for composites.

HexFlow®RTM6 in conjunction with HexForce® Reinforcements for **Liquid Composite Moulding** has become established as the industry standard for Resin Transfer Moulding of aerospace components. This mono-component resin system is preferred for its high glass transition temperature, mechanical performance and good processing characteristics.

Recently, Hexcel has developed a bi-component version of RTM6 resin called HexFlow®RTM6-2.

HexFlow®RTM6-2 is chemically the same as RTM6 and provides the same high performance. Separating the reactive components in the bi-component version provides several benefits over RTM6: air shipment is allowed, storage at +5°C for 12 months and bigger packages are possible (up to 200 kg).

The purpose of this brochure is to present HexFlow® and HexForce® products for **Liquid Composite Moulding** and to give more detailed information about the technology currently being used.

COMPOSITES AND PROCESSING

Many manufacturing technologies are available to produce high performance composites. Today, the most widely used and known is prepreg technology. However composite parts can also be directly manufactured from low viscosity resins and dry reinforcements using **Liquid Composite Moulding**. The process selected to manufacture a particular part will depend on the required geometry, performance, cost and production rate.

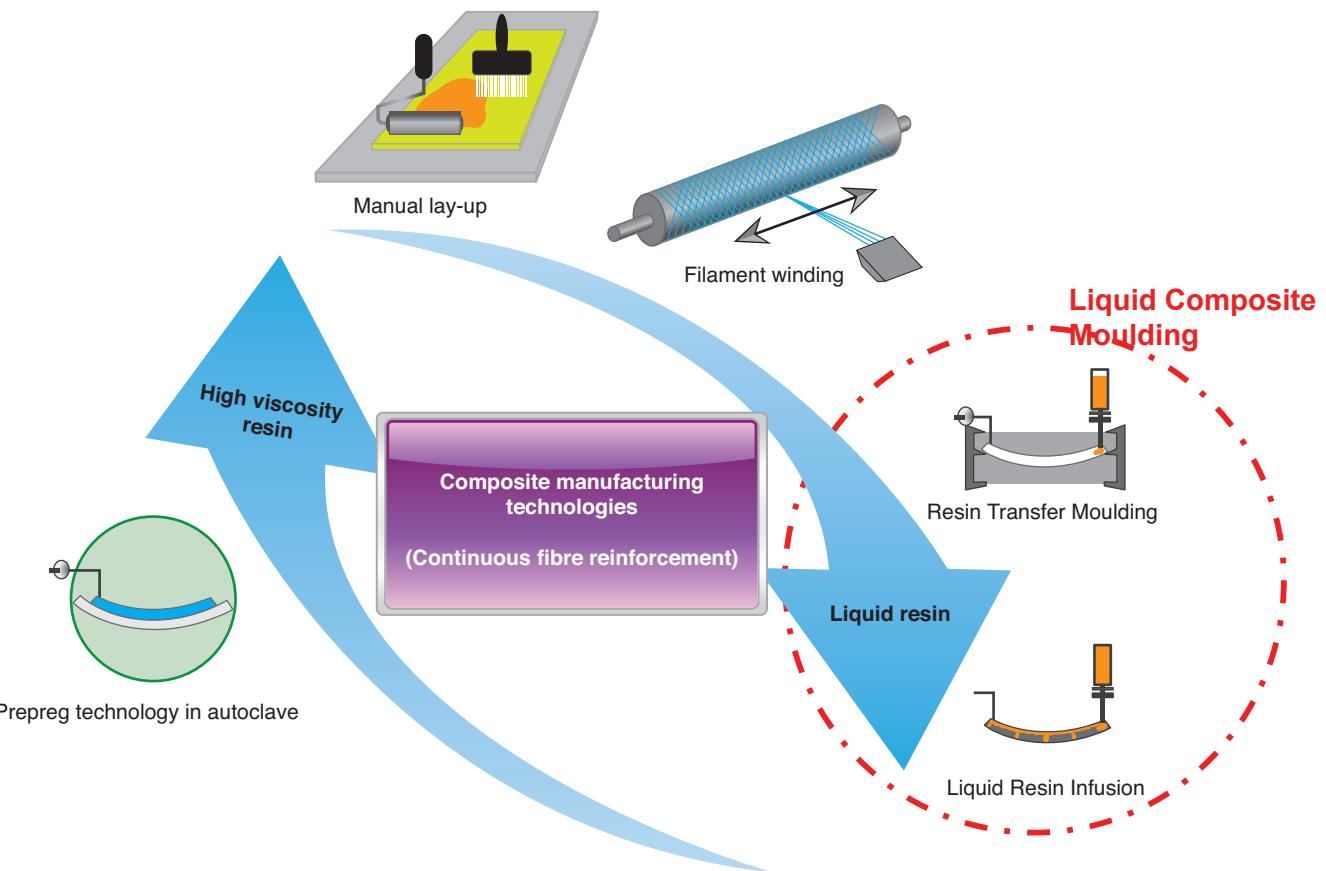


Figure 1: Major composite manufacturing technologies available for continuous fibre reinforcements

INTRODUCTION TO LIQUID COMPOSITE MOULDING

1. Liquid Composite Moulding

Liquid Composite Moulding (LCM) processes belong to a manufacturing category fundamentally different from prepreg based fabrication technologies.

Unlike prepreg, in LCM processes the resin and reinforcement are combined and cured in the same moulding operation, offering a very different processing route to the component manufacturer. This has generated strong interest and many LCM processes have been developed in recent years.

Resin Transfer Moulding (RTM), Liquid Resin Infusion (LRI), and Resin Film Infusion (RFI) are the principal processes and the most well-known. Different variants of these technologies have also been developed.

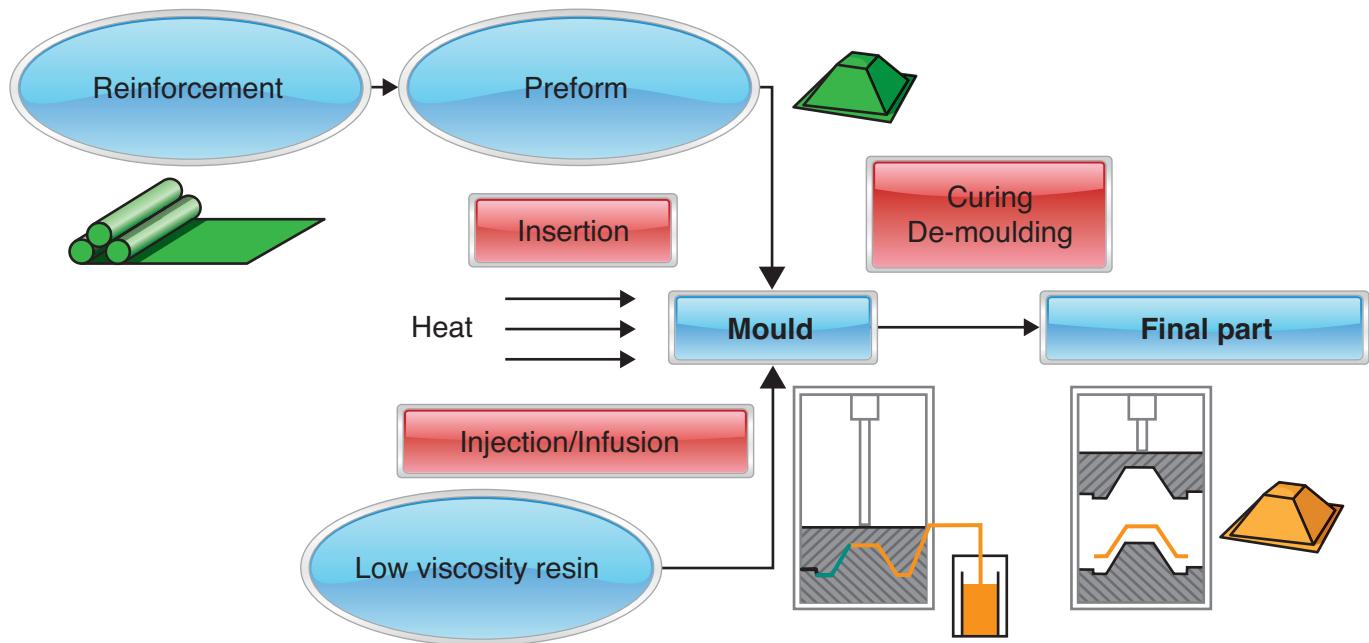


Figure 2: Principal steps of Liquid Composite Moulding Moulding

In most LCM processes, a pre-shaped reinforcement, called a preform, is placed in a mould and impregnated with the resin. The impregnation path can be 'in plane', 'through thickness' or a combination of 'in-plane' and 'through thickness' as indicated below.

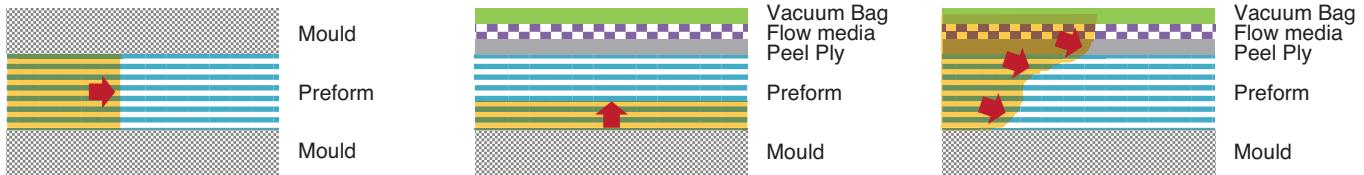


Figure 3: Examples of 'in plane', 'through thickness' and combination of 'in plane' and 'through thickness' impregnation paths

Although the impregnation path can be helpful in determining the type of LCM process being used, it's not the most important factor.

The main differences between injection and infusion are the complexity of the tooling and the pressure applied. For RTM matched metal tooling is usually employed, which gives good dimensional tolerances and surface finish to each face of the component and injection pressures are normally greater than one bar. For infusion, one face of the tooling will be a flexible vacuum bag and the maximum pressure that can be applied to the part is atmospheric pressure.

A) Why use Liquid Composite Moulding?

The main advantages for LCM processes are:

- Potential higher degree of part integration
- Reduced investment in autoclaves and cold storage
- Reduced shipment costs
- Less bagging, packaging, trimming and finishing wastes
- Shorter processing cycles
- Suitable for higher production rate
- Better thickness accuracy and surface finish compared to prepreg

2. Resin Transfer Moulding (RTM)

Resin Transfer Moulding, known as RTM, is a composite manufacturing process where a low-viscosity, reactive resin is pumped into a matched mould containing a preform or a reinforcement. The resin fills the mould wetting out the fibres before curing. RTM is used in many applications to manufacture high quality parts. Its main characteristics are:

- Automated process for relatively high volumes
- Net shape and high dimensional tolerances

The RTM process is recognised as a cost-effective alternative to manual composite processes and traditionally has been employed by the aerospace industry to manufacture selected primary and secondary structure parts.

To support the RTM process, Hexcel has developed a range of resins and structural reinforcements.

Figure 4: Airbus A380 door hinge arm manufactured by Airbus Helicopters using HexFlow® RTM6 resin and HexForce® G0926 carbon fibre fabric. There are 16 door hinge arms on each A380. As well as saving weight, they provide better thermal insulation in the cabin, reducing heat loss



Figure 5: Airbus A380 aileron spar, manufactured by Airbus France (Nantes), using HexFlow®RTM6 resin and Injectex® woven carbon reinforcement



Figure 6: Embraer's Legacy 500 BizJet Horizontal Tail Plane Tip Fairing HexFlow®RTM6-2 resin and HexForce® G0926 carbon fibre fabric

Advantages	Limitations
<ul style="list-style-type: none"> ■ Resin and reinforcement separated <ul style="list-style-type: none"> ◆ Dry fibre architecture is easier to handle and to drape ◆ Thick complex shapes achievable ◆ Binders to facilitate handling dry reinforcement and lay-up ■ Integration of inserts in the preform ■ High performance precision moulded parts <ul style="list-style-type: none"> ◆ Tight dimensional tolerances ◆ Good surface quality on all sides ◆ Mechanical properties comparable to autoclaved parts ■ Void content < 1% ■ Fewer steps and cost reduction <ul style="list-style-type: none"> ◆ No bagging required ◆ Minimal handling of resins ◆ Fewer trimming and finishing operations ◆ Short cure cycle ◆ Low pressure operation (usually less than 7 bar) ■ Process can be automated <ul style="list-style-type: none"> ◆ High production rates ◆ Low scrap 	<ul style="list-style-type: none"> ■ Expensive tooling for large parts ■ Only low viscosity resins are suitable for RTM (0.1 to 1 Pa.s) ■ Not cost effective for low production rate ■ Improper sealing of tools can cause resin leakage ■ Lower toughness compared to latest generation prepgs – except for toughened reinforcements (e.g. HiTape®)

2.A) Resin Transfer Moulding (RTM) Process steps

Most RTM processes can be summarised as follows:

1. Preforming: the dry reinforcement is processed to obtain a preform with the final geometry. The aim is to facilitate handling and to prevent any fabric slip during injection.
2. Moulding: first, a full vacuum is applied to the mould containing the preform to evacuate the air. Then the resin is injected into the mould. During injection, the resin fills the mould cavity and fully impregnates the preform.
3. Curing: heat is applied to the mould, activating the resin's polymerisation/curing mechanism.
4. De-moulding: the cure is completed and the part develops sufficient strength to be de-moulded when cooled.

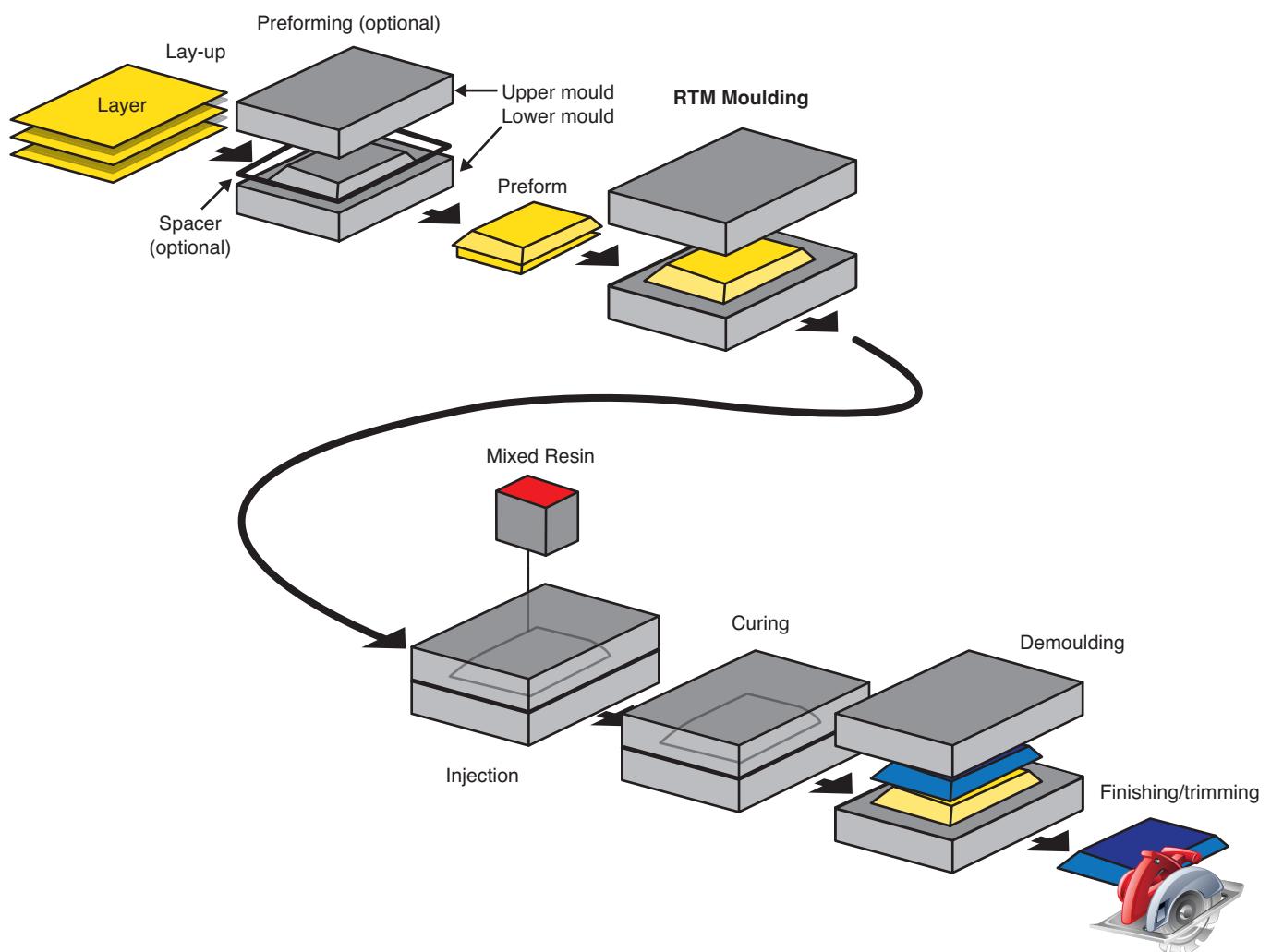


Figure 7: Schematic example of Liquid Composite Moulding

2.B) Resin Transfer Moulding (RTM) Equipment

The RTM equipment is mainly composed of

- Injection, heating and cooling systems,
- Balance, vacuum pump and a mould.

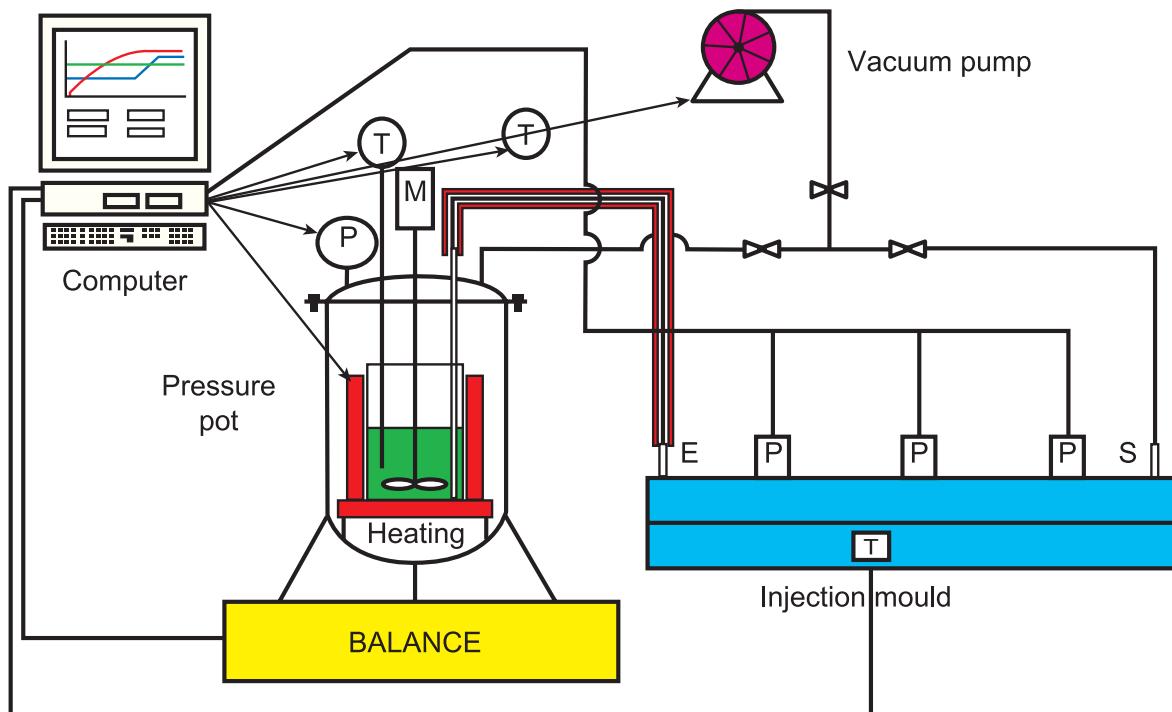


Figure 8: Typical RTM equipment

3. Liquid Resin Infusion (LRI)

LRI is a variant of the traditional RTM process using single-sided moulds in combination with a specific vacuum bag set-up. The bag set-up provides resin distribution and also consolidation.

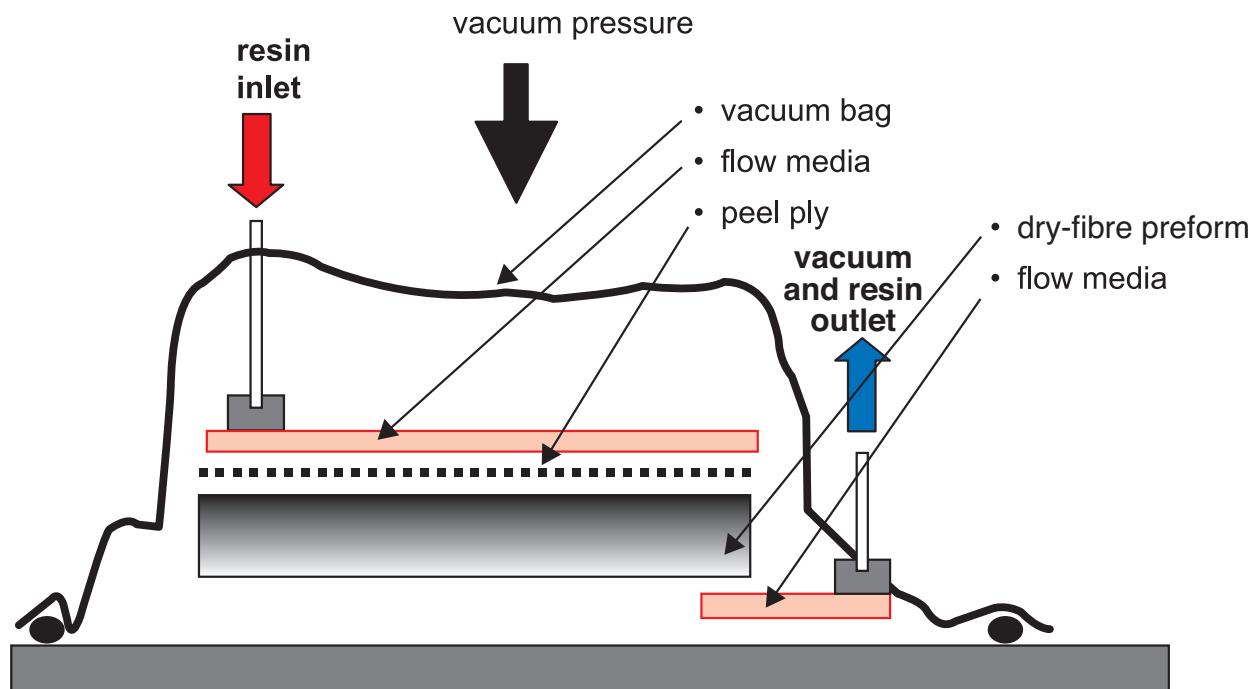


Figure 9: Typical LRI bagging

3.A) Liquid Resin Infusion (LRI) Steps

LRI is typically a three-step process:

1. **Lay-up of a fibre preform:** The reinforcement is placed onto a rigid tool surface. Once the reinforcement lay-up is complete, it is covered with resin distribution media and finally with the formable vacuum bag.
2. **Resin preparation:** In some cases, resin can be preheated to have lower viscosity. Degassing may be recommended if the resin has been manipulated.

3. **Impregnation of the preform with resin:** Depending on part size and shape, the resin is introduced through single or multiple inlet ports. A network of distribution channels for the resin is integrated into the vacuum bag set-up to control resin flow into complex parts.

The air is evacuated from the preform via a vacuum port prior to impregnation.

A resin pot is connected to an inlet port. The pot may be held at atmospheric pressure. The pressure differential between the vacuum port and the pot forces the resin into the highly-porous flow media which distributes the resin across the surface of the part, prior to infusion through the part thickness.

The vacuum bag provides consolidation pressure. Sometimes a second vacuum bag can be used to guarantee vacuum level and consolidation pressure.

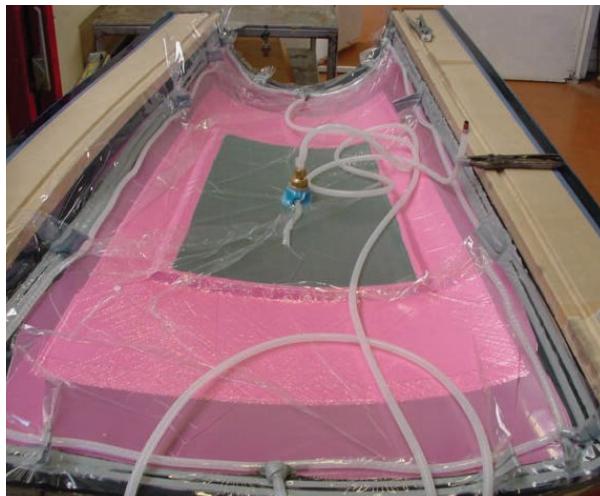


Figure 10: Infusion bag example

4. **Curing the impregnated preform:** the infusion process is normally carried out at an intermediate temperature, whereby the resin viscosity is low enough to allow a good infusion but not sufficiently high to start the curing process. Once infusion is complete, the temperature is raised to the final curing temperature.

With experience and using appropriate reinforcements it is possible to obtain high quality components at the 60% fibre volume necessary for high quality composite parts.

3.B) Advantages of LRI over RTM

- Larger parts are possible, particularly large surface components, such as thick covers and fuselage panels
- LRI uses simple, single-sided moulds, compared to relatively costly matched-mould tooling for RTM
- Lower cost in infrastructure and tooling

4. Hexcel's RTM/LRI materials package

Hexcel proposes the following resin systems for RTM and LRI processes:

- HexFlow®RTM6: mono-component epoxy system, operating at service temperatures from -60°C to 120°C (-76 to 248°F)
- HexFlow®RTM6-2: bi-component version of HexFlow®RTM6 presenting the same properties after mixing and degassing.

Examples of aerospace qualified Injectex® fabrics used with HexFlow® LCM resins are:

- G0926 (5HS, 6K, 370 gsm)
- G0986 (T 2 x 2, 6K, 285 gsm)
- G1157 (UD, 6K, 270 gsm)
- G1151 (Interlock, 6K, 600 gsm)
- 48302 (T 2x2, 12K, 300 gsm)

Other fabrics are also available on request. Please contact Hexcel for more information.

All Injectex® fabrics are supplied with epoxy binder on both sides to allow preforming. The binder represents approximately 5% of the total fabric weight.

For primary aircraft structures, Hexcel has been developing new generation reinforcements, such as HiTape® and multiaxial NCF, which combined with RTM6 or RTM6-2 can meet primary structure requirements.

For more information, please consult individual Product Data Sheets or contact Hexcel Technical Support.

REINFORCEMENTS FOR LIQUID COMPOSITE MOULDING

Hexcel is a leading manufacturer of woven, unidirectional and multiaxial reinforcements for composites, in glass, carbon, aramid and hybrid fibres. We have applied our experience and knowledge of fibre-reinforcements to develop a range of textile options that are ideal for LCM Processes such as RTM, RFI and LRI.

1. HexForce® Woven Fabrics

The aerospace industry relies on Hexcel's woven glass, carbon, aramid and hybrid fabrics for use in advanced composites. Due to their high strength and mechanical properties today's commercial aircraft industry uses HexForce® in the design and manufacture of secondary structures (wing-to-body or belly fairings, leading edges, and flight control systems), engines, nacelles, radomes and interior panelling systems.

A standard woven fabric is characterized by reinforcing yarns in two orientations, 0° (warp) and 90° (weft). Woven fabrics can be manufactured with different areal weights and styles. The fabric definition will drive the characteristics in terms of mechanical performance, drapeability, and permeability. Low crimp fabrics provide better mechanical performance because fibres are straighter, allowing them to carry greater loads. A drapeable fabric is easier to lay-up over complex forms.

There are three main weave styles:

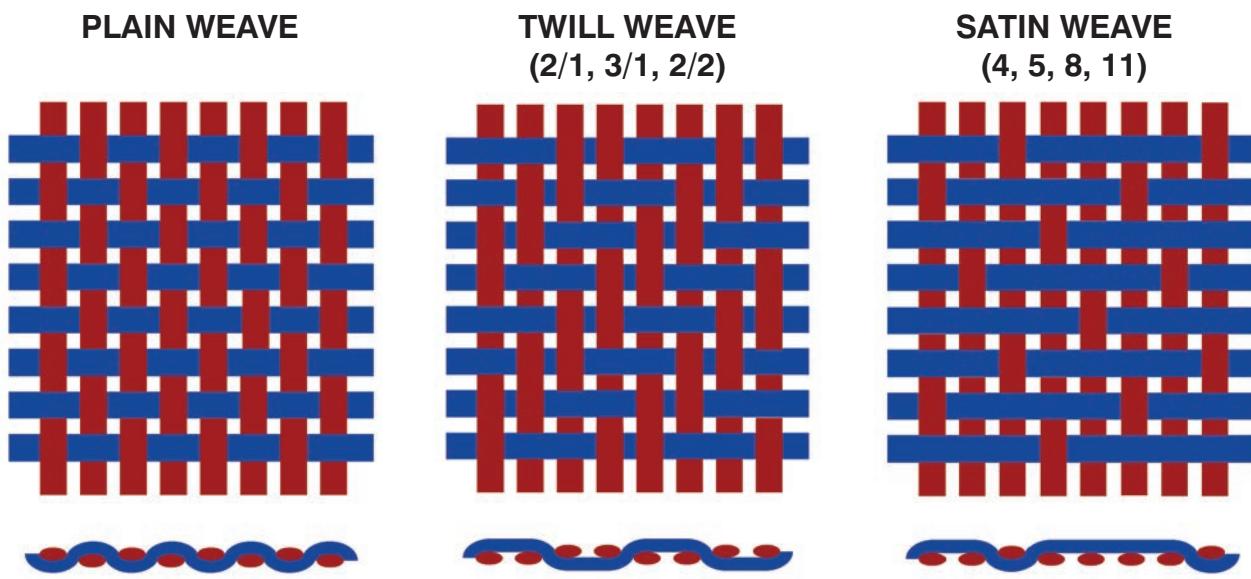


Figure 11: Standard weave styles and examples

Balanced woven fabrics provide strength and stiffness in two directions. They have good handling characteristics and good drapeability depending on weave style. There is a wide range of weave types and it is always possible to mix fibres to provide hybrid fabrics. Standard HexForce® fabrics weigh 50 to 630 gsm.

A) Injectex® Woven Fabrics

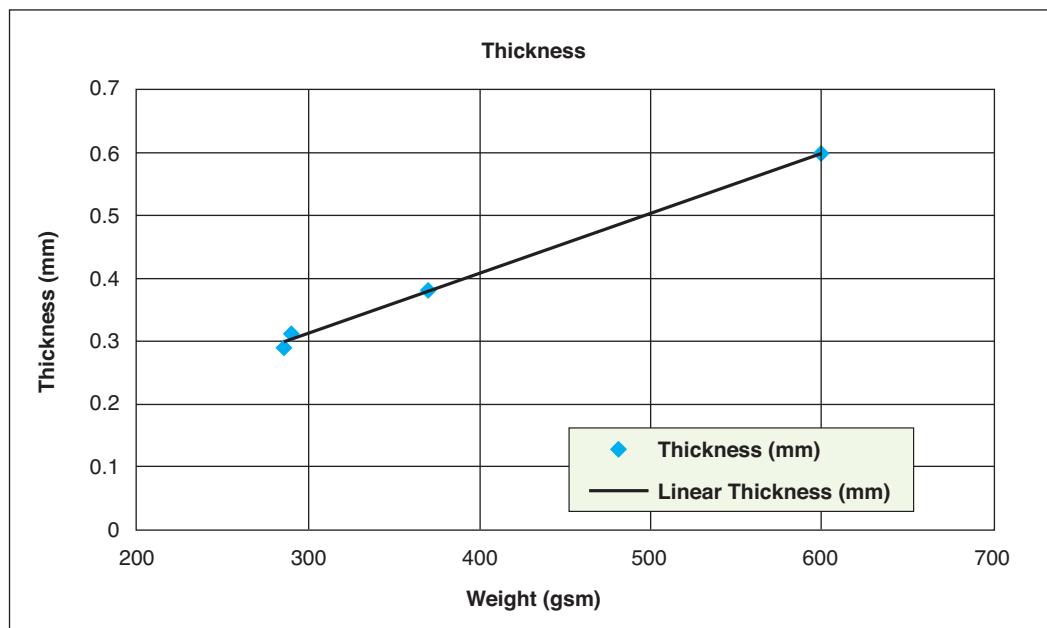
Injectex® is Hexcel's range of qualified woven fabrics especially developed for aerospace preforms for injection and infusion.

All Injectex® fabrics are supplied with epoxy binder on both sides to allow fabric stabilisation for handling, cutting and preform assembly.

The binder represents approximately 5% of the total fabric weight and is compatible with HexFlow® systems. The reinforcement with binder can be stored at room temperature

EU/US Designation	Weave	Weight Ratio % Warp/Weft	Type of yarns (Warp/Weft)	Weight (gsm)	Thickness ¹ (mm)	E01 Binder (% per side)
G0926/613	5H Satin	50/50	Carbon 6K HS/Carbon 6K HS	390	0.38	2.5
G0986/463	Twill 2x2	50/50	Carbon 6K HS/Carbon 6K HS	299	0.29	2.5
G1157	UD Plain Weave	97/3	Carbon 6K HS/EC9 34tex	290	0.26	2.5
G1151	3X Formable	51/49	Carbon 6K HS/Carbon 6K HS	630	0.62	2.5

¹ The above average values are obtained with epoxy laminate at 55% of fibres volume

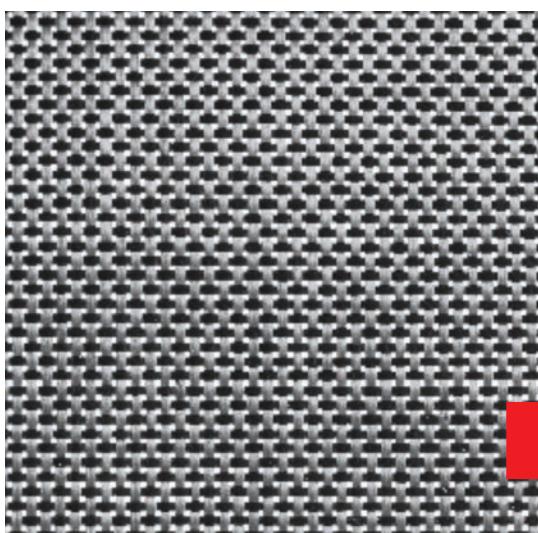


LIQUID COMPOSITE MOULDING TECHNOLOGY MANUAL

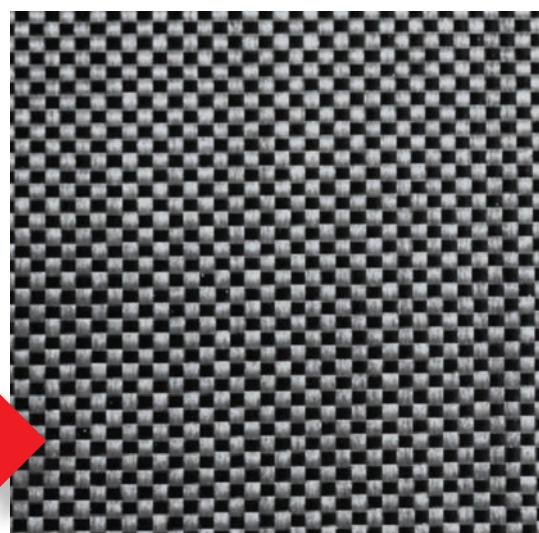
B) PrimeTex®

PrimeTex® is a range of carbon fabrics which have been developed to improve cost by using high K tow fibres for low areal weight carbon fabrics. The fibre tows are spread in both the warp and weft direction for unique distribution and lower crimp in order to reduce resin rich areas and improve performance. PrimeTex® fabrics are more uniform as the filaments in each tow are spread out creating a thinner and more closely woven fabric that provides better mechanical properties and less porosity in a composite. It can also be used for a smooth, closed weave and uniform cosmetic appearance.

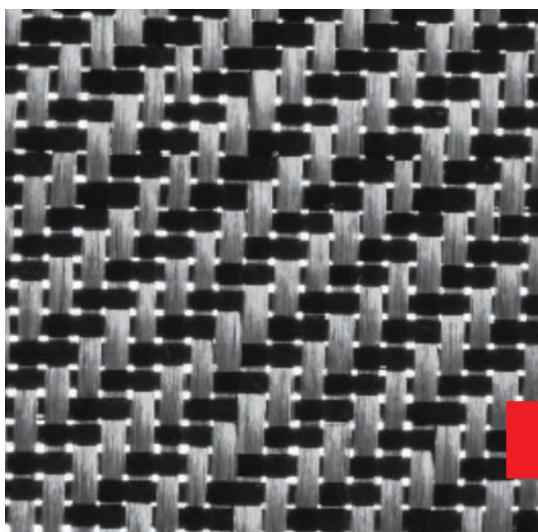
PrimeTex® technology extends the applications for woven carbon composites and enables new customer requirements to be met for enhanced performance and cost reduction.



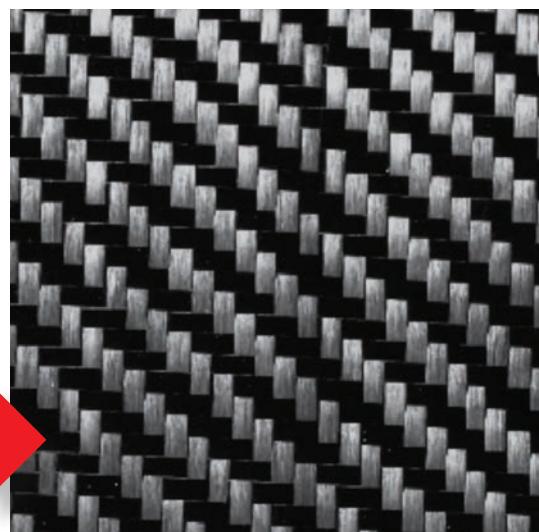
HexForce® 43199 UE1250
Fibre coverage: 93%



PrimeTex® 43199 UE1250 S
Fibre coverage: 99% 43199 UR



HexForce® 48194 C 1270
Fibre coverage: 96%



PrimeTex® 48194 C1270 S
Fibre coverage: 99.5%

Figure 12: PrimeTex® Technology Examples

PrimeTex® is obtained from Hexcel's Proprietary Spreading Technologies and its principal key features and benefits are:

- Cost reduction by using high K tow fibres for low areal weight carbon fabric

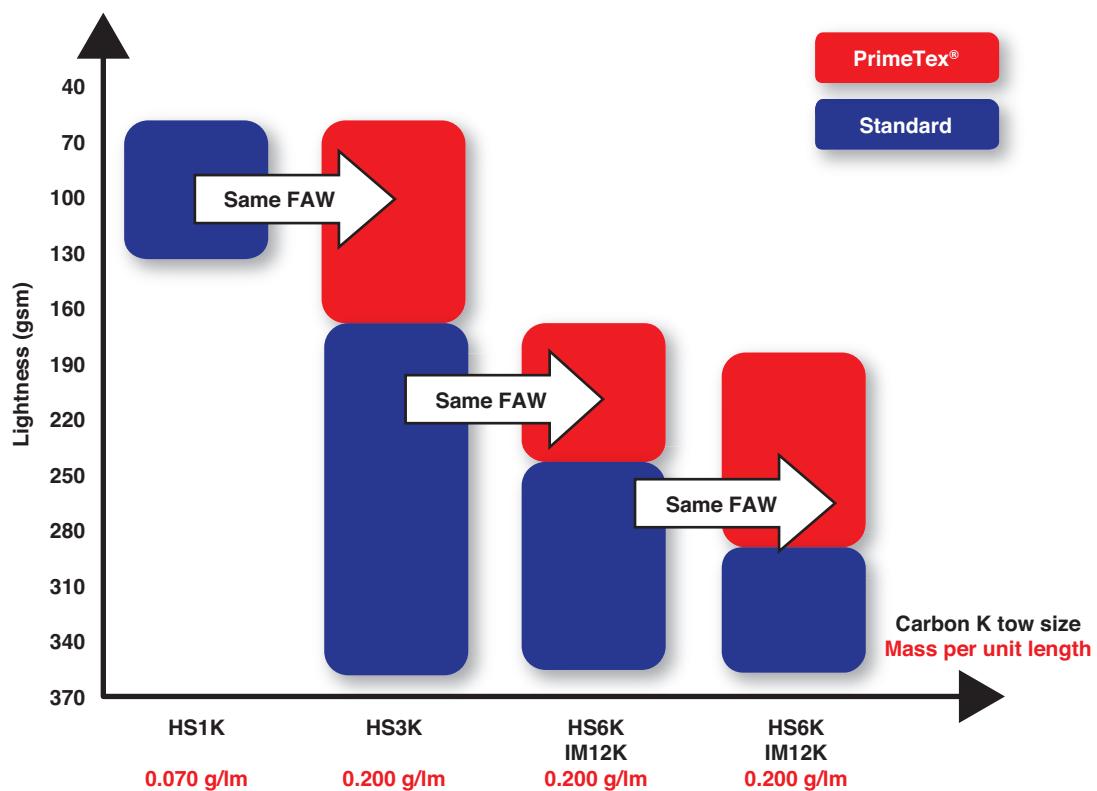


Figure 13: Cost reduction by using high K tow fibres

LIQUID COMPOSITE MOULDING TECHNOLOGY MANUAL

- Enhancing laminate mechanical properties by reducing resin rich areas

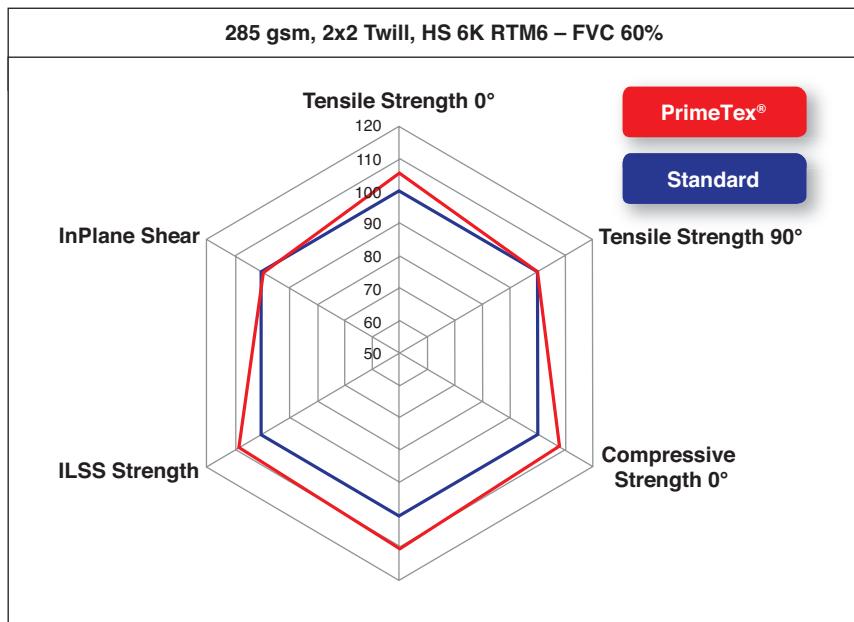


Figure 14: Laminate mechanical properties comparison

- Clear visual benefit to the final product

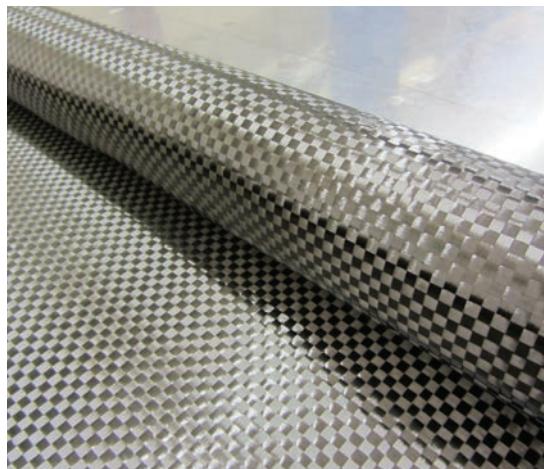


Figure 15: PrimeTex® 43098 : 98 gsm - HexTow® AS4 3K

Some of Hexcel's established PrimeTex® fabric ranges:

- With 3K fibre, from 100 to 245 gsm
- With 6K fibre from 240 to 370 gsm
- With 12K fibre from 193 to 400 gsm

For more information on a style not listed here, please contact Hexcel.

C) HexForce® Specialties: Woven Shapes

Hexcel can tailor woven composites to fit customer designs by using different techniques. Preform geometries can vary from simple cross section shapes, such as circular continuous warp reinforcement, to extremely complicated shapes, such as cones.

These reinforcements are directly manufactured in net-shape and are ready to be used with minimum trimming and hand work.



Figure 16: Example of Specialty woven shapes

The main advantages over two-dimensional preforms are in most cases:

- A less time-consuming and less expensive multi-step process (cutting, shaping profiles and bonding).
- Better reinforcement distribution than two-dimensional preforms
- Reduced areas of resin concentration in complex parts
- Increased inter-laminar stiffness and strength and integrity.
- Versatility in design.

D) HexForce® Thermoplastic Veil

HexForce® Thermoplastic Veil co-bonding technology can be used to improve handling and cutting operations and to significantly increase impact resistance of the final laminate.

For more details, please contact Hexcel Technical Support.

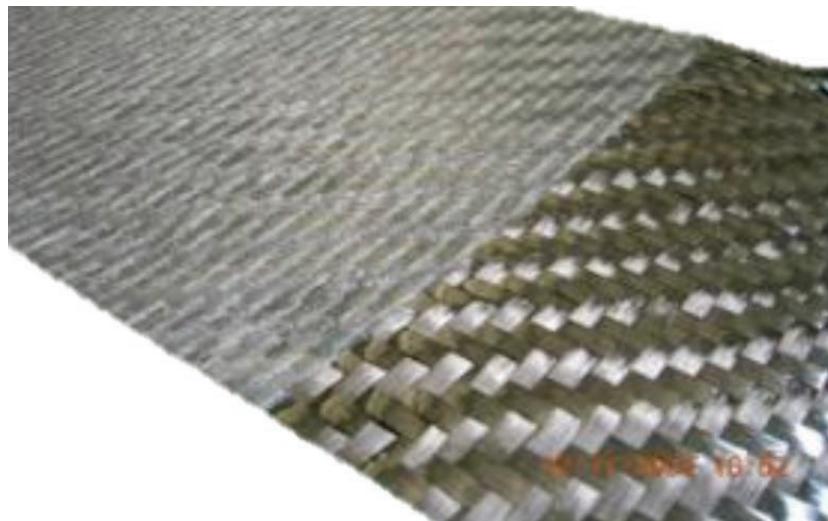


Figure 17: HexForce® reinforcement with and without co-bonded veil

E) Non-crimp Fabrics

Multiaxial reinforcements, also known as non-crimp fabrics, are layers of unidirectional reinforcement stitched together. They provide strength and stiffness in multiple directions depending on the controlled fibre orientation. The weight distribution in the fabric is optimised and it is possible to mix different fibre types.

The non-crimp concept allows in-plane mechanical properties, such as tension and flexure, to be enhanced. There is less waste for complex lay-ups and lay-up time is also reduced by using thicker materials. Processing costs are reduced and heavy tow fibres can be used.

F) HiTape®

HiTape® is a new unidirectional dry carbon reinforcement developed to meet the requirements of aircraft primary structures. Made from Hexcel's HexTow® carbon fibre and used with HexFlow® infusion resin, it combines the benefits of automated processing and the cost-effective injection/infusion technologies with the high performance of latest-generation UD prepreg materials. The key characteristics of this new material are:

- A fully controlled automated process for dry preforms using conventional automated placement AFP or ATL machines.
- HiTape® is available in different versions enabling vacuum infusion of parts up to 30 mm thick with a 58 to 60 % fibre volume content.
- Outputs of 50 kg/h are achievable, depending on part design.
- When combined with infusion technologies, a high fibre volume content is achieved and high mechanical performance including compression after impact, matching the performance of the latest generation prepgres.

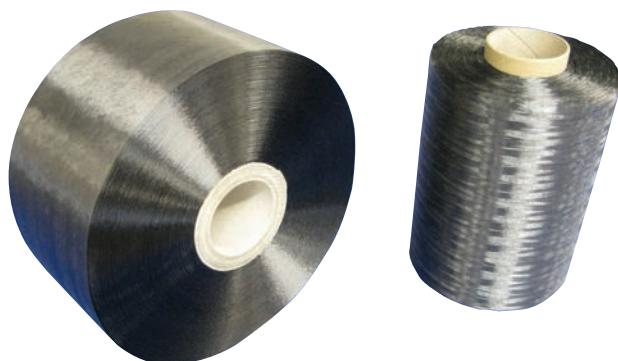


Figure 19: HiTape® spool

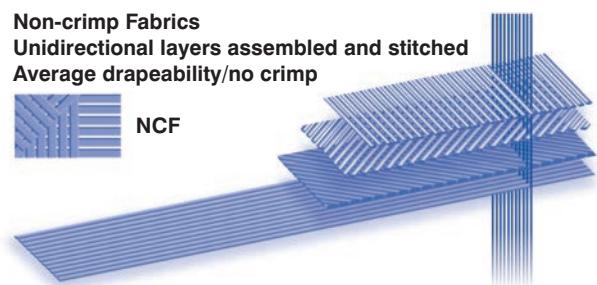


Figure 18: Diagram showing possible fibre orientation in multiaxial reinforcement

PREFORM MANUFACTURING FOR LIQUID COMPOSITE MOULDING

Preforms are pre-shaped reinforcements used with LCM technology, RTM or vacuum infusion to facilitate handling and to avoid fibre movement during injection and to control resin uniformity. Preforming is an important step for manufacturing high quality parts.

Preforming processes can use different techniques: AFP, ATL, weaving, braiding, stitching and knitting or manual. The preferred technique depends on the application and requirements.

1. Manual Preforming

A common way to create a preform is to do it manually. Dry fabric with binder is usually supplied on rolls which may be handled in the following order to build a preform:

- I. Cut the part plies ;
- II. Lay up the plies on the preform tooling;
- III. Apply heat and pressure as recommended per the relevant product data sheet to consolidate the preform*;
- IV. Trim preform to the required dimensions;

*To create the preform, a binder-material is incorporated onto the reinforcement. The pre-consolidation occurs when the binder is thermally activated. The binder can influence the preform's properties (strength, stiffness...) and, in some specific cases, could impact final part properties. Binder compatibility with the resin used may also impact reinforcement impregnation and the surface aspect.

Usually, the binder represents 5% or less of total fabric weight.

A) Hexcel binder E01

Binder E01 is a dry epoxy powder system for high performance textile reinforcements compatible with HexFlow®RTM6 & RTM6-2. Today, all Hexcel woven reinforcements for RTM have E01 epoxy binder on both faces but E01 is not sold separately. It gives some rigidity to the fabric, to allow ease of handling and cutting of shapes.

For Hexcel E01 standard binder the following parameters are recommended:

- 30 ± 5 minutes for standard applications or enough time to all plies to reach 100°C
- 100 ± 10 °C
- Under vacuum < 50 mbar ± 10% (depends on target FVC)

For more information, please consult the relevant Technical Data Sheet.

B) Hexcel binder HP03

Binder HP03 is compatible with epoxy & PU systems used for LRI & RTM process. Today, all Hexcel woven reinforcements can be supplied with HP03 on both faces. As for E01, it provides some rigidity to the fabric facilitating handling and cutting of preform shapes.

The main difference with HP03 is the permitted injection temperature after preforming: starting at 60°C with a recommended range between 80 and 100°C.

Please refer to the HP03 data sheet for more information.

2. Automated placement

HiTape® can be successfully used to manufacture preforms with automated placement machines, such as conventional AFP and ATL machines.

Please consult the **Reinforcements for Liquid Composite Moulding; Section F, HiTape®** to compare the advantages of HiTape® over conventional fabrics.

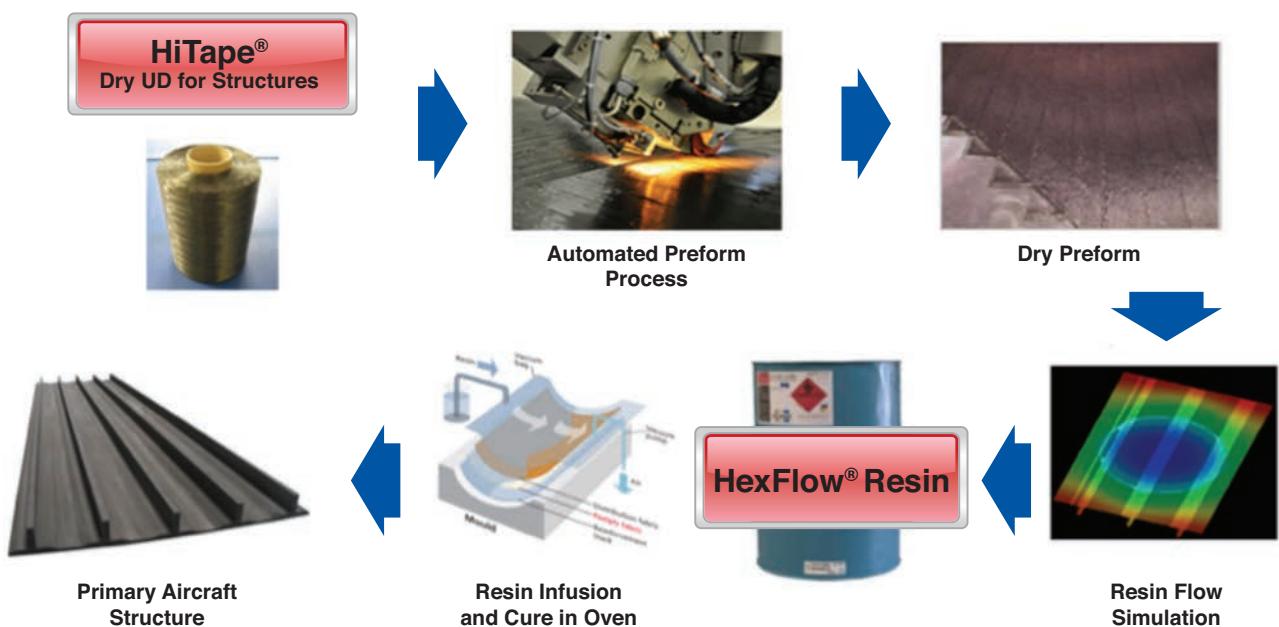


Figure 20: How to manufacture parts using HiTape®

For more information, please contact Hexcel Technical Support or visit Hexcel.com.

HEXFLOW® RESIN SYSTEMS FOR LIQUID COMPOSITE MOULDING

1. HexFlow® epoxy resins

HexFlow®RTM6 resin was developed in the 1990s and has become the industry standard RTM resin for aerospace applications with an extensive aerospace qualification database.

It is a 180°C curing epoxy system specifically developed to fulfil the requirements for structures in the aerospace and space industries. It is suitable for service temperatures from -60°C up to 120°C. Its main characteristics are:

- High glass transition temperature
- Excellent hot/wet properties
- Easy to process (low injection pressure)
- Large processing window

Two forms of RTM6 resin have been developed to offer the customer the widest flexibility in their manufacturing processes.

With the same chemical formulation, each version presents several key benefits.

A) HexFlow®RTM6 Mono-component

The mono-component version is pre-mixed, ready to be directly injected or infused.

At room temperature, RTM6 is a brown translucent paste. However, its viscosity decreases quickly when heated.

A second degassing step is not mandatory but may be performed if the resin has been manipulated (change of container, stirring, etc.).

B) HexFlow®RTM6-2 Bi-component

HexFlow®RTM6-2 is delivered as two different components but is chemically the same as RTM6 and provides the same high performance. After mixing, HexFlow® RTM6-2 is fully equivalent to RTM6.

For the bi-component version separating the resin and the hardener allows storage at +5°C, easier transportation (including by air) and larger pack sizes (see the comparison table on page 27).

C) HexFlow®RTM6-2 Part A

Part A is the epoxy resin system. This component is a brown translucent high viscosity liquid at RT.

D) HexFlow®RTM6-2 Part B

Part B is the hardener system. It is a crystalline solid at RT as shown at in the picture.

Melting point: 75 – 80 °C.

Part B can be heated and cooled several times without affecting its quality.



Figure 21: HexFlow® RTM6-2 Part A and Part B

2. Regulations

Updated safety data sheets (SDS) are available upon request. Please contact Product Stewardship for more detailed information.

As with most Hexcel products, HexFlow®RTM6 and HexFlow®RTM6-2 are subject to changes in legislation and must be monitored for status change.

For REACH or other regulatory compliance, please contact REACH@hexcel.com

		HexFlow®RTM6 Mono-component resin system	HexFlow®RTM6-2 Bi-component resin system
Transport		<ul style="list-style-type: none"> ■ Road transport at -18°C ■ Air shipment forbidden due to UN 4.1 regulation ■ Sea shipment at -18°C uniquely with a double refrigerator unit 	<p>Before mixing:</p> <ul style="list-style-type: none"> ■ Road, air and sea transport at RT if the transport is completed in less than 10 days ■ Transport at -18/+5°C for longer transportation
Storage		<ul style="list-style-type: none"> ■ 9 months at -18°C ■ 15 days at RT 	<p>Before mixing:</p> <ul style="list-style-type: none"> ■ 12 months at +5°C ■ 1 month at RT
Volumes		Limited to low volumes (10 and 25 kg) due to transport regulations and thermal stability	<ul style="list-style-type: none"> ■ 45 kg standard kit ■ Larger sizes possible for high volume processing (200 kg drums)
Pre-processing		<p>No resin pre-processing needed:</p> <ul style="list-style-type: none"> ■ Ready for use ■ Already degassed 	<p>Pre-processing needed:</p> <ul style="list-style-type: none"> ■ Mixing the two Parts ■ Degassing is recommended
Processing			Same injection/infusion process
Mechanical properties		Equivalent mechanical properties	

PRE-PROCESSING OF HEXFLOW® RTM6 & RTM6-2 RESINS

The pre-processing of the resin is an important step to obtaining good composite parts. HexFlow®RTM6 monocomponent system has the advantages that the mixing is assured and the resin is supplied pre-degassed.

For HexFlow®RTM6-2, it is important to ensure a good quality of mixing and accurate ratio of components. Degassing is highly recommended to release the air trapped within the resin and to ensure low-porosity and high quality parts.

The information and processing parameters provided in this and other Hexcel documents are recommendations of best practice. In our opinion the most important considerations to ensure good parts and safe processing are:

- Time
- Temperature
- Stirring

1. HexFlow®RTM6 pre-processing

Already pre-degassed, HexFlow®RTM6 monocomponent has the advantage of not requiring any pre-processing steps.

However, a degassing step is recommended if the resin has been manipulated (change of container, stirring...).

2. HexFlow®RTM6-2 pre-processing

At customer facilities, HexFlow®RTM6-2 Parts A and B have to be mixed prior to injection or infusion. Three typical mixing routes are:

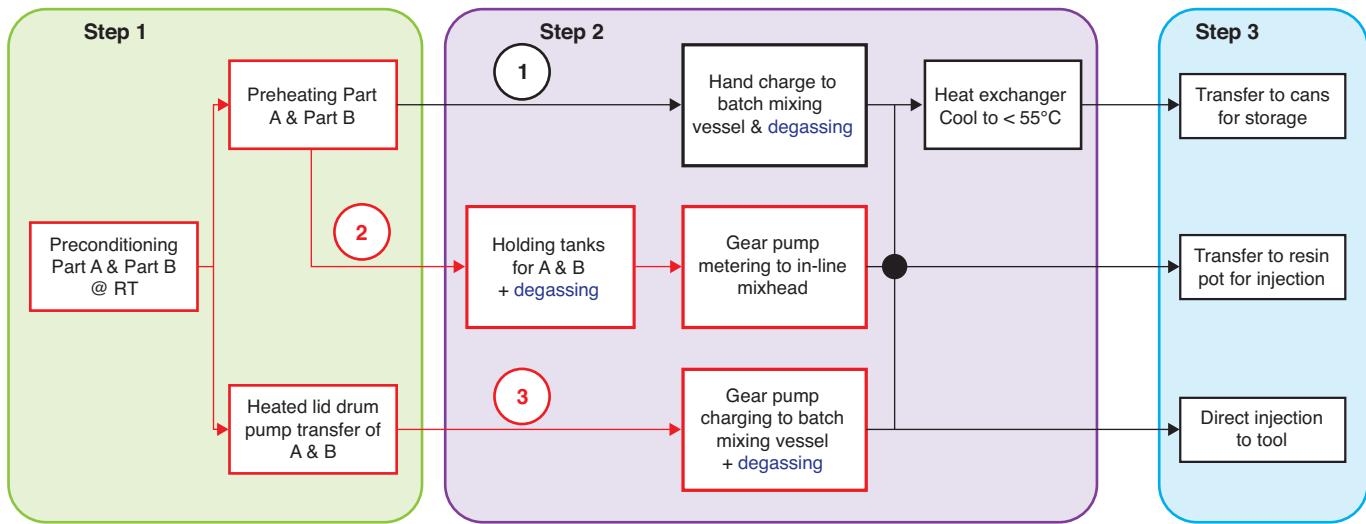
- Manual weighing into a conventional batch mixing vessel
- Automated metering into an automated batch mixing vessel
- Automated metering to an in-line mixer.

The mixing of the resin prior to use can be separated into three stages:

1. Heating and transfer of the Part A and B components to the mixer
2. Mixing
3. Transfer to part processing or storage

LIQUID COMPOSITE MOULDING TECHNOLOGY MANUAL

Some possible routes to progress through these three stages are summarised in the diagram below.



Hexcel has been working closely with machine suppliers to develop an automated system for mixing HexFlow®RTM6-2. Hexcel's recommended and supported routes are indicated in red in the above diagram.

In addition to these process routes for mixing resin in bulk, smaller amounts of resin (e.g. for quality control tests) can be mixed using simple laboratory equipment. Please contact Hexcel Technical Support for detailed information.

A) Step 1: Pre-conditioning and pre-heating of Part A and Part B

Step 1.1: Pre-conditioning of Part A and Part B

Prior to use, the drums of Part A and B should be preconditioned at room temperature for at least 24 hours.

Step 1.2: Pre-heating of Part A and Part B

The next step is to heat the A and B components and transfer to the mixing equipment. This can be done by either heating the drums in an oven or by the use of a drum pump with a heated lid or follower plate.

Part A should be heated to 60-80°C to reduce its viscosity

Part B should be heated to 85±5°C to fully melt the crystals and obtain a low viscosity brown liquid.

If heating cans in the oven, a typical heating time of 8 hours for a standard 45 kg kit is recommended.

For more information about preheating times and temperatures, please refer to HexFlow® RTM6/RTM6-2 Safety & Processing Recommendations or contact Hexcel Technical Support.

B) Step 2: Part A and Part B Mixing

The mixing ratio for components A and B are shown in the table below. Parts A and B should be either weighed or metered to the mixer with an accuracy of $\pm 1\%$.

	In weight	In volume
Part A: Part B	100:68.1	100:79.5

There are different possibilities for mixing the resin according to customer needs and subsequent component processing requirements. The most common processing routes are described below.

I. Manual transfer to a batch mixing vessel

In this case, the heated components are manually weighed and transferred to a batch mixing vessel. For safety reasons, a maximum batch size of 50 kg is recommended. The vessel should have good stirring to ensure a homogenous mixture can be produced within a recommended mix time of 30 minutes. Ideally the vessel will also have vacuum to allow degassing during mixing.

II. Automated gear pump transfer to an automated batch mixer

In this case, the heated components are transferred via drum pumps to a batch mixing vessel which automatically controls the mix ratio and mixing operation functions. It is recommended to have vacuum to allow degassing during mixing.

III. Automated gear pump transfer to an in-line mixer

In this case, the heated components are first transferred to holding tanks for A and B components, set at 60-80°C for Part A and 85 ± 5 °C for part B, where the degassing can take place. Gear pumps and flow meters then accurately meter the components to an in-line mixer to produce the mixed resin.

In all cases, the total amount of time for mixing and degassing time must not exceed 30 min. This is to preserve the thermal stability of the resin for subsequent processing operations.

For more information, please refer to 'HexFlow® RTM6/RTM6-2 Safety & Processing Recommendations' or contact Hexcel Technical Support.

Step 2.1: Degassing - Optional depending on process route

For all mixing processes it is recommended to have a degassing stage where air is removed from the resin. Dependent on the mixing process selected, the degassing can be done at different stages as defined above (e.g. on each component, during or after mixing). The recommended residual vacuum level for degassing operations is <5 mbar.

C) Step 3: Use and Storage

Once mixed, the resin can be either directly used or cooled down to temperatures below 55°C before -18°C storage.

The maximum recommended pot size is 50 kg for mixing and for storage, the maximum recommended can size is 25 kg. Care must be taken to monitor the temperature of mixed resin to avoid exotherm.

D) Safety

Suitable personal protection equipment should be worn for all operations. Mixed resin has the potential for uncontrolled exotherm and should be closely monitored and controlled when heated. A contingency plan in case of exothermal reaction should be in place for all stages of the mixing operation. For further guidance refer to '**HexFlow®RTM6/RTM6-2 Safety & Processing Recommendations for Injection & Infusion**'.

For more detailed information, please contact Hexcel Technical Support.

E) Pre-Processing equipment

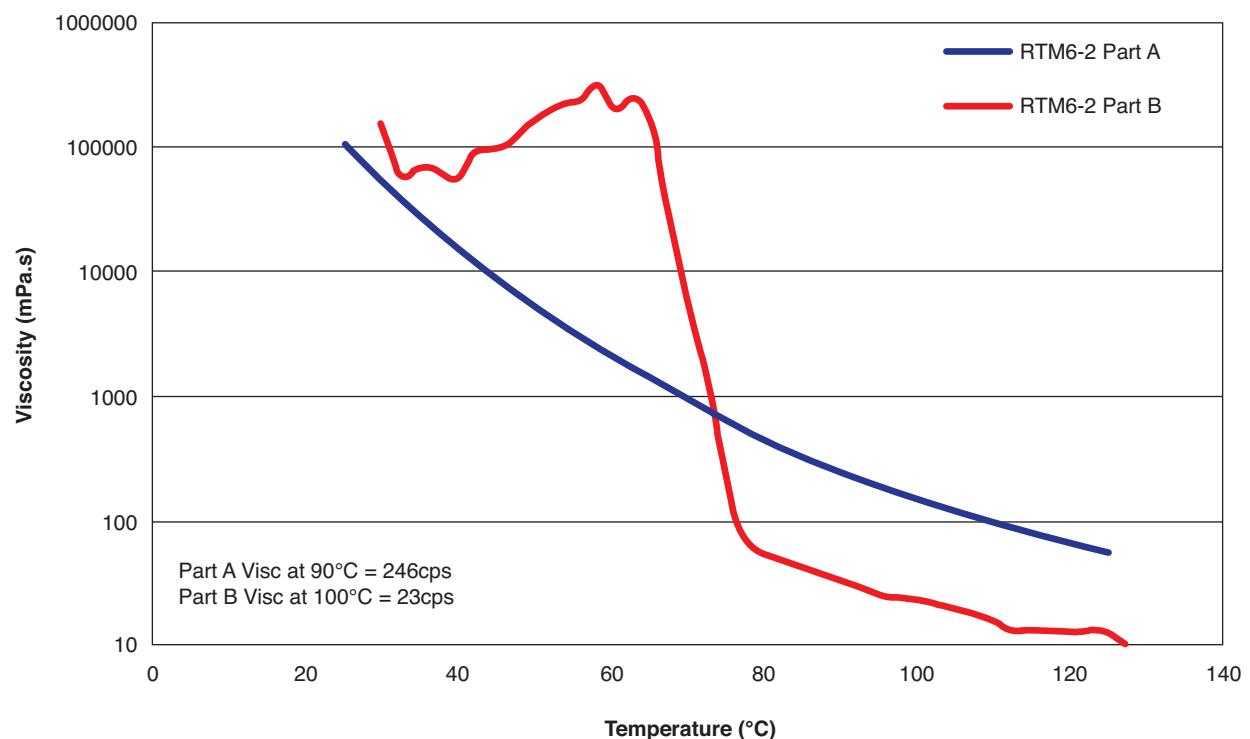
Using higher volumes of HexFlow®RTM6-2 may imply having specific equipment. Different machine designs are currently available on the market.

For processing of HexFlow® RTM6-2, Hexcel defines the principal requirements for the equipment as:

- Separate preheating of parts A and B.
- Weight control (balance) or volume control (flow meters) with $\pm 1\%$ accuracy.
- Automated stirring.
- All parts of the equipment heated and controlled to maintain low viscosity of the components.
- Possibility to perform direct injection or fill cans for storage.
- Meet the safety requirements for exothermal resins.

To help with equipment design, especially when flow meters are used, the viscosity of A and B components with temperatures are shown in the graph below.

RTM6-2 Part A and B viscosity 25°C to 125°C



PROCESSING HEXFLOW® RTM6 & RTM6-2 MIXED

1. HexFlow®RTM6 Presentation

The mono-component version is ready to be directly injected or infused.

At room temperature, RTM6 is a brown translucent paste. However, its viscosity decreases quickly when heated.

2. HexFlow®RTM6-2 mixed presentation

After mixing, HexFlow® RTM6-2 is fully equivalent to RTM6 and can be processed using the same guidelines.

3. HexFlow®RTM6 and RTM6-2 mixed key characteristics

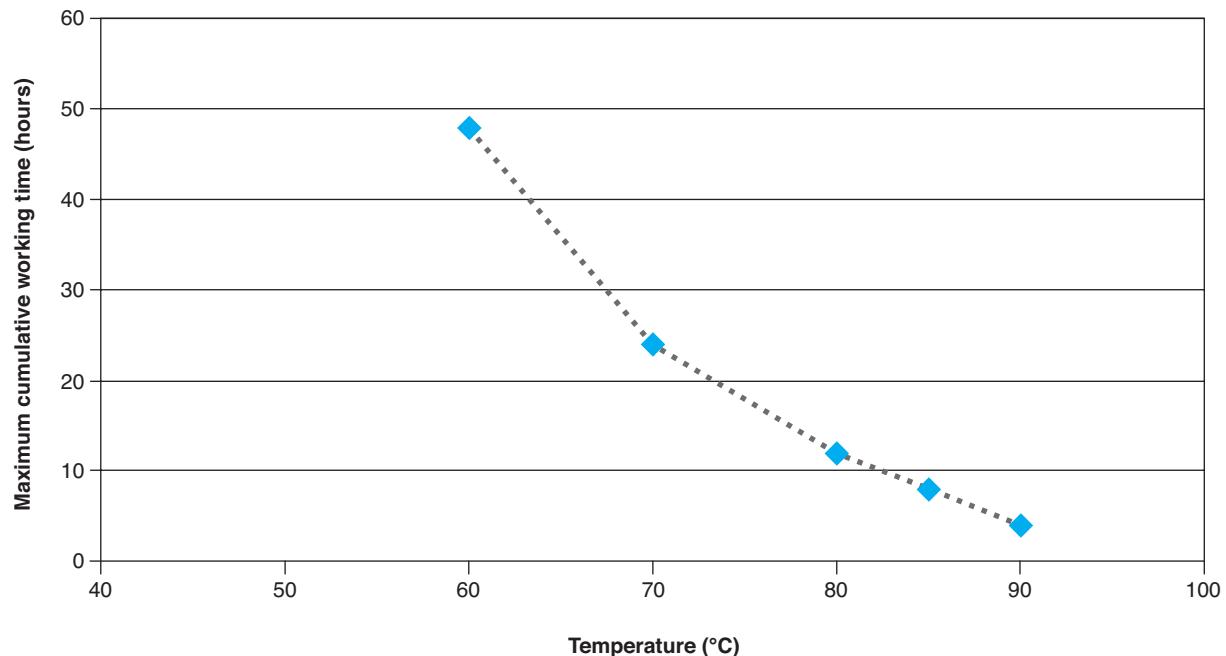
A) Resin working time

HexFlow® epoxy resin systems are suitable for LCM Processes because of their low viscosity when heated to the process temperature. It is this low viscosity that allows the reinforcement to be impregnated. However, heating the resin also introduces risks associated with the thermal stability of reactive resin which could lead to an uncontrolled exotherm if not properly managed. However, the resin can be processed safely by following **Hexcel RTM6/RTM6-2 Safety and Processing Recommendations for Injection and Infusion**.

The temperature and time that the resin experiences during all parts of the process must be considered when determining safe working time. **The following table and graph give a guide to maximum cumulative working times that are considered to be safe. These working times should not be exceeded.**

Temperature (°C)	Maximum cumulative working time (hours)
60	48
70	24
80	12
85	8
90	4

RTM6 Maximum cumulative working time 60°C to 90°C



B) Viscosity

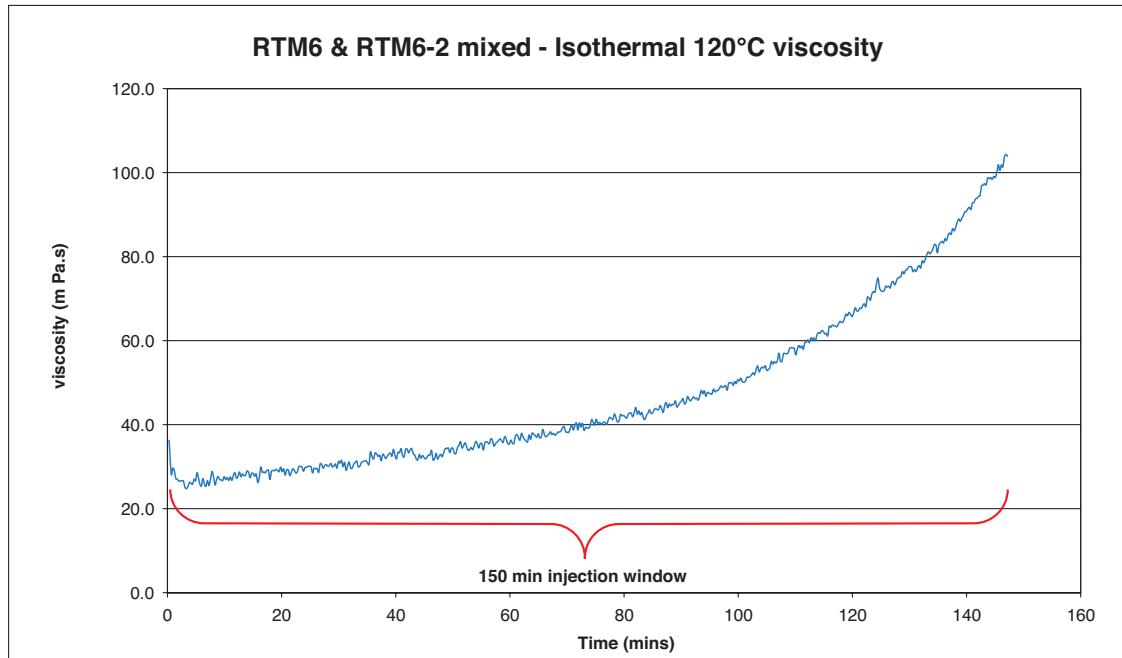
The quality of a part depends on the reinforcement's impregnation. It is often necessary to adapt the **LCM** parameters (vacuum, temperature, pressure) for each resin and reinforcement system.

Viscosity behaviour over time at the preheating and working temperatures is essential to choose the right parameters for the process.

Hexcel's recommendations for HexFlow®RTM6 and RTM6-2 (mixed) resins are:

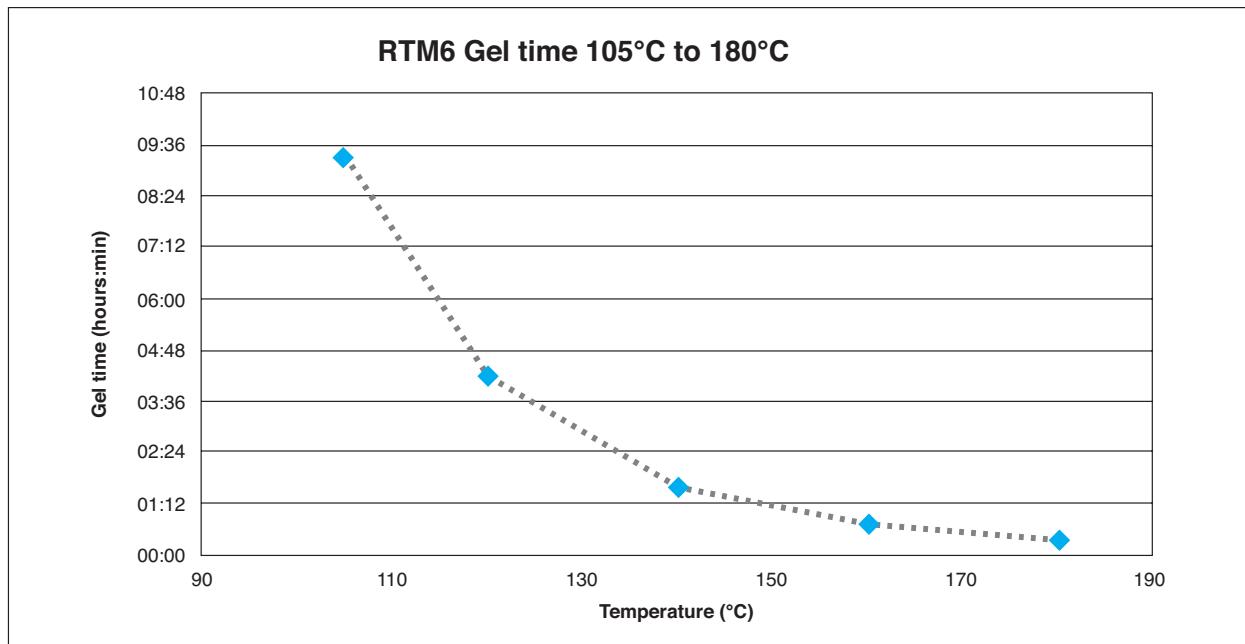
1. Preheating temperature: 60-80°C.
2. Process temperature (injection/infusion): 100-140°C in the mould and 60-80°C in the injection/infusion pot.

HexFlow®RTM6 has an injection window of 150 minutes at 120°C. At lower temperatures, the injection window is longer but must be off-set against higher viscosity that will reduce the speed at which the resin can permeate through the preform. Typically a mould temperature of 120°C is used for RTM processes and 100°C for infusion processes.



HexFlow®RTM6 and RTM6-2 mixed resin gel times:

Temperature (°C)	Gel time (hours : min)
105	9:20
120	4:10
140	1:35
160	0:45
180	0:20



4. HexFlow®RTM6 and RTM6-2 mixed RTM Guidelines

RTM6 resin should be defrosted at RT for 24 hours before starting injection operations. The main steps for the injection process are.

A) Preform Preparation

- Cut the required plies
- Lay up the preform
- Consolidate the preform with heat and pressure:
 - ◆ For example for a standard panel with E01 binder
 - 30 minutes at 100°C or enough time to all plies to reach 100°C
 - 50 mbar if using a vacuum bag (may vary to achieve an specific FVC)
- Trim preform to exact dimensions

B) Mould preparation:

- Mould preparation
 - ◆ Cleaning and application of a release agent
- Place the preform into the mould
- Close the mould and connect it to the RTM machine

C) Preheating

- Preheat the resin in the injection pot before injection
 - ◆ For RTM6 & mixed RTM6-2 : 60-80 °C
- Preheat the mould to the injection temperature
 - ◆ For RTM6 & mixed RTM6-2 : 100-140 °C
- Preheat the injection pipework/tube to a temperature between the resin temperature and the injection temperature.
- Apply vacuum in the mould. Recommended residual vacuum level: < 5 mbars.

D) Injection

Once the required temperatures are reached, the part can be injected. Three main routes are possible:

1. With a constant pressure
 - ◆ Only for small parts with high permeability of the reinforcement
2. With a constant flow
 - ◆ Not suitable in case of large thickness variations or if the flow front size is variable
3. With a continuous pressure ramp
 - ◆ Allows a reasonably constant flow to be obtained. Start with low pressure to prevent fibre push up and washing

For the injection, Hexcel recommends the following guidelines:

- Apply vacuum to the mould cavity. Recommended vacuum level: < 5mbars.
- Inject the resin into the mould at low pressure (up to 5 bar), whilst maintaining vacuum.
- Once resin has reached the exit and no bubbles are seen in the exit line, clamp/close the exit port.
- Continue to maintain the pressure at the injection port to compensate for resin shrinkage.
- Increase the mould to the curing temperature (normally 180°C).

E) Finishing

- After the cure cycle, cool down the mould.
- Demould the part.
- If required a post cure can be performed in an oven.
- Clean the RTM machine and injection hoses.

5. HexFlow®RTM6 and RTM6-2 mixed LRI Guidelines

The infusion procedure is fundamentally the same as injection, but uses vacuum instead of injection pressure to fill the mould. Please refer to the previous sections for more information.

6. Parameters and cure cycles

Resin preheating		60-80°C
Injection	Temperature	100-140°C
	Pressure	1 to 5 bars
Standard cure cycle	Ramp	1-3 °C/min
	Temperature	180°C
	Time	90-120 min

For more detailed information regarding the process parameters, please refer to **HexFlow®RTM6 & HexFlow®RTM6-2 Technical Data Sheets** or contact Hexcel Technical Support.

MECHANICAL PROPERTIES OF LAMINATES

RTM and infusion manufacturing processes have been used for many years to make composite parts for applications and laminates with excellent mechanical properties.

Shown below are some room temperature properties of RTM laminates produced using HexFlow®RTM6 and Hexcel woven reinforcements:

Properties (RT/DRY)		Test Method	RTM6/G0926 ¹	RTM6/G1157 ²
Tensile 0°	Strength (MPa)	ISO 527-4	904	1854
	Modulus (GPa)		68.2	128.9
Tensile 90°	Strength (MPa)	ISO 527-4	864	47
	Modulus (GPa)		67.1	9.1
Compression 0°	Strength (MPa)	EN 2850 A1	687	1216
	Modulus (GPa)		62.5	115.6
Compression 90°	Strength (MPa)	EN 2850 A1	701	193
	Modulus (GPa)		61.8	10
IPS	Strength (MPa)	EN 6031	95	91
	Modulus (GPa)		4.5	4.5
ILSS Strength 0° (MPa)		EN 2563	62	91

Data is the result of several tests on cured laminates and normalized to 58% fibre volume content for tensile and compression. Results are un-normalized for IPS and ILSS.

¹ 390H5 AS4C

² 290UDPW AS4C

Some of the values achieved will have been higher, and some lower, than the figure quoted. These are nominal values.

For more information about mechanical properties of RTM or infusion laminates, please contact Hexcel Technical Support.

Important

All information is believed to be accurate but is given without acceptance of liability. Users should make their own assessment of the suitability of any product for the purposes required. All sales are made subject to our standard terms of sale which include limitations on liability and other important terms.

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

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:

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