Manufacture of a Carbon Composite Wheelchair – Part 1
Acknowledgements

I would like to acknowledge the help of the following people;

Dr Phil Harrison my supervisor for his guidance during this project

Dr Safa Hashim for advice on composites and adhesives

Mr John Davidson for his help in the testing

Mr Brian Robb and the technical workshop staff for their work on the moulds.

Mr Alan Birkbeck for his advice on fibreglass wet lay-up.

Mr John Kitching and the technical aero staff at Acre Rd wind tunnel for their help in finishing the moulds.

Mr Edmund Pratt for assisting me with Abaqus and proofing the report

Mr Martin Armstrong from GURIT for his advice on material choices and wheelchair design aspects and advice throughout the first half of the project

The staff at East Coast Fibreglass Supplies for advising me and putting together a resin infusion kit for me.

The Staff at Allscot Ltd for supplying materials and there advice on mould release.

The Staff from Ebalta UK Limited for their advice on mould materials.
Abstract

This project gives a brief overview a brief introduction and overview of composites; it touches upon manufacture design and testing. It also experiments with a number processes and advanced manufacturing techniques with composites including wet lay-up, vacuum resin infusion and a combined process and settles on a recommended method of part production.

It has establishes an understanding of wheelchairs and reviewed what is currently on the market. By doing this a solid platform of knowledge has is created which will allow for the future design to begin swiftly.

FEA is then used to model simple composite structures then compared to written calculations and physical testing. This has shown the importance of physical testing in order to validate or devaluate computerised simulations.

Finally this project leads through the design and manufacture process of producing tooling to create a composite bicycle frame.
# Contents

## Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acknowledgements</td>
<td>1</td>
</tr>
<tr>
<td>Abstract</td>
<td>2</td>
</tr>
<tr>
<td>Contents</td>
<td>3</td>
</tr>
<tr>
<td>Figures</td>
<td>6</td>
</tr>
<tr>
<td>Nomenclature</td>
<td>9</td>
</tr>
<tr>
<td>Intro</td>
<td>10</td>
</tr>
<tr>
<td>Aim</td>
<td>10</td>
</tr>
<tr>
<td>Objectives</td>
<td>10</td>
</tr>
<tr>
<td>Primary Objectives</td>
<td>10</td>
</tr>
<tr>
<td>Secondary Objectives</td>
<td>10</td>
</tr>
<tr>
<td>Background</td>
<td>11</td>
</tr>
<tr>
<td>Composite History</td>
<td>11</td>
</tr>
<tr>
<td>Design Considerations</td>
<td>15</td>
</tr>
<tr>
<td>Introduction to composites</td>
<td>15</td>
</tr>
<tr>
<td>Fibre Volume Fraction</td>
<td>15</td>
</tr>
<tr>
<td>Rule of Mixtures</td>
<td>16</td>
</tr>
<tr>
<td>Common Manufacturing Processes</td>
<td>19</td>
</tr>
<tr>
<td>Moulding and Moulds</td>
<td>20</td>
</tr>
<tr>
<td>The Wet Lay Up</td>
<td>22</td>
</tr>
<tr>
<td>The Vacuum Infusion Process</td>
<td>23</td>
</tr>
<tr>
<td>Autoclave Moulding</td>
<td>29</td>
</tr>
<tr>
<td>Press Moulding</td>
<td>29</td>
</tr>
<tr>
<td>Pressure Bag Moulding</td>
<td>30</td>
</tr>
<tr>
<td>Filament Winding</td>
<td>30</td>
</tr>
</tbody>
</table>
Figures

Figure 1 - Material Timeline ................................................................. 11
Figure 2 - Strength V. Density Table .................................................. 12
Figure 3 - Young’s Modulus V. Density Table ........................................ 13
Figure 4 - Weave Styles .................................................................... 14
Figure 5 - Crimp Angle Correction Factor .......................................... 18
Figure 6 - Male Mould .................................................................... 21
Figure 7 - Female Mould .................................................................. 21
Figure 8 – Kart Wheel Part ................................................................. 21
Figure 9 - Kart Wheel Assembly ........................................................... 21
Figure 10 - Vacuum infusion Diagram .................................................. 23
Figure 11 - Preparing the Mould ............................................................ 24
Figure 12 - Preparing the Catch Tank .................................................... 24
Figure 13 - Cutting the Fibre ................................................................. 24
Figure 14 – The Cut Fibre ................................................................ 24
Figure 15 - Cutting the Peel Ply .............................................................. 25
Figure 16 - Stacking the Fibre ............................................................... 25
Figure 17 - Setting Up the Resin/Air Channels ........................................ 25
Figure 18 - Laying the Breather Cloth .................................................... 25
Figure 19 - Inserting the Resin Tube ...................................................... 26
Figure 20 - Covering with Vacuum Bagging ........................................... 26
Figure 21 - Testing the Vacuum ............................................................. 27
Figure 22 - Checking for Leaks .............................................................. 27
Figure 23 - Starting the Infusion ............................................................. 27
Figure 24 - Infusion Complete ............................................................... 27
Figure 25 - Peeling Back the Vacuum bag .............................................. 28
Figure 26 - The Part Shown ................................................................. 28
Figure 27 - Finished Part .................................................................. 28
Figure 28 - Consumables Waste ............................................................. 28
Figure 29 - Press Moulding ................................................................. 29
Figure 30 - Pressure Bag Moulding ....................................................... 30
Figure 31 - Filament Winding ............................................................... 30
Figure 32 - Photoelastic Fringes Shown in Matrix by Isochromatic Photography ......................................................... 34
Figure 33 - Tennis Chair ................................................................ 35
Figure 34 - Basketball Chair ................................................................. 36
Figure 35 - Rugby Chair .................................................................. 36
Figure 36 - Fully rigid Chair ................................................................. 37
Figure 37 - Fully Rigid Chair, Wheels Off ______________________________________ 37
Figure 38 - Chair with Folding Back __________________________________________ 38
Figure 39 - Chair with Folding Back, Back Folded ________________________________ 38
Figure 40 - Chair with Folding Back, Totally Collapsed __________________________ 39
Figure 41 - Fully Folding Chair ______________________________________________ 40
Figure 42 - Fully Folding Chair, Wheels Off, Back Folded ________________________ 40
Figure 43 - Fully Folding Chair, Totally Collapsed ______________________________ 40
Figure 44 - Fully Folding Chair, Flat __________________________________________ 40
Figure 45 - Wheelchair Size Comparison ________________________________________ 41
Figure 46 - Wheelchair Size Comparison 2 ______________________________________ 41
Figure 47 - Wheelchair Wheel ________________________________________________ 42
Figure 48 - Wheelchair Axel __________________________________________________ 42
Figure 49 - Wheelchair Camber ______________________________________________ 43
Figure 50 - Tube samples being manufactured ___________________________________ 45
Figure 51 - Tube Sample ____________________________________________________ 46
Figure 52 - 3 point bend test in progress ________________________________________ 47
Figure 53 - Oven Wall Section ________________________________________________ 49
Figure 54 - Oven Casing _____________________________________________________ 50
Figure 55 - Digital Kitchen Thermometer ________________________________________ 50
Figure 56 - Road Bike CAD __________________________________________________ 51
Figure 57 - Solidworks Full Suspension Frame Sketches ____________________________ 53
Figure 58 - Linkage Model ____________________________________________________ 54
Figure 59 - Raw Mould Render LHS ____________________________________________ 55
Figure 60 - Completed Mould Render RHS ______________________________________ 55
Figure 61 - Frame Render 1 __________________________________________________ 56
Figure 62 - Frame Render 2 __________________________________________________ 56
Figure 63 - Machining Mould ________________________________________________ 57
Figure 64 - Machined mould before sanding _____________________________________ 58
Figure 65 - Holes Filled ______________________________________________________ 58
Figure 66 - Wet Sanding ______________________________________________________ 58
Figure 67 - Fully Primed _____________________________________________________ 58
Figure 68 - Mould Complete __________________________________________________ 59
Figure 69 - Mould Comparison ______________________________________________ 59
Figure 70 - Mould Damage __________________________________________________ 59
Figure 71 - Mould Fixed _____________________________________________________ 59
Figure 72 - Fixing Mould Step 1 ______________________________________________ 60
Figure 73 - Fixing Mould Step 2 ______________________________________________ 60
Figure 74 - Fixing Mould Step 3 ______________________________________________ 60
Nomenclature

\( V_f = \) Volume fraction of fibres

\( W_f = \) Weight of fibres

\( W_m = \) Weight of matrix

\( \rho_f = \) Density of fibres

\( \rho_m = \) Density of matrix

\( E = \) Young’s Modulus

\( \eta_L = \) Length correction factor

\( \eta_0 = \) Correction factor for non-unidirectional reinforcement

\( \alpha_i = \) Proportion of the fibres

\( \theta_i = \) Orientation of fibres
Intro

Aim

This project is the first part of a two year undertaking to research, design and build a carbon fibre composite wheelchair. The aim of this introduction is to introduce composites, their benefits, capabilities and shortcomings. It will explain several different manufacturing methods commonly used to create composite parts and discuss why these are used.

It will then move to the use of finite element analysis (FEA)\(^1\) software to help predict the response of the design under normal loads and compare the results with real testing in order to confirm the effectiveness of this process.

This half of the project will be concluded by the design and manufacture of a carbon fibre bicycle frame. This should create a good foundation in manufacturing and testing methods for whoever continues the project in the following year.

Unfortunately the manufacture of the frame was not completed by the end of this project, this was due to unforeseen delivery times, machining and preparation time of the moulds which took well over a month.

Objectives

Primary Objectives

1. Research advanced composite background and manufacturing techniques
2. Review current Wheelchairs
3. Investigation of wheelchairs for baseline design
4. Manufacture laminate parts using different methods
5. Characterisation flexural / tension - determine correct BS and test accordingly
6. Simulate flat plates under 3 - point bend test
7. Simulate tube (tensile + torsion)

Secondary Objectives

1. Composite Bicycle design and tooling
2. Composite Bicycle manufacture

---

\(^1\) In this project the software used is ABAQUS FEA – DS Simulia
Background

This section will provide some background information on the history of composites and why they are a good choice of material for this project.

Composite History

“The word ‘composite’ means ‘consisting of two or more parts’”²

In this project the type of composites I will be referring to are fibre reinforced composites. As is visible in Error! Reference source not found. these types of composites have only existed for the past 50 years. This makes them a very young technology in comparison to standard metals, ceramics etc. which have been in use for thousands of years.

It is understood that the reason the measured strengths of most materials are much smaller (by orders of magnitude in some cases) than their theoretical strengths, is the result of flaws and imperfections in the material\textsuperscript{3}. Attempting to minimise or eliminate these inherent flaws enhances the strength of the material. Flaws that affect the strength of the material propagate through the bulk material. However, in the case that the block is broken into thin fibres, it is hoped that any flaws are contained within a single strand and cannot propagate through the material. Therefore compared to the strength of bulk materials, manmade filaments and fibres exhibit a much higher strength along their length \textsuperscript{2}. This is the rationalisation behind fibre reinforced composites Advanced composites also exhibit some of the highest stiffness to density ratios as shown in Figure 3 - Young’s Modulus.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{strength_density.png}
\caption{Strength V. Density Table}
\end{figure}

\textsuperscript{3} Materials Selection in Mechanical Design 3rd Edition, by Michael F. Ashby
Until very recently composites have been used much like wood i.e. they were made into blocks and machined to size and shape. It has only been in the last 20 years that composites such as glass fibre reinforced plastics (GFRP) have become widely commercially used. Most use in structural applications consists of multiple layers of fibrous composites. There are two reasons behind this; firstly, each layer of composite material is thin, typically 0.1mm, so is unlikely to be useful in a single layer configuration. Secondly, as the fibres are aligned in one direction the strength characteristics are asymmetric. To counteract this issue, fibres are laid in different orientations and held together with a matrix material. Each layer of fibre is commonly known as a ‘ply’. Once a composite material has been laid up it is referred to as a laminate. In the case that there are multiple types of fibrous material in a laminate for example carbon and aramids the laminate is referred to as a hybrid laminate.

The matrix material in a composite is needed to hold the fibres together, whilst they provide the strength. It keeps the fibres in the correct position and orientation and transfers loads to and between the fibres. The matrix is also responsible for the majority of the composites strength in its transverse direction. The matrix is commonly the limiting factor of the material as its maximum service temperature and other factors are usually considerably lower than those of the fibres. The matrix is commonly an epoxy, phenolic or
polyester resin, although there are many more resins and even materials are used including metals for a variety of applications \(^4\)

It is also possible to get alternate configurations of fibres other than unidirectional, these come as woven fabrics that are available in many different weaves and can also be hybrid weaves with two or more materials woven together. Some common weaves are shown in Error! Reference source not found.; these are plain, twill and satin. This figure is taken from a dress making book and demonstrates the origin of the techniques. In fact, the first high strength woven fabrics and still some now are woven on looms designed for household cloths and textiles \(^5\)

![Weave Styles](image)

Figure 4 - Weave Styles

Also commonly available are chopped strand matting and loose fibres. These are comparatively short fibres ranging from 2mm to 50mm in length. These fibres are held together with a small amount of resin/adhesive which dissolves in the wetting process of the manufacture. Loose strands can also be mixed with resin and injection moulded to form complex shapes.

It is also possible to get material already impregnated with an optimal amount of resin; this is commonly referred to as prepreg.

\(^4\)Composite Basics – 5, by Andrew C. Marshall
\(^5\)An Introduction to Composite Products: Design, Development, and Manufacture, by Kevin Potter, published by Chapman & Hall
Design Considerations

Introduction to composites

There are several important factors which affect the running of simulations on composites. These factors are mostly to do with the asymmetric nature of the material and because of the mix of materials and therefore mix of properties in a part. This section will cover and explain some of the important factors.

Fibre Volume Fraction

The fibre volume fraction tells us the volume of fibre in a cured composite i.e. a composite in which the matrix material has set or solidified. The fibre volume fraction is calculated by the following formula.

\[
V_f = \frac{\rho_m W_f}{\rho_f W_f + \rho_m W_m}
\]

Equation 1 - Fibre Volume Fraction

\( V_f \) = Volume fraction of fibres

\( W_f \) = Weight of fibres

\( W_m \) = Weight of matrix

\( \rho_f \) = Density of fibres

\( \rho_m \) = Density of matrix
The fibre weight can be calculated by chemical matrix digestion\textsuperscript{6}, this is a process where the matrix is dissolved out of the part. Once you are left with just fibres they can be weighed. It is important that a chemical is chosen that will not attack the fibres so as to provide the true weight. Another method is the matrix burn-off method\textsuperscript{7} commonly used for glass fibres. It is also possible to use a photo micrographic technique in which a polished cross section of a material is taken and the fibre ends counted to calculate the area, the volume fraction is then determined as the area fraction of each part. Unfortunately these are both destructive methods of testing.\textsuperscript{8}

In this project the test method used was to measure the weight of the fibres before moulding then the weight of the part after. With the equation above the fibre volume fraction was then determined. I believe this is the best method to use as it is accurate, non-destructive and uses very minimal instrumentation.

**Rule of Mixtures**

'Rules of Mixtures' are mathematical expressions which give some property of the composite with respect to quantity and arrangement of its constituents.

Generalised Rule of mixtures:

\[
E = \eta_L \eta_O E_f V_f + E_m (1-V_f)
\]

\textbf{Equation 2 - Generalised Rule of Mixtures}

\(E = \text{Young’s Modulus}\)

\(\eta_L\) is the length correction factor. \(\eta_L \approx 1\) when fibres are longer than 10mm

\(\eta_O\) is the correction factor for non-unidirectional reinforcement:

\[
\begin{array}{c|c}
\text{Unidirectional} & 1.0 \\
\text{Biaxial} & 0.5 \\
\end{array}
\]

\textsuperscript{6} ASTM D3171, ASTM D3171

\textsuperscript{7} ASTM D2584

\textsuperscript{8} Analysis and Performance of Fibre Composites, by Bhagwan D. Agarwal and Lawrence J. Broutman
Biaxial at ±45°  0.25
Random (in-plane)  0.375
Random (3D)  0.2

Theoretical Orientation Correction Factor

\[ \eta_o = \sum \alpha_i \cos^4 \theta_i \]

Equation 3 - Theoretical Orientation Factor

\( \eta_o \) is the sum of all the different orientations in the reinforcement. \( \alpha_i \) is the proportion of the fibres with the orientation \( \theta_i \).

For example in a ±45° bias fabric:

\[ \eta_o = 0.5 \cos^4(45°) + 0.5 \cos^4(-45°) \]

Equation 4 - Theoretical Orientation Factor Example

Another correction factor can be added assuming the fibre path is sinusoidal. This factor is shown in Figure 5 - Crimp Angle Correction Factor in the y axis of the graph it currently has no symbol.
Although in practice as much as there can be as much as a 40% decrease. \(^9\)

---

\(^9\) Formulae and graph from University of Plymouth - Composites Design and Manufacture – MATS 324 Lecture notes
Common Manufacturing Processes

When dealing with composites there are several factors to consider. It is important to envisage the design and manufacture in a different way than you would working with metals, plastics etc. It is much more important to think about the direction of stresses in the part. When using traditional materials the material is purchased and then shaped to create a part. With composites there is an extra stage; the raw components are used to create the material and part simultaneously. The result of this is that the manufacturer is in control of the strengths and stiffness in the required directions. They are also responsible for any voids and defects in the material, so it is very important that the process is not only well planned but also carried out in a methodical manner.

This section will discuss moulds and will describe manufacturing methods, three of which were tried throughout the course of this project.
Moulding and Moulds

When manufacturing composites a mould is usually used to shape the part. The most accurate surface is created on the face of the mould. This demonstrates the need both male and female moulds to manufacture a multitude of parts. For example if you are creating a part with a bearing housing then you would use a male mould so the surface is accurate and smooth to ensure a good fit for the bearing.
Above are renders of a male and female mould of a 2 part go-kart wheel. It can be seen that the male mould creates a good surface for a bearing housing (The bearing can be seen in Figure 9 - Kart Wheel Assembly) whereas the female mould would require post machining which can be a difficult process with composites.

You can see what the final part would look like below.

It is possible to create accurate surfaces on each side by using a process such as vacuum assisted resin transfer moulding (VARTM). This process among others will be described in the next section this report.
The Wet Lay Up

The wet layup is the oldest and most common process for laying up composites.

For a wet layup a mould, resin and fibre are required.

1. The first stage in this process is to prepare the mould, this is done first by cleaning it with compressed air or a brush and a solvent such as acetone on a soft cloth then applying a mould release, which in this test was a honey wax.

2. The second stage is to apply resin, then the reinforcement material. In the case of this project, woven fibreglass roving was used. Then more resin to wet any fibreglass that is still dry

3. Stage 1 and 2 are then repeated until the correct number of layers has been attained.

4. The third and final stage is to allow the resin to cure before releasing the piece from the mould.

This well documented process has been created to achieve the minimum of dry spots which can cause weaknesses in the finished component. However, it is unfortunately likely that there will still be several small bubbles and voids throughout part.
The Vacuum Infusion Process

The vacuum infusion process is considerably more complicated than a traditional wet layup. It is used mainly for larger parts, as well as parts where strength and weight are critical factors.\[^{10}\]

Figure 10 - Vacuum infusion Diagram\[^{11}\]

Figure 8 shows the different components in a vacuum infusion process.

The first stage in this process is the same as the wet layup, preparation of the mould. In the case of this project honey wax was used for this. I also covered the catch tank bowl so any excess resin could be easily removed. The catch tank is sit between the vacuum tube and pump, its job is to collect the excess resin and prevent it from reaching the pump where is could cause damage.

\[^{10}\] Engineered Materials Handbook Volume 1: Composites, published by ASM International

\[^{11}\] http://www.tygavac.co.uk/assets/images/infusion-diagram.jpg
The second stage is to lay the reinforcement material (dry) into the mould, 12 layers in total were used; six with 0/90° orientation and 6 of ±45°.

The third stage is to cut the peel ply, breather and vacuum bagging and trim them to the correct size. Then the fabric was arranged and stacked.
Resin channels consisting of spiral wrap, a T-joint and peel ply were laid and taped securely in place. The vacuum pipe is then attached and the breather cloth is laid on top and again securely taped down.

A perforated tube is then fed into the fold left in the breather cloth, this acts as the resin flow channel. Once the setup looks satisfactory the sealant tape is positioned and the vacuum bag can be stuck down.
Figure 19 - Inserting the Resin Tube

Figure 20 - Covering with Vacuum Bagging
The vacuum pump can now be turned on to test the system. Once it has been seen that the system reaches the correct pressure the vacuum hose is sealed off and the pump is turned off in order to search for any leaks. One is found in this test and is quickly repaired with some sealant tape.

![Figure 21 - Testing the Vacuum](image1)

![Figure 22 - Checking for Leaks](image2)

Resin can be now introduced into the system, this can take some time. Once the resin has saturated the part the resin pipe is sealed off. The part is left under vacuum to cure for the allocated time.

![Figure 23 - Starting the Infusion](image3)

![Figure 24 - Infusion Complete](image4)
The part is then removed from the mould and the vacuum system. It can be seen, the resin did not cover the whole part. This was due to two things; firstly the breather cloth was not very effective (in future layups a green plastic breather was used in conjunction to the white cloth). Secondly, the resin set too quickly, it can also be seen that the resin pot melted due to the exothermic reaction (Figure 24 - Infusion Complete), this shows too much hardener catalyst was used.

Figure 25 - Peeling Back the Vacuum bag
Figure 26 - The Part Shown

Once the part has been removed the covering can be discarded. Most of it cannot be used again as it is saturated with resin, but the spiral wrap and T-Junction can be recovered by soaking in pure acetone.

Figure 27 - Finished Part
Figure 28 - Consumables Waste
This process is more complicated than a wet layup but results in a part with a better strength to weight ratio as the fibre volume fraction of the part will be higher. Moreover, there are far less air bubbles and voids left in the part. The difficulty with this process is making sure there are no dry spots. As the resin will choose the easiest way to flow is quite possible that bits of the part will be missed out which will render the part useless.

**Autoclave Moulding**

Autoclave moulding is the same process used with any vacuum bag consolidation except the part is placed in an autoclave while still under vacuum to cure at high pressure. An autoclave is basically a high pressure oven or furnace, usually pressurised to 7 bar (reference?). This creates a higher pressure on the vacuum bag giving better consolidation and a higher fibre volume fraction. This process is commonly used for large structural components such as aircraft parts.

**Press Moulding**

![Figure 29 - Press Moulding](12 www.advanced-composites.co.uk)

Press moulding is effectively the same process as cold forming metal except the moulds are heated to cure the resin. This process is usually used with some form of prepreg material.

---

12 www.advanced-composites.co.uk
Pressure Bag Moulding

Pressure bag moulding is the opposite of vacuum bag consolidation. The process uses two or more female moulds clamped together. Material inside the moulds is pressed against the surface by an internal bladder system filled with air at a high pressure, commonly between 2 and 10 bar. This method has been used to create simple parts such as tubes and even complex trusses such as complete bicycle frames.

Filament Winding

A filament winding system is used to make pipes, pressure vessels, drive shafts and even objects as large as train bodies and sections of large aircraft fuselage. This is done by wrapping wet filaments round a mould in the case of pressure vessels and some other parts the mould becomes a component of the part as a whole, in other

13 www.advanced-composites.co.uk
14 Manufacturing of Polymer Composites, by B.T. Åströ
parts the mould can be reused. The process is usually computer controlled but some machines use a geared mechanical system.

**VARTM**

VARTM or vacuum assisted resin transfer moulding is similar to both plastic injection moulding and resin infusion moulding. It uses a mould with two halves, a male and a female. Reinforcement material is then placed between these two halves and trimmed to shape. The process after this point is the same as resin infusion moulding. The benefit of using a vacuum is that large expensive clamps and moulds are not need as the vacuum pressure holds the mould halves together. These moulds are usually made of thick fibreglass (5mm). This type of moulding creates a relatively low fibre volume content and is why it is not used for highly loaded structural parts.

**Pultrusion**

This manufacturing method is very similar to extrusion. It is used to produce commonly used beams and parts with regular cross sections. Common uses are I-Beams and large parts for bridges etc. The process is performed by dragging dry filaments through a bath of resin then out a heated die. This method has a very high production rate but difficulties in Pultrusion mean some resins require the addition of release agents; these can weaken the final product.

**The combined process**

Because of the weaknesses of both vacuum resin infusion and wet layups a new method for creating parts was developed. The technique is to create a wet layup with a generous amount of resin, then vacuum bag it to consolidate the layers and remove excess resin and air bubbles.
Using this process it is guaranteed to get a good saturation of resin throughout the part and the strength to weight ratio will benefit. The one downside that was found is that there is no chance to test the vacuum bag setup for air leaks before the resin is applied but this has not been a problem with testing so far in this project.
Common Testing

Fibre composites are a relatively new material, as such there is not the same large database of reliable material properties as is present for common metals in engineering. Therefor testing to generate a general properties database is a common task in composite engineering projects.

In most cases standard test methods used with metals cannot be used with composites. Groups such as ASTM (American Society for Testing and Materials) have developed and tuned standard test methods for composites.

The use of gauges and measuring techniques must also be modified for composite use. Gauges have been developed for use in metals which are isotropic and have a high thermal conductivity so do not take into account factors such as gauge-fibre misalignment, material anisotropy, material non uniformity and low thermal conductivity.

Recommended gauges types are liquid metal strain gauges (for high strain materials) and embedded fibre optics and methods such as moiré interferometry, shearography, and thermography can be sued for strain field measurement.

Similarly to metals, both destructive and non-destructive testing can be carried out. It can be difficult with composites to determine whether damage is cosmetic or critical, shearography, and thermography have the potential to be used non-destructively to determine without the calibration testing of ultrasonic and radiography.\(^\text{15}\)

\(^{15}\) Manual on Experimental Methods of Mechanical Testing of Composites, 2nd edition, edited by C.H. Jenkins you need to make sure all the references are at the end in the references section and also all the footnotes have the same font and size!
Figure 32 - Photoelastic Fringes Shown in Matrix by Isochromatic Photography

16 Applied Science and Manufacturing, Volume 36, Issue 2. F. Zhao, R. Martin, S. Hayes, E. Patterson, R. Young, F. Jones
An Introduction to Wheelchairs

As this project will conclude with the manufacture of a wheelchair this part will introduce and explore the anatomy and the uses of different types of chairs.

The final aim of this project is to manufacture a carbon composite wheelchair so we will firstly look at sports chairs as these are made to be light weight and tough, which are desirable attributes in all situations as they are easier to manoeuvre and less likely to be damaged. Secondly, three types of general every day chairs will be explored.

Sports Chairs

There are many wheelchairs available for specific purposes varying from tennis chairs which are lightweight and manoeuvrable but fragile, basketball chairs which whilst still relatively lightweight are tougher and Rugby chairs which are heavily armoured.

Figure 33 - Tennis Chair

---

In this project it is the aim is to produce a general purpose chair that is as light and manoeuvrable as possible but also rugged enough for day to day use.

Figure 34 - Basketball Chair

Figure 35 - Rugby Chair

18 http://www1.pictures.gi.zimbio.com/Paralympics+Day+10+Wheelchair+Basketball+4l8ZBtq4wGtl.jpg
19 http://www1.pictures.gi.zimbio.com/Paralympics+Day+10+Wheelchair+Basketball+4l8ZBtq4wGtl.jpg
General Wheelchairs

There are three main configurations of day to day use wheelchairs. In this part I will discuss the benefits of each type and choose the style best suited to this project.

**Fully Rigid**

The first type of chair is the fully rigid chair, this is the lightest of the three, but also the least portable, especially if it has high back support.

The only option to reduce the size of this chair is removal of the wheels.
Folding Back

The second type of chair is the semi foldable; this is where only the back folds down making it lighter than a fully folding chair but not as compact in its foldaway configuration.

There are two operations to collapse this chair

1. Fold down back support and wheel guards
2. Remove wheels

Figure 38 - Chair with Folding Back

Figure 39 - Chair with Folding Back, Back Folded
The final type of chair I will discuss is the fully folding chair. It is the most compact, but due to the folding mechanism is also the heaviest.

There are three operations to fold this chair,

1. Remove Wheels
2. Unlock and Fold down Back support and wheel guards
3. Unlock and Fold Frame
Each of these chairs also has the option of rear stabilisers, these reduce the chance of the chair toppling backwards this gives beginners more confidence but an experienced user is less lightly to need this option. These can also be rigidly attached or fold away.
Wheelchair Design

Wheelchair design depends primarily on the users’ abilities and requirements. For example, using a high or low back support is due to the point of paralysis of the user. Other considerations include adjustability; which consist of leg supports seat base and back angle, seat height, wheel camber and position.

The chair type recommended to move forward with this project would be the foldable back type. It is almost as compact as the fully folding but saves the weight of the folding mechanism which makes it only marginally heavier than the fully rigid. Moreover, it retains the rigidity of the fully rigid chair as the fully foldable mechanisms can have some play between the moving parts. When testing these chairs this play gave me an unsecure feeling similar to riding a bike with a flexible frame.
Wheelchair Design - Aspects and Standard Parts

Wheelchair wheels are held on by a quick release pin. These double as the wheel axels.

By having a negative camber on the wheels the wheelchair not only feels more stable but the bottom of the wheel will hit an object like a door frame before the user’s hand, avoiding painful hand jams.

By tucking the leg supports back behind the front wheel lets the user get closer to counter tops etc. and minimises any damage done to legs or feet by hitting objects.

Force testing etc. and other useful information can be found in the appendix.

21 http://www.assistireland.ie/eng/Information/Information_Sheets/Choosing_an_Attendant-Propelled_Wheelchair.html
Methodology

Any truss type of structure is made up of members. To simplify problems these members are usually looked at as pin jointed therefor the loads associated are that of a tie or of a strut. Of course in real life the members will also have to receive bending forces as loads are not always at nodes and forces moments at nodes occur. As a standard wheelchair or bicycle is basically a truss type frame testing tension and bending of composite tubes could be useful.

Unfortunately the equipment available would not allow for the bending of tubes, so a 3 point bend test was seen as a useful alternative.

It was also seen as useful to test different layup methods to compare characteristics.
Layup – specimen production

For the layup of the tube the combined layup method (talked about earlier) was used. For the mould a steel tube was polished, coated in release wax then coated in a PVC release agent. This method is not recommended as the composite tube is very difficult to release. Heating the steel tube internally melted the wax which loosened the composite but it still took about 2 hours to separate with the help of a friend. I believe if the part was cured in an oven or autoclave around aluminium the shrinkage of the aluminium once cooled would make the release much easier.

Figure 50 - Tube samples being manufactured

Once the tube was uncovered it was cut into sample lengths and steel inserts after having there surfaces roughed were glued in place. The adhesive used was araldite 2011.
The tube sample consisted of 5 plies of e-glass at a 0/90° orientation.

Two sets of the he 3 point bend specimens were produced; one using the combined layup method and the other under vacuum infusion. Each layup consisted of 6 plies of 0/90° and ±45° orientation E-glass and Fibre volume content was 65% for both. Specimens were then cut to size according to the 3 Point Bend Standard EN2746 for composites (attached in appendix).
Testing

The tensile tests on the tubes did not follow a standard but would later be compared to an abacus simulation.

The first tube test highlighted a major problem; when the test began to run instead of the clamp holding the specimen in place, it rose up and crushed the sample. This showed that the inserts were not strong enough to take the load. Another sample was tested grabbing the composite but the matrix was crushed and the sample slipped out. This problem was solved by machining solid steel inserts on a lathe to sit tightly into the ends of the tubes. Two inserts were made and reused successfully for each subsequent sample tested.

In total six samples were tested but two were wasted in the problem highlighted above. A 50KN load cell was used for the tests and the speed was set to 2mm per minute.

For the 3 point bend test the goal was to follow the 3 Point Bend Standard EN2746 for composites. Unfortunately the equipment available to me could not perform this test to the standards without special tooling being produced. This was because the rollers were too large. Smaller rollers were tried but the sample touched ended up supported by the roller clamp instead of the roller. It was decided to go ahead with the test using larger rollers as the results could still be compared and Abaqus simulation run.

![Image of 3 point bend test in progress]

Figure 52 - 3 point bend test in progress

Again six samples in total were tested, three from each layup technique. The test speed was 3mm/min
Design

Oven

While working through this project it became apparent that the ovens accessible in the mechanical engineering department at the University of Glasgow would not be large enough to cure a structure the size of a wheelchair. In this section it a design for a large low temperature collapsible oven will be demonstrated. This design is based on the oven shown in the book ‘An Introduction to Composites’ the design is completely scalable so can fit any size of part required.

The oven consists of 6 panels; a base, four walls and a roof. Each panel is made from 4 aluminium angle sections, a section of wood (coated with fire retardant paint) 2” insulation foam and wire mesh to hold the foam in place.

![Figure 53 - Oven Wall Section](image)

The panels are held together with toolbox style latches in order for ease of disassembly.
After receiving a quote from 'Watlow Electric Manufacturing it was clear that a professional heating solution would be beyond the budget of the project. Therefore, heating for the oven would be supplied by either a fan heater blowing through a hole in the side, or a set of heat lamps. A normal desk fan inside the oven would keep the air circulating and prevent any hot or cold spots. Digital kitchen thermometers would be used to check the temperature at various positions in the oven. A sample was obtained from a company based in china for less than £5 to test their accuracy. They were found to be accurate enough for the requirements of this project.

Feedback would be open loop and temperature controlled manually by adjusting by altering the current/voltage supplied to the headlamp or on the temperature dial of the fan heater.

It was decided (in discussion with my supervisor) it would be too costly and unnecessary to go ahead with the construction of the oven at the current time.
Bike

It was decided at this stage of the project a wheelchair would be too complex to model and construct so a more simple part was chosen; a bicycle frame.

Road Frame

To start with a model of a road bike was created, but we found that the frame mould tooling would be too large to machine in one go and it would not fit into any of our ovens to cure the resin. Below is a render of the frame designed in solid works. However, the idea was shelved just prior to finishing the model hence the lack of chain stays.

Figure 56 - Road Bike CAD
**Full Suspension Frame**

It was decided that a full suspension mountain bike frame was to be designed. These frames are smaller that road frames to begin with and as they are full suspension only the front triangle would need a mould. It was also thought that a full suspension bike would have more in common with a wheelchair as it will have moving parts and pivots which will have to be moulded into the composite.

The first thing that was done was to settle on the geometry for the frame. This was completed by comparing dozens of bikes already on the market, testing and reading reviews. Some of the components that would be used on the bike were then modelled, these were important for the geometry calculations, and for checking that no parts would collide during operation.

The bike was then modelled in solid works and with the help of this program, designed the suspension system.
Figure 57 - Solidworks Full Suspension Frame Sketches

The above figure shows all of the sketches and used to make up the frame and geometry; there are 33 separate sketches in this model all with references to each other and equations to set up the correct geometry’s.

I attempted to create a model with a high moment of area in order to create a stiff rigid frame hence the large diameter tubes. This helps transmit power more efficiently and feels more responsive to the rider.
A program called Linkage by racooz software was used to check the suspension design several iterations were required to achieve the final geometry. It was decided to use a high single pivot design early in the process. This design allows both wheels to take a similar path. (Axel path, Chain growth, Force curves and Geometry curves in appendix.)

![Linkage Model](image)

**Figure 58 - Linkage Model**

With the help of this program it was discovered that the chain growth was too large - optimal chain growth for a mountain bike is between 25-30mm through the entire range of its travel\(^23\) - currently chain growth in my model is 76mm. This will be resolved by placing an idle gear on the swing arm and running the chain over that. The optimum position of the idle gear was checked by creating sketches in SolidWorks and measuring the change in chain length in a simulation. The Balfa BB7 downhill bike uses a similar set up, although the idler is fixed around the main pivot of the swing arm.\(^24\)

\(^{23}\) D’ARCY O’CONNOR – Engineer at Rocky Mountain Bicycles

\(^{24}\) Balfa Bikes – Balfa BB7
From the CAD model two male mould models were created, one of each half of the bike. By using male moulds an accurate internal structure on the moulded part would be left, this would hopefully eliminate or at least reduce the need for post machining to accommodate any inserts.
CAD of Frame

Figure 61 - Frame Render 1

Figure 62 - Frame Render 2
Manufacturing

Mould making

The process to making the mould had many stages, firstly the block of ‘Ebaboard 60’ foam from Ebalta was cut to size to fit in the CNC milling machine (1000X500X50mm) the block was then clamped down and a rough cut was programmed and run. This process took roughly 3 days per side. The mould was then finish cut, this involved repeatedly passing the mould with the cutting bit in 0.5mm steps. This stage took about 7 hours per mould to complete.

Figure 63 - Machining Mould
Machining the foam left small tooling marks and ridges which could create stress concentrations on produced parts if left. These were sanded smooth. This process took about 2 hours per mould. Any holes were also filled and smoothed.

![Machined mould before sanding](image1)

![Holes Filled](image2)

The moulds were then covered in a coat of grey cellulose primer and left to dry overnight. Once dry they were wet sanded to remove any roughness and undesirable features. This took another 2 hours per mould. This process was repeated 3 times.

![Wet Sanding](image3)

![Fully Primed](image4)
Finally the mould was painted with a high gloss black acrylic paint and polished. The total time for post machining process was 10-12 hours labour broken up by 4 days of drying time. Here you can see the 2 moulds one finished and one about to go through the post machining process.

An additional day of work had to be performed on the left hand side mould as a programming error damaged a large section of the mould. This can be seen in the picture below.
To fix this car body filler was used to rebuild the feature. This was done in 5 stages.

1. A piece of thin flexible birch wood was covered in tape and shaped around the missing feature.
2. The base was filled with car body filler.
3. The feature was built up to height.
4. A piece of wood was cut to shape and used to top the feature.
5. Once the rough shape was built up it was refined by chiselling and sanding.

The fix can be seen beside the finished mould in Figure 69 - Mould Comparison.
Frame Manufacture

The bike frame will be made in two halves from unidirectional carbon fibre and epoxy resin. The moulded halves will be glued together clamped by the flange left from moulding. Inserts and ribs will guarantee the alignment of the two halves. Once the adhesive has set the flange will be trimmed off and a final covering of 2x2 twill weave carbon will be applied this will reinforce the joint and help stiffen the bike in torsional.

Results

Testing

It was decided that two physical tests would be performed and results compares to Abaqus FEA simulations. The first test that was performed was a 3 point bend test. (Standards in appendix) 3 Point Bend

For this test two different layup methods were compared, first to each other, then to the Abaquis simulation. The weights of the samples are near identical (±2%).

![3 Point Bend - Vacuum Consolidation](image)

*Figure 77 - 3 Point Bend, Vacuum Consolidation Test Results*
As you can see by the graphs there is a slight difference of stiffness (about 5%) also the ultimate tensile strength is higher on average in the vacuum infusion test. I believe this is due to differences in the samples and not due to the layup process as the resin was mixed separately so may have slightly different characteristics. Of course I cannot say this for certain without further testing. Sample 3 on the first chart may also have been slightly damaged as it had been scored when inserting it into the machine.

**Figure 78 - 3 Point Bend, Vacuum Infusion Test Results**
As mentioned before unfortunately the equipment available was unable to match the 3 Point Bend Standard EN2746 for composites as the rollers available were too large and the samples were slightly undersized. But an Abaqus simulation could still be run.

### Tensile Test on Tubes.

The second test that was performed was a tensile test on tubes.

### Specimen Testing

There were a number of issues with these tests as you can see below.
Test 1 was crushed by the jaws of the clamp. This problem was addressed by pressing solid inserts into the thin metal inserts already attached. In test 5 was the attempt to clamp the composite directly instead of the insert the displacement shown is the sample slipping. The trend equation shown is modified as the line does not cross the Y axis at 0 as it should. The curve at the base is the machine overcoming the play in the clamps.
Hand Calculations

**Equation 5 - Stress Equation**

\[ \sigma = \frac{F}{A} \]

**Equation 6 - Stress Calculation**

\[ \sigma = \frac{10000}{0.001 \times \pi \times 0.038} \]

**Equation 7 - Stress**

\[ \sigma = 126 \times 10^6 \]

**Equation 8 - Strain Equation**

\[ e = \frac{\delta \ell}{\ell} \]

**Equation 9 - Strain Calculation**

\[ e = \frac{0.0034}{0.1} \]

**Equation 10 - Strain**

\[ e = 0.04 \]

**Equation 11 - Young’s Modulus Equation**

\[ E = \frac{\sigma}{e} \]

**Equation 12 - Young’s Modulus Calculation**

\[ E = \frac{81.6 \times 10^6}{0.034} \]

**Equation 13 - Young’s Modulus**

\[ E = 2.401 \times 10^9 \]
The maximum displacement of the model was just $1.43 \times 10^{-2} \text{m}$. 

Figure 81 - FEA on 3 point bend
Tensile Test on Tube

Figure 82 - FEA Tensile Test on Tube

The maximum displacement of the model was $3.3 \times 10^{-6} \text{m}$
Discussion and Conclusions

Discussion of results

3 Point Bend Test

The displacement of the Abaqus simulation is out by a factor of about 3 in comparison to the testing carried out. This is likely due to the following factors; In the Abaqus simulation there is no factor to account for voids and air bubbles, the simulation also assumes perfect adhesion between plies, finally the simulation does not run with a woven cloth, instead the interwoven fibre directions are split up and modelled as separate plies.

Tensile Test on Tube

As you can see the results of the hand calculation physical test and Abaqus simulation are out by a number of magnitudes. It is believed this is likely due to an error while programming the simulation. If these magnitudes can be attributed to some sort of scaling issue then the results are very similar. In the Abaqus model the woven roving was split up into a 0° and 90° ply. This is because the simulation would be far more complicated and way beyond the scope of this report to run with a woven fabric. Other than the error in magnitude, this is thought to be the main reason for the simulation model results showing a stiffer part. Also the Abaqus model and hand calculations do not take into account voids and air bubbles in the part which could affect the parts stiffness.
Conclusions

This project has given a brief introduction and overview of composites; it has touched upon manufacture design and testing.

It has established an understanding of wheelchairs and reviewed what is currently on the market. By doing this a solid platform of knowledge has been created which will allow for the future design to begin swiftly.

It has also physically experimented with a number processes and advanced manufacturing techniques with composites including wet lay-up, vacuum resin infusion and a combined process and settled on a recommended method of part production.

FEA has been used to model simple composite structures and compared to written calculations and physical testing. This has shown the importance of physical testing in order to validate or devaluate computerised simulations.

Finally this project has gone through the design and manufacture process of producing tooling to create a composite bicycle frame.

Unfortunately the manufacture of the frame was not completed by the end of this project, this was due to unforeseen delivery times, machining and preparation time of the moulds which took well over a month.

With more time on this project further testing and comparisons would have been performed to get a more accurate result.

Also with a larger allowance of pages a more detailed report on the design process would have been written.
Bibliography

-The Behavior of Sandwich Structures of Isotropic and Composite Materials, by Jack R. Vinson

-Wheelchair Selection And Configuration – Rory A. Cooper PH.D.


-Engineering Mechanics of Composite Materials by Isaac M. Daniel

-The Behavior of Structures Composed of Composite Materials by J.R. Vinson and R.L. Sierakowski

-Materials Selection in Mechanical Design 3rd Edition by Michael F. Ashby

Analysys and Performance of Fibre Composites by Bhagwan D. Agarwal and Lawrence J. Broutman

-Composite Basics – 5, by Andrew C. Marshall


-Composites for Automotive Applications, by C.D. Rudd

- An Introduction to Composite Products: Design, Development, and Manufacture, by Kevin Potter, published by Chapman & Hall, 1997,

-Theory of Composites Design, by Stephen W. Tsai, published by THINK Composites, 1992,


Appendices
1 - Mechanical loads

The aim of this project was to develop an extreme lightweight and perfect fitted wheelchair. For the optimum dimensioning it is necessary to know as much as possible about the mechanical loads. To learn more about the load types, several wheelchair users were accompanied during their daily routine. As a first result it can be said, that the maximum (impact) load was caused by the jump off the kerb [VCRB1] (Figure 1). The height of a standard kerb according to DIN EN 1340 and DIN EN 483 is about 120 mm. To simulate the jump off the kerb a vertically adjustable stage (100-440 mm) was built. To collect the data (vertical force) a Kistler load cell was used (Figure 2).

Two wheelchair users were recruited, a male and a female. Tyres, pressure of the tyres and height of the stage were changed. Before the dynamic test the static loads and the load distribution were measured (Table 1). The biggest part of the static loads was found on the rear wheels (77-93%). To determine the dynamic loads in connection with the stage height, the subjects were instructed to do five jumps from 100 mm, 200 mm and 300 mm stage height. The male subject, the winner of three gold medals at the paralympic winter games in Torino 2006, the professional monoski rider Martin Braxenthaler was able to jump off 440 mm, so that it was possible to get extreme data.

Figure 1 - Jump off the kerb.

Figure 2 - Kistler load cell.
2- Measurement and adaptation process

Normally the fitting process and the selection of a wheelchair result from the measurement of body data [HLMSZW1]. The advisor measures the femoral and lower leg length and some more body data and selects the wheelchair model and size. Rarely it is possible for the customer/patient to try the selected wheelchair to check the seating position and the driving behaviour. In many cases it is impossible to change the seating position without changing the driving behaviour. The perfect wheelchair offers the optimum seating position, an adequate driving behaviour and minimum weight. To achieve the aim of the best possible seating position and driving behaviour a multi adjustable measurement/fitting wheelchair has been developed. The measuring/fitting chair was realized as a lightweight construction. To be as close as possible to the geometry and handling behaviour of the customised wheelchair, the same moulded CFRP-parts has been used. With the new measuring/fitting wheelchair (Figure 5) it is possible, to adapt and optimize the seating position separately from the driving behaviour. An enormous advantage is that the customer can feel the seating position and check it with his therapist concerning to medical requirements. The customer can also verify the driving behaviour, especially the break over characteristics.
Table 1 - Wheelchair characteristics and static loads.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Tyres</th>
<th>Vertical force</th>
<th>Vertical force</th>
<th>Vertical force</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>[N]</td>
<td>rear wheels</td>
<td>front wheels</td>
</tr>
<tr>
<td>1 (female, rigid)</td>
<td>Schwalbe Marathon Plus 26x1.95 (599), 8 bar</td>
<td>813</td>
<td>688 (77.7%)</td>
<td>197 (22.3%)</td>
</tr>
<tr>
<td>2 (male, rigid)</td>
<td>Schwalbe Racing Ralph 26x2.1 (599), 2.4 bar</td>
<td>618</td>
<td>800 (90.6%)</td>
<td>53 (6.1%)</td>
</tr>
<tr>
<td>2 (male, foldable)</td>
<td>Schwalbe Marathon Plus 26x1.95 (599), 8 bar</td>
<td>924</td>
<td>834 (90.3%)</td>
<td>90 (9.7%)</td>
</tr>
</tbody>
</table>

The vertical force is about 2300-2500 N caused by the jump off the kerb. With a 200 mm stage height the vertical force is higher than 3800 N. The maximum force was collected at 440 mm stage height (5000 N), Figure 3 shows the results of the measurements.

![Dynamische Kraftermittlung der Hinterräder](image)

Figure 3 - Vertical force in connection to stage height.

Further dynamic loads appear as a result of collisions between barriers and the front wheels (Figure 4). Depending on the moving direction the collisions between barriers and the front wheels involves planar stresses or torsion in the structure. Simulations of the collisions between barriers and the front wheels were realized by the fixation of different rails (20 mm and 30 mm). To determine the dynamic loads in connection with the rail height, the subjects were instructed to do five high speed collisions (straight and rotating) with 20 mm and 30 mm rail height. The maximum horizontal force (straight collision) is about 2500 N.
Project Joker Carbon Wheelchair
Bike Graphs

Magnified Axle Path
Untitled

Y (mm)

X (mm)
Chain extension
Untitled

Wheel travel (mm)
These curves are not true to real life as the suspension shock I am using has an exponential spring rate. This should compensate for the falling rate shown by the graph. Also the spring rate is set at 400Lbs and cannot be changed as this is a demo version of the program.
3 Point Bend Tests

Standard

BRITISH STANDARD AEROSPACE SERIES

Glass fibre reinforced plastics — Flexural test — Three point bend method

The European Standard EN 2746:1998 has the status of a British Standard
National foreword

This British Standard is the English language version of EN 2746:1998.
The UK participation in its preparation was entrusted to Technical Committee
AC2/04, Aerospace structural reinforced plastics, which has the responsibility
to:
— aid enquirers to understand the text;
— present to the responsible international/European committee any
enquiries on the interpretation, or proposals for change, and keep the UK
interests informed;
— monitor related international and European developments and
promulgate them in the UK.

A list of organizations represented on this committee can be obtained on
request to its secretary.

Cross-references

The British Standards which implement international or European
publications referred to in this document may be found in the BSI Standards
Catalogue under the section entitled “International Standards Correspondence
Index”, or by using the “Find” facility of the BSI Standards Electronic
Catalogue.

A British Standard does not purport to include all the necessary provisions of
a contract. Users of British Standards are responsible for their correct
application.

Compliance with a British Standard does not of itself confer immunity
from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages 1 and ii,
the EN title page, pages 2 to 6 and a back cover.

This standard has been updated (see copyright date) and may have had
amendments incorporated. This will be indicated in the amendment table on
the inside front cover.

Amendments issued since publication

<table>
<thead>
<tr>
<th>AMD. No.</th>
<th>Date</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Contents

<table>
<thead>
<tr>
<th>National foreword</th>
<th>Inside front cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foreword</td>
<td>2</td>
</tr>
<tr>
<td>Text of EN 2746</td>
<td>3</td>
</tr>
</tbody>
</table>
EN 2746
August 1998

Aerospace series — Glass fibre reinforced plastics — Flexural test — Three point bend method

This European Standard was approved by CEN on 15 May 1996.
CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

CEN
European Committee for Standardization
Comité Européen de Normalisation
Europäisches Komitee für Normung

Central Secretariat: rue de Stassart 36, B-1050 Brussels

© 1996 CEN All rights of exploitation in any form and by any means reserved worldwide for CEN national Members.
Ref. No. EN 2746:1998 E
EN 2746-1998

Foreword

This European Standard has been prepared by the European Association of Aerospace Manufacturers (AECMA).

After inquiries and votes carried out in accordance with the rules of this Association, this Standard has received the approval of the National Associations and the Official Services of the member countries of AECMA, prior to its presentation to CEN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by February 1999, and conflicting national standards shall be withdrawn at the latest by February 1999.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

Contents

<table>
<thead>
<tr>
<th>Contents</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foreword</td>
<td>2</td>
</tr>
<tr>
<td>Scope</td>
<td>3</td>
</tr>
<tr>
<td>Normative references</td>
<td>3</td>
</tr>
<tr>
<td>Definitions</td>
<td>3</td>
</tr>
<tr>
<td>Principle</td>
<td>3</td>
</tr>
<tr>
<td>Apparatus</td>
<td>3</td>
</tr>
<tr>
<td>Specimens</td>
<td>4</td>
</tr>
<tr>
<td>Procedure</td>
<td>4</td>
</tr>
<tr>
<td>Expression of results</td>
<td>5</td>
</tr>
<tr>
<td>Test report</td>
<td>6</td>
</tr>
<tr>
<td>Figure 1 — Detail of test apparatus</td>
<td>4</td>
</tr>
<tr>
<td>Figure 2 — Force/deflection curve</td>
<td>5</td>
</tr>
</tbody>
</table>
1 Scope
This standard specifies the three point bend method for the determination of the flexural properties of glass fibre reinforced plastics for aerospace applications.

2 Normative references
This European Standard incorporates by dated or undated reference provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.
EN 2374, Aerospace series — Glass fibre reinforced mouldings and sandwich composites — Production of test panels.
EN 3488, Aerospace series — Fibre reinforced plastics — Determination of the action of liquid chemicals.
EN 2743, Aerospace series — Reinforced plastics — Standard procedures for conditioning prior to testing[1].
EN 2883, Aerospace series — Fibre reinforced plastics — Test method for the determination of the effect of exposure to humid atmosphere on physical and mechanical characteristics[1].

3 Definitions
For the purpose of this standard the following definitions apply:
3.1 deflection
the distance travelled during the test by a point on the upper or lower face of the specimen at the centre of its span measured from its initial position
3.2 conventional deflection
unless otherwise specified, a deflection equal to 1,5 times the specimen thickness
3.3 flexural stress
the stress at the surface of the material in the middle of the span of the specimen between the supports at any time during the test
3.4 flexural strength
flexural stress at the moment when the applied force reaches the maximum value
3.5 flexural stress at failure
flexural stress at the moment of failure of the specimen
3.6 flexural modulus
slope of the tangent at the origin of the stress/strain curve calculated from the force/deflection recording

4 Principle
The method consists of the measurement of the deflection at the central loading nose as a function of the applied force during a flexural test carried out at constant speed until failure occurs. The strain parallel to the specimen length is calculated as a function of the applied flexural stress.

The following properties may be determined:
— flexural stress and deflection at failure of specimens which break before or on reaching conventional deflection;
— flexural stress at conventional deflection of specimens which break beyond conventional deflection;
— flexural strength of specimens which reach maximum load before or at conventional deflection;
— flexural strength or flexural stress at failure if this is required by the material standard;
— flexural modulus.

NOTE The flexural modulus is only an approximate value of YOUNG’s modulus of elasticity.

5 Apparatus
A test machine, allowing relative displacement of the loading nose with respect to the supports at a constant speed, and indicating forces to ± 1 % and deflections to ± 2 %.
The supports and the loading nose shall be at least as wide as the specimen and shall be parallel to one another.
The radius, \( r_1 \), of the loading nose and the radius, \( r_2 \), of the supports shall be as follows:
\[ r_1 = (5 \pm 0.1) \text{ mm}; \]
\[ r_2 = (2 \pm 0.2) \text{ mm}. \]
It shall be possible to adjust the span (see Figure 1).

[1] Published as ABIUMA Preliminary at the date of publication of the present standard.
6 Specimens

6.1 Dimensions
- Thickness "h": (3 ± 0.2) mm
- Width "b": (15 ± 0.5) mm
- Length "L": [(200 ± 1) mm]

NOTE: If it is impossible to obtain specimens from the finished component, prepare test pieces according to EN 2374 or to a suitable method by agreement between the parties concerned.

If it is necessary to use a thickness of specimen greater than 3 mm or if a failure in compression is expected, the radius of the supports may be increased on condition that:

\[ r_2 = 1.5 \times h \]

6.2 Number
Minimum of five.

7 Procedure

7.1 Conditioning
EN 2748 for tests in the initial state.
EN 2489 for tests after immersion.
EN 2823 for tests after exposure to humid atmosphere.

7.2 Specimen measurement
In the central section of the specimen, measure the width \( b \) to ± 0.1 mm, then make three measurements of the thickness \( h \) to ± 0.02 mm and calculate their arithmetic mean.

7.3 Support span
Adjust the span, \( L \), to comply with the following equation:

\[ L = (10 \times h) + 1 \]

where:
- \( L \) is the span, in millimetres;
- \( h \) is the thickness of the specimen, in millimetres.

Measure the span to ± 0.5 %.

7.4 Test speed
Set the test machine to the speed \( V \), according to one of the following:
- \( V \) is specified;
- the rate of strain is specified;
- calculate \( V \):

\[ V = \frac{Sr \cdot r^2}{6 \times h} \]

where:
- \( V \) is the test speed, in millimetres per minute;
- \( Sr \) is the rate of strain, in units per minute;
- \( r \) is the span, in millimetres;
- \( h \) is the thickness of the specimen, in millimetres.
If there is no requirement, calculate $V$:

$$V = K \times h$$

where:

- $V$ is the test speed, in millimetres per minute;
- $h$ is the thickness of the specimen, in millimetres;
- $K = 0.5$ mm min$^{-1}$.

### 7.5 Test atmosphere

Carry out the tests at $(23 \pm 2)$ °C and $(50 \pm 5)$ % relative humidity.

### 7.6 Tests

Position the specimen symmetrically with respect to the supports, ensuring that its length is perpendicular to these supports. Ensure that the loading nose is placed exactly in the middle of the span and apply force at a constant speed, avoiding shock loading.

The force and deflection shall be simultaneously recorded.

Note the values of the required characteristics:
- at conventional deflection;
- at maximum force;
- at failure.

### 8 Expression of results

#### 8.1 Flexural stress

$$\sigma_f = \frac{3FL}{2bh^2}$$

where:

- $\sigma_f$ is the flexural stress, in megapascals;
- $F$ is the force applied, in newtons;
- $L$ is the span, in millimetres;
- $b$ is the width of the specimen, in millimetres;
- $h$ is the thickness of the specimen, in millimetres.

**Note**: A more precise calculation of the flexural stress takes into account the horizontal component of the flexural moment:

$$\sigma_f = \frac{3FL}{2bh^2} \left(1 + \frac{4d^2}{h^2}\right)$$

where:

- $d$ is the deflection, in millimetres.

#### 8.2 Flexural modulus

Examine the force/deflection curve and determine the modulus from the initial rectilinear part, using at least five points.

If the initial part of the curve is not linear, then a straight line shall be drawn between 10 % and 25 % of the maximum force, see Figure 2.

![Figure 2 — Force/deflection curve](image)
$E_t = \frac{L}{4bth^3} \frac{\Delta F}{\Delta d}$

where:

$E_t$ is the modulus, in megapascals;
$L$ is the span, in millimetres;
$b$ is the width of the specimen, in millimetres;
$h$ is the thickness of the specimen, in millimetres;
$\Delta F$ is a chosen difference in force, in newtons;
$\Delta d$ is the difference in deflection corresponding to the difference in force $\Delta F$, in millimetres.

9 Test report

It shall include the following:

— number of this standard;
— all data ensuring the traceability of the material (trade mark, identification marking, date of receipt, batch number, etc.);
— all information regarding specimen preparation;
— specimen dimensions;
— span;
— radius of supports if it differs from 2 mm;
— test conditions;
— exposure time at the test temperature;
— specimen face in contact with the loading nose;
— test speed;
— force/deflection curve;
— flexural stress at conventional deflection;
— flexural strength;
— flexural stress at failure and mode of failure;
— flexural modulus;
— individual values, arithmetic mean and standard deviation of results of tests or retests (if applicable);
— any incident which may have affected the results.

8.3 Modes of failure

During the flexural test, three different modes of failure may occur:
— failure initiated at the surface by the tensile stresses;
— failure initiated at the surface by the compression stresses;
— internal failure due to the shear stresses.

For each specimen, indicate the mode(s) of failure.

If the modes of failure of specimens of the same set are different, the calculated values of the flexural stress are no longer statistically homogeneous and great care is needed in the evaluation of the results. If specimens fail in an area other than the area of the loading nose, the results shall not be taken into consideration. Carry out a set of retests in this case.
BS EN
2746:1998

BSI — British Standards Institution

BSI is the independent national body responsible for preparing
British Standards. It presents the UK view on standards in Europe and at the
international level. It is incorporated by Royal Charter.

Revisions

British Standards are updated by amendment or revision. Users of
British Standards should make sure that they possess the latest amendments or
editions.

It is the constant aim of BSI to improve the quality of our products and services.
We would be grateful if anyone finding an inaccuracy or ambiguity while using
this British Standard would inform the Secretary of the technical committee
responsible, the identity of which can be found on the inside front cover.
Tel: 020 8996 9000, Fax: 020 8996 7400.

BSI offers members an individual updating service called PLUS which ensures
that subscribers automatically receive the latest editions of standards.

Buying standards

Orders for all BSI, international and foreign standards publications should be
addressed to Customer Services. Tel: 020 8996 9001, Fax: 020 8996 7001.

In response to orders for international standards, it is BSI policy to supply the
BSI implementation of those that have been published as British Standards,
unless otherwise requested.

Information on standards

BSI provides a wide range of information on national, European and
international standards through its Library and its Technical Help to Exporters
Service. Various BSI electronic information services are also available which give
details on all its products and services. Contact the Information Centre.
Tel: 020 8996 7111. Fax: 020 8996 7048.

Subscribing members of BSI are kept up to date with standards developments
and receive substantial discounts on the purchase price of standards. For details
of these and other benefits contact Membership Administration.
Tel: 020 8996 7002, Fax: 020 8996 7061.

Copyright

Copyright subsists in all BSI publications. BSI also holds the copyright, in the
UK, of the publications of the international standardization bodies. Except as
permitted under the Copyright, Designs and Patents Act 1988 no extract may be
reproduced, stored in a retrieval system or transmitted in any form or by any
means – electronic, photocopying, recording or otherwise – without prior written
permission from BSI.

This does not preclude the free use, in the course of implementing the standard,
of necessary details such as symbols, and size, type or grade designations. If these
details are to be used for any other purpose than implementation the prior
written permission of BSI must be obtained.

If permission is granted, the terms may include royalty payments or a licensing
agreement. Details and advice can be obtained from the Copyright Manager.
Tel: 020 8996 7070.
Fibre Volume fraction and other Calculations

Fibre Volume Fraction

known Resin Weight

Inputs:
known Part Weight

Inputs:
Fibre Weight (g/m^2) 160
Fibre Weight (g/m^2) 160

m^2 used 0.135
m^2 Used 0.135

Fibre weight in part 21.6
Fibre weight in part 21.6

Fibre Density (g/m^3) 2550000
Fibre Density (g/m^3) 2550000

Part Weight 48.6263
Matrix Weight (g) 27
Matrix Weight (g) 27.0263

Matrix Density (g/m^3) 1090000
Matrix Density (g/m^3) 1090000

Fibre Volume Fraction 65.18%
Fibre Volume Fraction 65.15%

Generalised Rule of Mixtures

Young's Modulus of Fibres 7.24E+10
Young's Modulus of Fibres 7.24E+10

ƞ

O

Force N 10000

Young's Modulus of Resin 3.80E+09
Young's Modulus of Resin 3.80E+09

Unidirectional 1
Biaxial 0.5
Biaxial at ±45° 0.25

ƞ

L

1

ƞ

L

0.5

Random (in-plane) 0.38
Random (3D) 0.2

ƞ

O

1

ƞ

O

0.5

Change in Length 0.0034

Young's Modulus 4.14E+10
Young's Modulus 2.49E+10

Strain 0.034

E 2.4E+09
Materials
1. CHEMICAL PRODUCT AND COMPANY INFORMATION

PRODUCT NAME: ENCORE 30
SDS NUMBER: STU0009
INTENDED USE AREA: PRODUCTION OF FIBRE REINFORCED COMPOSITES
SUPPLIER OR COMPANY NAME: CRAY VALLEY LTD.
FULL ADDRESS: LAPORTE ROAD, STALLINGBOROUGH, NORTH EAST LINCOLNSHIRE, DN41 8DR. UNITED KINGDOM
TELEPHONE: +44 (0) 1469 551035
FAX: +44 (0) 1469 571007
INTERNET: http://www.crayvalley.com

URGENCE / EMERGENCY / EMERGENCIA / NOTRUFNUMMER / N° 24/24

<table>
<thead>
<tr>
<th>Pays / Countries / Pays / Länder</th>
<th>Tel.</th>
</tr>
</thead>
<tbody>
<tr>
<td>DK, FI, FR, DE, IE, IT, LU, NL, NO, PT, ES, SE, BE, GB</td>
<td>+800 76676600</td>
</tr>
<tr>
<td>AT, TR, CH, RO, BG, AL, BA, HR, HU, SI, YU, MK</td>
<td>+49 99 45580 921</td>
</tr>
<tr>
<td>BY, CZ, SK, EE, LV, LT, MD, RU, PL, UA</td>
<td>+420 2 2188 0618</td>
</tr>
<tr>
<td>GR</td>
<td>+30 2 10 42 95 878</td>
</tr>
</tbody>
</table>

2. COMPOSITION / INFORMATION ON INGREDIENTS

PREPARATION / CHEMICAL NAME OR GENERIC NAME: Unsaturated Polyester Resin in Styrene

COMPONENTS OR IMPURITIES CONTRIBUTING TO HAZARDS:

Styrene
Symbols: Xn
Risk Phrases: R10, R20, R36/R38
Typical Concentration Range: 40 – 45 %

Cobalt Octoate
Symbols: XI
Risk Phrases: EINECS No: 202-851-5
CAS No: 100-42-5
Typical Concentration Range: 40 – 45 %

Phthalic Anhydride
Symbols: Xn
Risk Phrases: EINECS No: 201-607-5
CAS No: 85-44-9
Typical Concentration Range: 0.05-0.2 %

See section 16 for explanation to R-phrases
SAFETY DATA SHEET

3. HAZARDS IDENTIFICATION

SPECIFIC HAZARDS
Harmful by inhalation. Irritating to eyes and skin. May produce an allergic reaction

PHYSICAL AND CHEMICAL HAZARDS
Flammable
The mixture of product vapour and air could be explosive
Strongly exothermic polymerisation may be initiated by heat, peroxides or other free radical generators.

4. FIRST AID MEASURES

INHALATION
Remove patient from affected area and make rest.
Give oxygen in case of breathing difficulty.
Call emergency medical care.

SKIN CONTACT
Wash thoroughly with soap and water. Remove all contaminated clothing.

EYE CONTACT
Wash immediately (15 min) with water, opening eyelids.
Call emergency medical care.

INGESTION
DO NOT induce vomiting. Seek immediate medical advice.

5. FIRE FIGHTING MEASURES

EXTINGUISHING MEDIA SUITABLE
Carbon dioxide / Foam / Powdered Sand / Pulverised water

NOT SUITABLE
Water jet

PROTECTION OF FIRE FIGHTERS
Wear individual breathing apparatus

SPECIFIC HAZARDS
Formation of toxic products on combustion including carbon monoxide

SPECIFIC METHODS
Cool the container with sprayed water to avoid polymerisation
Eliminate all sources of combustion

OTHERS
Treat as hydrocarbon fire
Limit spreading of extinguishing fluids

6. ACCIDENTAL RELEASE MEASURES

PERSONAL PRECAUTIONS
Wear protective equipment: Gloves-Goggles-Boots
Avoid inhaling vapours. Wear self-contained breathing apparatus

ENVIRONMENTAL PRECAUTIONS
Do not discharge into sewers / Do not allow entry to the environment
If the product contaminates water-courses, inform the Environment Agency

METHODS OF CLEANING UP

RECOVERY
Spread sand
Collect the product in a container pending future destruction
SAFETY DATA SHEET

DISPOSAL
Burn in an approved installation
INCOMPATIBLE MATERIALS
Wood, sawdust

7. HANDLING AND STORAGE

HANDLING
Do not store beyond shelf life

PREVENTION OF WORKER EXPOSURE
Efficient ventilation is required in the working area. Collect emissions at source

NO SMOKING

PREVENTION OF FIRE AND EXPLOSION
Take precautionary measures against static discharges
Close containers after use.

STORAGE
Stable under normal storage conditions.

STORAGE CONDITION SUITABLE
Keep container tightly closed in a cool, well ventilated location
Keep at temperature not exceeding 35°C.

STORAGE CONDITION TO AVOID
Keep container out of sunlight.
Keep away from heat.
Keep away from sources of ignition - NO SMOKING
Do not transfer to other containers.

INCOMPATIBLE MATERIALS
Keep container away from oxidising materials.

8. EXPOSURE CONTROLS / PERSONAL PROTECTION

OCCUPATIONAL EXPOSURE LIMITS (MEL - TWA, MEL - STEL)
Registry (UK HSE EH 40 - 2002)
8 hours (MEL = TWA)
100 ppm 430 mg/m³
250 ppm 1080 mg/m³
Phthalic Anhydride (UK HSE EH 40 - 2002)
8 hours (MEL = TWA)
4 mg/m³ 
Short Period - 15 min (MEL = TWA): 12 mg/m³

PERSONAL PROTECTIVE EQUIPMENT (Ref. CEN Dir. 89/686)
RESPIRATORY PROTECTIVE EQUIPMENT
Do not breathe vapours
In case of insufficient ventilation, wear suitable respiratory equipment. Air-fed face mask recommended

HAND PROTECTION
Wear solvent-proof gloves. Neoprene gloves recommended

EYE PROTECTION
Wear a face-shield or chemical goggles. Contact lenses should not be worn.

SKIN AND BODY PROTECTION
Wear impermeable apron.

SPECIFIC HYGIENE MEASURES
When using do not eat, drink or smoke
Remove working clothes after work.

9. PHYSICAL AND CHEMICAL PROPERTIES

APPEARANCE
PHYSICAL STATE
Dioctyl phthalate
COLOUR
Pink
SAFETY DATA SHEET

ODOUR
Aromatic

SPECIFIC TEMPERATURES

BOILING POINT OR RANGE
2145°C

RISK OF FIRE OR EXPLOSION

FLASH POINT
31 °C (EN 22719)

AUTO IGNITION TEMPERATURE(*)
498°C

EXPLOSIVE OR FLAMMABLE LIMITS IN AIR / %(*)
Lower : 1.1
Upper : 6.1

VAPOUR PRESSURE(*)
6.52 hPa at 20 °C

DENSITY

RELATIVE DENSITY (WATER)
1.05 • 1.2 (Typical Values)

SOLUBILITY

IN WATER
Insoluble in water.

IN ORGANIC SOLVENTS
Soluble in aromatic solvents.

Typical Viscosity 2.3 - 2.7 mPa.s (@25°C)
(*) these values are referred to the used solvent and not to the preparation.

10. STABILITY AND REACTIVITY

STABILITY
Stable under normal storage conditions.

CONDITIONS TO AVOID

Light / Heat / Sources of ignition

HAZARDOUS REACTIONS WITH
Exothermic polymerisation may occur with strong oxidising agents / peroxides

11. TOXICOLOGICAL INFORMATION

SENSITISATION
May produce an allergic reaction due to phthalic anhydride and cobalt octoate

SKIN IRRITATION
Irritating to the skin.

EYE IRRITATION
Irritating to the eyes.

INHALATION

Hazards by inhalation
Specific symptoms include headaches, dizziness, tiredness

12. ECOLOGICAL INFORMATION

PERSISTENCE / DEGRADABILITY
Styrene is readily biodegradable.

POSSIBLE ENVIRONMENTAL IMPACT / ECOTOXICITY
Do not discharge into drains or the environment, dispose at an authorised waste collection point

13. DISPOSAL CONSIDERATIONS

MEASURES FOR DISPOSAL
SAFETY DATA SHEET

Incompatible with water, alkalis and oxidizing agents.

Crushing the mixture when the solid proportion is high may cause dust explosion

This material and its container must be disposed of as hazardous waste

DESTROYING PROCEDURE OF CONTAMINATED PACKAGING

Cleaned packaging may be recycled.

Contaminated packaging must be disposed of as hazardous waste

14. TRANSPORT INFORMATION

SEA (IMDG)

<table>
<thead>
<tr>
<th>Proper shipping name</th>
<th>UN No</th>
<th>IMDG Class</th>
<th>IMDG Packing group</th>
<th>EMS No</th>
<th>Marine Pollutant (P or PP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resin Solution, Flammable</td>
<td>1856</td>
<td>3</td>
<td>III</td>
<td>F-E, S-E</td>
<td>no</td>
</tr>
</tbody>
</table>

AIR (ICAO / IATA)

<table>
<thead>
<tr>
<th>UN / ID No</th>
<th>Proper shipping name</th>
<th>IATA / ICAO Class</th>
<th>IATA-ICAO packing group</th>
</tr>
</thead>
<tbody>
<tr>
<td>1856</td>
<td>Resin Solution, Flammable</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

ROAD (RID/ADR, RTMDR/RTMDF)

<table>
<thead>
<tr>
<th>Transport name</th>
<th>UN No</th>
<th>ADR Class</th>
<th>Hazards</th>
<th>Hazard No (ADR)</th>
<th>ADR LABEL No</th>
<th>HAZCHEM CODE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resin Solution, Flammable</td>
<td>1856</td>
<td>3</td>
<td>III/F1</td>
<td>30</td>
<td>3</td>
<td>3Y</td>
</tr>
</tbody>
</table>

RAIL TRANSPORT

<table>
<thead>
<tr>
<th>RID Class No</th>
<th>RID Packing group</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>III</td>
</tr>
</tbody>
</table>

15. REGULATORY INFORMATION

EU LABELLING

R Phrases

R10 Flammable
R20 Harmful by Inhalation
R36/38 Irritating to eyes and skin

S Phrases

S23 Do not breathe vapours
S36/37/39 Wear suitable protective clothing, gloves and eye protection

Symbols

Xn Harmful

Contains styrene
Contains phthalic anhydride and cobalt octoate. May produce an allergic reaction.

UK / EU REGULATION

SAFETY DATA SHEET

provisions relating to the classification, packaging and labeling of dangerous substances (Official Journal L 225 - 21/08/2001)


16. OTHER INFORMATION

In accordance with the requirements of Directive 2001/58/EC, the full text of risk phrases (R) referred to in chapter 2 is stated here.

R10 Flammable
R20 Harmful by inhalation
R22 Harmful if swallowed
R36/38 Irritating to eyes and skin
R37/38 Irritating to respiratory system and skin
R41 Risk of serious damage to eyes
R43 May cause sensitisation by skin contact
R42/43 May cause sensitisation by inhalation and skin contact

User Notes : This information ONLY applies to this product which conforms to the specification of CRAY VALLEY.
In case of formulations or mixtures, the user must ensure that new hazards are not apparent in line with the above.
The information contained herein is based on our knowledge of the product, at the date of publishing and it is given in good faith.
Please note the possible risks involved if this product is used for applications other than those for which it is intended.
This sheet shall only be used and reproduced for Health & Safety purposes.
The references to legislative & regulatory information and codes of practice are not exhaustive. Other applicable regulations may be considered.
It is the responsibility of the user to refer to existing legislation concerning the use, the storage and the safe handling of the product.
It is also the responsibility of the user to communicate ALL information related to the protection of Health, Safety & Environment contained within this Material Safety Data Sheet to those persons involved in the handling of this product.
Dear Alan

I am sorry but Gurit has a £5,000 minimum order value and only sell full rolls

But you will be pleased to know that our UK distributor Marineware (details below) will cut reinforcements and vacuum bagging materials to the square metre.

Marineware Ltd
Unit 6
Cross House Centre
Cross House Road
Southampton
SO14 5GZ

tele 02380 330208
e-mail sales@marineware.com
website www.marineware.com

With regard to infusion resins I would suggest the Prime 20LV as it is very good but if possible use the Prime 20 ULV hardener as it is far tougher (impact resistant) but it does have a long gel time and will require a post cure (heat to 50°C for 16 hours) to get the best properties.

I would suggest that you look a woven 2 x 2 twill 200g/m.sq 3 or 6K carbon if cosmetics are important, 12K if less so. Also a stitched carbon biaxial (+/-45°) and/or a unidirectional about 200 or 300g/m.sq - all carbons HSC (High Strength Carbon)
If you want to keep it simple you can just buy the unidirectional and effectively make your own biaxial by laying it down at 90° to each other - and unidirectional is cheaper than biaxial.

Be careful when infusing with unidirectional in the laminate as the resin has a tendency to "gutter" along the fibres which may cause dry spots / zones.

If you want to talk this over give me a call (01983 828103) or e-mail

Regards
**UT-C300**

![Image of UT-C300 fabric](image)

<table>
<thead>
<tr>
<th><strong>Fabric Description</strong></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gurit Style</strong></td>
<td>Unit</td>
<td>Width (mm)</td>
<td>Style</td>
<td>Nominal g/sqm</td>
</tr>
<tr>
<td>UT-C300</td>
<td>sq.m</td>
<td>500</td>
<td>Unidirectional Unitex</td>
<td>300</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Fabric Construction</strong></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary Fibre Type</strong></td>
<td>Fibre tex</td>
<td>Count ends/cm</td>
<td>Theoretical g/sqm</td>
<td>Filament Type</td>
<td>Fibre Tex</td>
<td>Count ends/cm</td>
<td>Theoretical g/sqm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon 12k</td>
<td>800</td>
<td>3.75</td>
<td>300</td>
<td>p.e.</td>
<td>10</td>
<td>0.56</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The policy of Gurit is one of continual development and improvement. Gurit reserves the right to alter specifications and prices without prior notice. Any information or advice obtained from Gurit by other means and whether relating to Gurit material or other materials, is given in good faith. However, it remains the responsibility of the customer to ensure that Gurit materials are suitable for the particular purpose intended.
RC200T

![Fabric Image]

### Fabric Description

<table>
<thead>
<tr>
<th>Gurit Style</th>
<th>Unit</th>
<th>Width (mm)</th>
<th>g/sq.m</th>
<th>Weave</th>
</tr>
</thead>
<tbody>
<tr>
<td>RC200T</td>
<td>sq.m</td>
<td>1000</td>
<td>195</td>
<td>2x2 twill</td>
</tr>
</tbody>
</table>

### Fabric Construction

<table>
<thead>
<tr>
<th></th>
<th>Warp</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibre</td>
<td>Tex</td>
<td>Ends</td>
<td>Theoretical g/sq.m</td>
<td>Fibre</td>
<td>Tex</td>
<td>Ends</td>
<td>Theoretical g/sq.m</td>
</tr>
<tr>
<td>Carbon 3k</td>
<td>200</td>
<td>4.9</td>
<td>96.5</td>
<td>Carbon 3k</td>
<td>200</td>
<td>4.9</td>
<td>96.5</td>
</tr>
</tbody>
</table>

The policy of Gurit is one of continual development and improvement. Gurit reserves the right to alter specifications and prices without prior notice. Any information or advice obtained from Gurit by other means and whether relating to Gurit material or other materials, is given in good faith. However, it remains the responsibility of the customer to ensure that Gurit materials are suitable for the particular purpose intended.
PRIME™ 20LV
Epoxy Infusion System

- Very low viscosity
- Variable infusion times
- Very low exotherm even in thick sections
- Suitable for infusing very large structures
- Germanischer Lloyds approved

Introduction

PRIME™ 20LV is the next generation of PRIME™ 20 epoxy infusion system, which is specifically designed for use in a variety of resin infusion processes including RTM (resin transfer moulding), SCRIMP™ and RIFT (resin infusion under flexible tooling).

PRIME™ 20LV has a much reduced viscosity resin and longer working time, which makes it ideal for infusing very large parts with complex reinforcements in one operation. It maintains the exceptionally low exotherm characteristic, which allows thick sections to be manufactured without risk of premature gelation due to the heat of exothermic reaction. This low exotherm will also help to extend the life of mould tools.

PRIME™ 20LV has been used successfully for the single-operation moulding of components ranging from narrow carbon yacht masts, up to 80’ yacht hulls and wind turbine blades. It achieves excellent mechanical and physical properties from a moderate (80°C) postcure, offering the finished laminate properties that lie between hand lamination and low-temperature cure prepreg processes.

The PRIME™ 20LV system is available with three hardeners, offering a range of working times and cure speeds. This enables the gettime of the resin to be more closely matched to the required infusion time for any particular size of moulded part.

Extensive tests at SP have shown that PRIME™ 20LV with Slow and Extra Slow Hardeners provide an excellent bond to certain types of vinyl ester resin. This permits production boat builders to use existing polyester gelcoat products with high performance epoxy infusion systems by using a vinyl ester tie-coat interface. This delivers significant benefits to the production boat builder, in terms of improved durability and performance of hulls/decks whilst retaining the high gloss and ease of gelcoat repair associated with polyester systems.

For further advice and comprehensive processing notes please contact Marine Technical Support.
Table 1. Component Properties

<table>
<thead>
<tr>
<th></th>
<th>LV Resin</th>
<th>Hardener</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fast</td>
<td>Slow</td>
<td>Extra Slow</td>
<td></td>
</tr>
<tr>
<td>Mix Ratio by Weight</td>
<td>100</td>
<td>26</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>Mix Ratio by Volume</td>
<td>100</td>
<td>31.4</td>
<td>31.4</td>
<td>31.4</td>
</tr>
<tr>
<td>Viscosity 80°C (cP)</td>
<td>1010-1070</td>
<td>26-27</td>
<td>22-24</td>
<td>15-18</td>
</tr>
<tr>
<td>Viscosity 93°C (cP)</td>
<td>600-640</td>
<td>20-22</td>
<td>16-17</td>
<td>13-19</td>
</tr>
<tr>
<td>Viscosity 130°C (cP)</td>
<td>280-310</td>
<td>16-18</td>
<td>12-14</td>
<td>10-12</td>
</tr>
<tr>
<td>Shelf Life (months)</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Colour (Gardener)</td>
<td>1</td>
<td>7</td>
<td>Clear</td>
<td>1</td>
</tr>
<tr>
<td>Mixed Colour (Gardener)</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>1.123</td>
<td>0.983</td>
<td>0.906</td>
<td>0.901</td>
</tr>
<tr>
<td>Mixed Density</td>
<td>-</td>
<td>1.089</td>
<td>1.084</td>
<td>1.083</td>
</tr>
<tr>
<td>Hazard Category</td>
<td>X, N</td>
<td>C</td>
<td>C</td>
<td>C</td>
</tr>
</tbody>
</table>

Mixing and Handling

PRIME™ 20LV resin must be mixed with PRIME™ 20 hardener in the following ratio:

PRIME™ 20LV resin: Prime 20 hardener (fast, Slow or Extra Slow)

100 : 26 (by weight)

The fast hardener is not usually used alone with the resin — although it can be used in this way, it is more often premixed with another PRIME™ 20 hardener to achieve shorter gel times than would otherwise be obtained with the use of Slow or Extra Slow hardener alone. The premixed hardener combination (Fast + Slow, or Fast + Extra Slow) is still mixed with resin at 100 : 26 by weight.

Accurate measurement and thorough mixing are essential when using this system, and any deviation from the prescribed mixing ratios will seriously degrade the physical properties of the cured system. The resin and hardener must be well stirred for two minutes or more, with particular attention being paid to the sides and bottom of the container. As soon as the material is mixed the reaction begins. This reaction produces heat (exothermic), which will in turn accelerate the reaction. If this mixed material is left in a confined mixing vessel the heat cannot disperse, and the reaction will become uncontrollable. See ‘Working Properties’ for details.

Application

PRIME™ 20LV system is intended for use in any established resin infusion process. The information provided in the tables in this datasheet should allow the user to achieve a successful result with PRIME™ 20LV system. However, if further information is required, please contact Technical Services.

Cure Schedule

To generate optimum mechanical properties for this system an elevated temperature cure is required. The recommended minimum cure schedule is 7 hours at 65°C or 16 hours at 80°C. Ambient temperature (15-26°C) cure of this system will not generate adequate properties and is therefore not recommended.

Parts can be ‘pre-cured’ in the mould at temperatures just above ambient (e.g. 36-49°C) to give the part sufficient strength and stiffness to allow easier demoulding. Such parts should still be post cured at the minimum recommended time/temperature indicated above. Contact Technical Services for ‘pre-cure’ time/temperature recommendations.
Table 2. Working Properties

<table>
<thead>
<tr>
<th></th>
<th>Fast Hardener</th>
<th>Slow Hardener</th>
<th>Extra Slow Hardener</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geltime – Secant 100g in water (hr : min)</td>
<td>1.30</td>
<td>1.09</td>
<td>0.30</td>
</tr>
<tr>
<td>Pot life 500g in air (hr : min)</td>
<td>9.25</td>
<td>6.28</td>
<td>4.22</td>
</tr>
<tr>
<td>Latest flow under vacuum (theoretical, thin film, hr : min)</td>
<td>3.90</td>
<td>3.10</td>
<td>2.40</td>
</tr>
<tr>
<td>Earliest vacuum off time (theoretical, thin film, hr : min)</td>
<td>5.10</td>
<td>4.15</td>
<td>3.30</td>
</tr>
<tr>
<td>Demould time (hr : min)</td>
<td>9.00</td>
<td>6.45</td>
<td>5.00</td>
</tr>
</tbody>
</table>

Notes: For an explanation of test methods used see Formulaed Products Technical Characteristics which can be found in the 110334 Form Product. This can be found in the Formulaed product section on the website www_prov.com.

All figures quoted are indicative of the properties of the product concerned. Some batches to batch variation may occur.

*Demoulding components made with Slow or Extra Slow Hardener should only be carried out after the part has received an elevated temperature cure in the mould.
Cured Properties

Cured System Thermal Properties
The thermal properties of SP PRIME™ 20LV system, as determined by Differential Scanning Calorimeter (Matter Toledo DSC821E), and Dynamic Mechanical Thermal Analysis (Rheodyne Thermal Analyser MKIII) are presented in Table 3.

<table>
<thead>
<tr>
<th>Hardener used</th>
<th>Fast</th>
<th>Slow</th>
<th>Extra Slow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cure Schedule</td>
<td>19hrs 50°C</td>
<td>19hrs 50°C</td>
<td>19hrs 50°C</td>
</tr>
<tr>
<td>Tg (DMTA - peak tan δ)</td>
<td>82.8</td>
<td>82.6</td>
<td>82.9</td>
</tr>
<tr>
<td>Tg(U) (DMTA)</td>
<td>74-76</td>
<td>87-89</td>
<td>90-92</td>
</tr>
<tr>
<td>Tg1 (DMTA)</td>
<td>58-70</td>
<td>58-70</td>
<td>69-71</td>
</tr>
<tr>
<td>ΔH - DSC (J/g)</td>
<td>1.54</td>
<td>7.3</td>
<td>0.00</td>
</tr>
<tr>
<td>Estimated HDT</td>
<td>67</td>
<td>68</td>
<td>67</td>
</tr>
</tbody>
</table>

Cured System Mechanical Properties (Matrix Properties)
The mechanical properties of the matrix system are presented in Table 4.

<table>
<thead>
<tr>
<th>Hardener used</th>
<th>Fast</th>
<th>Slow</th>
<th>Extra Slow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cure Schedule</td>
<td>19hrs 50°C</td>
<td>19hrs 50°C</td>
<td>19hrs 50°C</td>
</tr>
<tr>
<td>Tensile Strength (MPa)</td>
<td>75</td>
<td>73</td>
<td>69</td>
</tr>
<tr>
<td>Tensile Modulus (GPa)</td>
<td>3.2</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Strain to failure (%)</td>
<td>4.1</td>
<td>3.5</td>
<td>3.1</td>
</tr>
<tr>
<td>Moisture Absorption (%)</td>
<td>tba</td>
<td>tba</td>
<td>tba</td>
</tr>
<tr>
<td>Cured density (g/cm³)</td>
<td>1.153</td>
<td>1.144</td>
<td>1.132</td>
</tr>
<tr>
<td>Linear Shrinkage (%)</td>
<td>1.830</td>
<td>1.765</td>
<td>1.641</td>
</tr>
<tr>
<td>Barcol Hardness</td>
<td>21</td>
<td>27</td>
<td>25</td>
</tr>
</tbody>
</table>

Cured Laminate Properties
The cured laminate properties are presented in Table 5. The laminate is constructed using RE301 8 harness satin weave glass and PRIME™ 20LV/Extra-Slow.

<table>
<thead>
<tr>
<th>Hardener used</th>
<th>Fast</th>
<th>Slow</th>
<th>Extra Slow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cure Schedule</td>
<td>19hrs 50°C</td>
<td>19hrs 50°C</td>
<td>19hrs 50°C</td>
</tr>
<tr>
<td>Compr. Strength (MPa)</td>
<td>473</td>
<td>462</td>
<td>456</td>
</tr>
<tr>
<td>LSS (MPa)</td>
<td>47.6</td>
<td>47.0</td>
<td>52.6</td>
</tr>
<tr>
<td>LSS wet retention (%)</td>
<td>tba</td>
<td>tba</td>
<td>85</td>
</tr>
</tbody>
</table>

Compressive Strength of RE300 Glass Laminate
Cured 24hrs @ 21°C + 16hrs @ 50°C

Interlaminar Shear Strength of RE300 Glass Laminate
Cured 24hrs @ 21°C + 16hrs @ 50°C
Health and Safety

PRIME™ 20LV system

PRIME™ 20LV resin and hardeners have been designed for use in entirely closed-mould processes. This includes the mixing phase, which should only be carried out by automated mixing machines. It is not suitable for open-mould processing and strict adherence to the health and safety procedures stated in the product MSDS is essential.

Users should ensure that some elevated temperature-cure is applied to the component before trying to machine it. In a component made from PRIME™ 20LV which has seen no heat, there will be only a partial cure. Therefore the sanding dust will be more irritating than dust from a laminate cured at elevated temperature, in which there will be more thorough cross linking.

SP produces a separate full Material Safety Data Sheet (MSDS) for each component of this system. Please ensure that you have the correct MSDS to hand for the materials you are using before commencing work. A more detailed guide for the safe use of SP resin systems is also available from SP, and can be found on our website at www.gurt.com

Any accidental spillage should be soaked up with sand, sawdust, cotton waste or any other absorbent material. The area should then be washed clean (see appropriate Material Safety Data Sheet).

Applicable Risk & Safety Phrases

<table>
<thead>
<tr>
<th></th>
<th>Resin</th>
<th>Fast Hardener</th>
<th>Slow Hardener</th>
<th>Extra Slow Hardener</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symbol</td>
<td>33/68</td>
<td>43, 51/53</td>
<td>43, 52/53</td>
<td>42/63</td>
</tr>
<tr>
<td></td>
<td>23, 24, 26, 28, 37/38, 57</td>
<td>20, 26, 28, 36/37/39, 46</td>
<td>20, 26, 28, 36/37/39, 46</td>
<td>20, 26, 28, 36/37/39, 46</td>
</tr>
</tbody>
</table>

General Health and Safety Points

The following points must be considered:

1. Skin contact must be avoided by wearing protective gloves. SP recommends the use of disposable nitrile gloves for most applications. The use of barrier creams is not recommended, but to preserve skin condition a moisturising cream should be used after washing.

2. Overalls or other protective clothing should be worn when mixing, laminating or sanding. Contaminated work clothes should be thoroughly cleaned before re-use.

3. Eye protection should be worn if there is a risk of resin, hardener, solvent or dust entering the eyes. If this occurs flush the eye with water for 15 minutes, holding the eyelid open, and seek medical attention.

4. Ensure adequate ventilation in work areas. Respiratory protection should be worn if there is insufficient ventilation. Solvent vapours should not be inhaled as they can cause dizziness, headaches, loss of consciousness and can have long term health effects.

5. If the skin becomes contaminated, then the area must be immediately cleaned. The use of resin-removing cleansers is recommended. To finish, wash with soap and warm water. The use of solvents on the skin to remove resins etc. must be avoided.

Washing should be part of routine practice:

- before eating or drinking
- before smoking
- before using the lavatory
- after finishing work

6. The inhalation of sanding dust should be avoided and if it settles on the skin then it should be washed off. After more extensive sanding operations a shower/bath and hair wash is advised.
Transport & Storage
The system should be kept in securely closed containers during transport and storage. Storage should be in a dry place out of direct sunlight. The temperature should be between 18°C and 28°C. Containers should be firmly closed. The hardeners, in particular, will suffer serious degradation if left exposed to air.

Shelf Life
Adequate long-term storage conditions for both materials will result in a shelf life of two years for both the resin and hardeners.

Notice
SP is a technology brand of Gurit AG (the company). All advice, instruction or recommendation is given in good faith but the Company only warrants that advice in writing is given with reasonable skill and care. No further duty or responsibility is accepted by the Company. All advice is given subject to the terms and conditions of sale (the Conditions) which are available on request from the Company or may be viewed at the Company’s Website: www.gurit.com/termsandconditions_en.html.

The Company strongly recommends that Customers make test panels and conduct appropriate testing of any goods or materials supplied by the Company to ensure that they are suitable for the Customer’s planned application. Such testing should include testing under conditions as close as possible to those to which the final component may be subjected. The Company specifically excludes any warranty of fitness for purpose of the goods other than as set out in writing by the Company. The Company reserves the right to change specifications and prices without notice and Customers should satisfy themselves that information relied on by the Customer is that which is currently published by the Company on its website. Any queries may be addressed to the Technical Services Department.

Gurit are continuously reviewing and updating literature. Please ensure that you have the current version, by contacting Gurit Marketing Communications or your sales contact and quoting the revision number in the bottom right-hand corner of this page.
PRIME™ 20ULV
Ultra Low Viscosity Epoxy Infusion System

- Fast infusion times
- Gives higher quality, lower cost parts
- Excellent toughness at ambient only cures
- Ideal for production boatbuilders, who want to combine the use of polyester gelcoats with epoxy backing laminates

Introduction

PRIME™ 20ULV is an ultra low viscosity epoxy infusion system, which utilises PRIME™ 20LV resin with a slow (ULV) hardener.
2. Experimental

2.1 Thermal Properties
- Thermal properties were measured by either DSC or DMA according to Work Instructions WI-TAN01 and WI-TAN04.

2.2 Viscosity
- The viscosities of the samples were tested with the CAP2000LT.
- Hardener component settings: Cone 1, 2000rpm @ 20 & 25°C for 30 secs.
- Mixed system settings: Cone 1, 900rpm @ 20°C & 25°C for 15 secs.

2.3 150g Geltime in Water
- 150g geltimes were determined using a Tecnam gelimeter at 25°C according to Work Instruction WI-TMF1.

2.4 Mechanical Properties
- Neat resin casts were manufactured air-free between two glass plates separated by 5 mm o-ring according to WI-T-CP13.
- Samples were left to cure at ambient for 24hrs prior to a 16hr @ 50°C post cure, cut and then tested in accordance with the following standards:

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength, modulus and elongation</td>
<td>ISO 527 - 2 : 1998</td>
</tr>
<tr>
<td>Darryl impact strength</td>
<td>ISO 1794a</td>
</tr>
</tbody>
</table>

Table 1 - Test standards for neat resin casts.

2.5 Laminated Mechanical Properties
- Laminates were infused using RES01H8 as a carrier, panels were left to cure at ambient for 24hrs prior to a 16hr @ 50°C post cure.
- Samples are cut and tested in accordance with the following standards:

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength and modulus</td>
<td>BS5782 method 320</td>
</tr>
<tr>
<td>Compressive strength</td>
<td>BS EN ISO 14126</td>
</tr>
<tr>
<td>Compressive modulus</td>
<td>ISO 14126</td>
</tr>
<tr>
<td>ILSS</td>
<td>ASTM D2344</td>
</tr>
</tbody>
</table>

3. Results and Discussion

3.1 Component properties

<table>
<thead>
<tr>
<th>Property</th>
<th>PRIME™ 2OLUV Resin</th>
<th>Slow Hardener (ULV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mix ratio by weight</td>
<td>100</td>
<td>19</td>
</tr>
<tr>
<td>Mix ratio by volume</td>
<td>100</td>
<td>23.5</td>
</tr>
<tr>
<td>Viscosity @ 20°C (cP)</td>
<td>10/10/10/10</td>
<td>4</td>
</tr>
<tr>
<td>Viscosity @ 25°C (cP)</td>
<td>800/400</td>
<td>3</td>
</tr>
<tr>
<td>Viscosity @ 30°C (cP)</td>
<td>300/110</td>
<td>N/A</td>
</tr>
<tr>
<td>Shelf Life (months)</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Colour (Gardner)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Mixed Colour (Gardner)</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>1.123</td>
<td>0.880</td>
</tr>
<tr>
<td>Mixed density (g/cm³)</td>
<td>N/A</td>
<td>1.076</td>
</tr>
<tr>
<td>Mixed density (g/cm³)</td>
<td>Xi, N</td>
<td>C</td>
</tr>
</tbody>
</table>

3.2 Working properties

<table>
<thead>
<tr>
<th>Property</th>
<th>PRIME™ 2OLUV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Mixed viscosity @ 20°C (cP)</td>
<td>152</td>
</tr>
<tr>
<td>Initial Mixed viscosity @ 25°C (cP)</td>
<td>159</td>
</tr>
<tr>
<td>Geltime - Tecnam 150g in water @ 25°C (hrs/min)</td>
<td>3.85</td>
</tr>
<tr>
<td>Poniola 500g in air @ 20°C (hrs/min)</td>
<td>1.35</td>
</tr>
<tr>
<td>Latest flow under vacuum (theoretical, thin film, hrs/min)</td>
<td>0.00</td>
</tr>
<tr>
<td>Earliest vacuum off time (theoretical, thin film, hrs/min)</td>
<td>12.00</td>
</tr>
<tr>
<td>Demould time (hrs/min)</td>
<td>23.00</td>
</tr>
</tbody>
</table>

3.3 Cured system thermal properties

<table>
<thead>
<tr>
<th>Property</th>
<th>24 hours @ RT + 18 hours @ 50°C</th>
<th>24 hours @ RT + 19 hours @ 70°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tg, peak tan δ – DMA</td>
<td>81.0</td>
<td>91</td>
</tr>
<tr>
<td>Tg1, UC, °C – DMA</td>
<td>60-68</td>
<td>60-68</td>
</tr>
<tr>
<td>Tg1, 1°C – DMA</td>
<td>72</td>
<td>80</td>
</tr>
<tr>
<td>Est. DFT, °C</td>
<td>60</td>
<td>70</td>
</tr>
<tr>
<td>Tg2, UC, °C – DSC</td>
<td>60</td>
<td>91</td>
</tr>
<tr>
<td>Tg2, 1°C – DSC</td>
<td>63</td>
<td>84</td>
</tr>
<tr>
<td>AH, Jig – DSC</td>
<td>8.6</td>
<td>0</td>
</tr>
</tbody>
</table>
3.4 Cured system mechanical properties (matrix), cured 24 hours @ 21°C + 16 hours @ 50°C

<table>
<thead>
<tr>
<th>Property</th>
<th>PRIME™ 20UV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength, MPa</td>
<td>71.2</td>
</tr>
<tr>
<td>Tensile modulus, GPa</td>
<td>2.98</td>
</tr>
<tr>
<td>Stress to failure, %</td>
<td>6.28</td>
</tr>
<tr>
<td>Moisture absorption, %</td>
<td>TBC</td>
</tr>
<tr>
<td>Cure density, g/cm³</td>
<td>1.14</td>
</tr>
<tr>
<td>Linear shrinkage, %</td>
<td>TBC</td>
</tr>
<tr>
<td>Barcol hardness</td>
<td>25</td>
</tr>
</tbody>
</table>

3.5 Cured system mechanical properties (matrix), various cures

<table>
<thead>
<tr>
<th></th>
<th>3 days @ 21°C</th>
<th>7 days @ 21°C</th>
<th>24 hours @ 21°C + 16 hours @ 50°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charpy impact strength, kJ/m²</td>
<td>1.78</td>
<td>1.82</td>
<td>6.79</td>
</tr>
</tbody>
</table>

3.6 Cured laminate properties (10 plies R301H8), cured 24 hours @ 21°C + 16 hours @ 50°C

<table>
<thead>
<tr>
<th>Property</th>
<th>PRIME™ 20UV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strength, MPa</td>
<td>436</td>
</tr>
<tr>
<td>Compressive modulus, GPa</td>
<td>25.1</td>
</tr>
<tr>
<td>ILSS, MPa</td>
<td>48.4</td>
</tr>
<tr>
<td>ILSS wet retention, %</td>
<td>TBC</td>
</tr>
</tbody>
</table>

3.7 Adhesion to vinylester tiecoat

Cleavage strength achieved after infusing the products detailed through a laminate consisting of 3 plies of WRE 681 over the tiecoats described. Panels cured 24 hours @ 21°C + 16 hours @ 50°C.

<table>
<thead>
<tr>
<th>Adhesion to Vinylester Tiecoat</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
Notice

SP is the Marine Business of Gurit AG (the company). All advice, instruction or recommendation is given in good faith but the Company only warrants that advice in writing is given with reasonable skill and care. No further duty or responsibility is accepted by the Company. All advice is given subject to the terms and conditions of sale (the Conditions) which are available on request from the Company or may be viewed at the Company’s Website: www.gurit.com/termsandconditions_en.html.

The Company strongly recommends that Customers make test panels and conduct appropriate testing of any goods or materials supplied by the Company to ensure that they are suitable for the Customer’s planned application. Such testing should include testing under conditions as close as possible to those to which the final component may be subjected. The Company specifically excludes any warranty of fitness for purpose of the goods other than as set out in writing by the Company. The Company reserves the right to change specifications and prices without notice and Customers should satisfy themselves that information relied on by the Customer is that which is currently published by the Company on its website. Any queries may be addressed to the Technical Services Department.

Gurit are continuously reviewing and updating literature. Please ensure that you have the current version, by contacting Gurit Marketing Communications or your sales contact and quoting the revision number in the bottom right-hand corner of this page.

Gurit (UK) Ltd
St Cross Business Park
Newport, Isle of Wight
UK
T +44 (0) 1983 828 000
F +44 (0) 1983 828 100
E marine@gurit.com
W www.gurit.com

Gurit (Australia) Pty Ltd
Unit 1A / 81 Bassett Street,
Mona Vale, 2103 NSW, Australia
T +61 (0) 2 9979 7248
F +61 (0) 2 9979 6378
E sales.au@gurit.com
W www.gurit.com

Gurit (Canada) Inc
175 rue Peladeau, Magog, (Québec)
J1X 5G9, Canada
T +1 819 847 2152
F +1 819 847 2672
E info-ro@gurit.com
W www.gurit.com