Manufacture of Advanced Textile Composites

MSc Dissertation
Guided by DR Phil Harrison

Avinash Pandey
On this occasion of the completion of the dissertation, I would like to express my sincere gratitude to the following individuals who kept me motivated, helped and guided all the way through to complete the task. Without whose support, this dissertation could not have materialized.

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Avinash Pandey
Statement of Authenticity

I Avinash pandey, hereby declare that the submission of this project on Manufacture of Advanced Textile composites are my own work. It contains, to the best of my knowledge,

No any report published or written by any other person for any other degree and diploma

At UNIVERSITY OF GLASGOW or any other institution. I also declare that the

Intellectual content of this report is the product of my own work, except to the extent that

Assistance from others in the report design and conception or in style presentation or

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ABSTRACT

This project provides a brief introduction and overview of composites. It contains manufacturing and testing of 2D (Flat plate) and 3D (Hemispherical Model and Cart wheel) composite parts. Through an advanced manufacturing technique called vacuum resin infusion.

The experiments are performed with the use of Glass Epoxy Resin, whose properties are calculated with the use of rule of mixtures for composite, which can be used for computerised simulation. Physical testing of the 2D model has been performed for understanding the behaviour of the model.

Finally this project leads through understanding the vacuum resin infusion process for the manufacture of 2D and 3D models and how to make it better by different applications on the experiment.
INTRODUCTION

AIM

This project is the part of a course in Automotive Engineering. The aim of this introduction is to introduce vacuum infusion process used to manufacture composite parts. It will explain about the step by step procedure for understanding vacuum infusion manufacturing process.

It will then further move to different experiments performed and discuss the results and errors to overcome that. This will be a good help for those who want to do more in vacuum infusion experiments, further it will lead to testing 3 point bend test and tensional test real test as well as finite element analysis (FEA). Unfortunately the simulation part was not completed by the end of this project; this was due to unforeseen experimental times and lack of software knowledge (abaqus) which took some time for understanding.

Objectives

1. Understanding the background and manufacturing techniques of composites.
2. To review the process of vacuum resin infusion of manufacturing of composites.
4. Manufacture a 3d model for getting better concept of vacuum infusion.
5 Calculating the properties of the lamina (glass epoxy) through Rule of mixtures of composites.

6 Performing lab test of the 2d composite plate made of glass epoxy (3 point bend and torsion).
7 If the experiment is satisfactory then simulating flat plate under 3 point bend test and torsion test.

**Background**

This section will throw some light on the narration of the Textile composite and why they are known as the advanced class materials.

**Composites**

According to its name “composites” it’s an amalgamation of a distinct materials formed with a precise inner structure and with a precise outer shape or form. These are designed as such that exceptional mechanical properties and higher performance characteristics can be obtain which is hard to achieve with any single material component.

It is understood that composites are used from very old times to up till now. Reinforced concrete and plywood are the best examples of the modern composites widely used. In reinforced concrete, for providing tensile strength a set of metal rod and screening is used and for providing compressive strength a formulation of sand stone and cement is used. In sheets of plywood for providing tensile strength layers of wood veneer is used.
and for providing stiffness the layers of wood veneer are bonded together and a rigid adhesive is provided for the wood particulate filler this system is also known as resin system.

**Textile composites**

As the name suggests Textile composites, they are the rigid and textile containing materials having the properties like light weight, flexible, well-built and tough because of its quality they are used for structural or load bearing applications. Textile composites can also be distinct as the amalgamation of a resin system with a textile fiber, yarn or fabric system. Tires, inflatable life rafts and heavy duty conveyor belts are the good examples of the textile composites. In rubber component a elastic unreceptive matrix is found resulting to failure in the required performance but when this component is used as a team with textile system having tensile strength and stability as, textile reinforced rubber system then it becomes successful for flexible composite products.

Fiber reinforced plastic system (FRP) is an example of rigid textile composites. It is broadly accepted as an alternative of metals and woods. Application from fifties century onwards even fiber reinforced plastics is broadly used in interior and exterior panels as well a in parts of automobile and aircraft construction, some examples like, the hulls for pleasure boats, in a piping products, indoor and outdoor furniture’s, components used in housing construction, in industries for cabinets and casings, appliances and
containers etc. mostly its used in variety of application, the rigid textile composites related thus for are in the form of surface panels and sheathings i.e. the skin instead of load bearing skeleton.

**Textile structural composites**

Primary and secondary load bearing application such as common frame work for buildings, bridges, vehicles etc are designed by structural material. Best examples of those materials are woods and metal beam which are used in primary and secondary load bearing members.

Definition: Textile structural composites are the composite which are accomplished of bearing the primary or secondary loads to which basic frame work in buildings and
bridges, vehicles etc are subjected, parallel, it must have textile and resin, Metal or ceramic compound. Majority of these composites are fiber reinforced plastic (FRP) fact is that the large amount of stress which on the basic framework of building, bridges and vehicles is due to its own weight (structures). According to the theory if lighter weight structure is designed than the basic load bearing requirement can be statically decreased.

Figure 2 textile composite

Resin system

Providing rigidity or inflexibility and holding the textile reinforcement material in a prescribed suspension or orientation in composite, are the primary functions of resin system. Even some of the resins system can be moulded into three dimensional forms with considerable structural integrity, especially in compression or unidirectional structure integrity cannot be formed by assemblage of textile material, it can be only done when rigid and stabilizing effects of a resin system occurs.
Textile perform, is an assemblage of flexible textile material, which is presented in a variety of forms. Textile perform can be in many ways like chopped fibre malt, a yarn assembly, a stack of fabrics or a tight 3D fabric construction. For continuous matrix and ruggedizing network, resin should be capable enough to penetrate all of the interstices and wet all the outer fibre surfaces throughout the performance of textile. Related to the nature of the textile perform which is lose or tight fibre packing as well as method of application in atmospheric or pressure condition, viscosity of resins is also very important even, the outer fibre surface should be clean and compatible with the resin system.

During forming, shaping and moulding, resin saturated textile performances are exposed to considerable pressure, because of this no resin carrying air bubbles are entrapped permanently with in the composites. It is important to remove excess resin because most high performance textile has a 70 to 30-ratio textile performance to resin matrix. Finally, resin matrix must be rigid. Its curing can be done at room temperature depending upon matrix factors like, textile material, the resin system, composite construction technique, rate of curing, degree of curing end-use product requirement etc. Improve in heat resistance but decrease toughness in the product or composite the results when fully cured resin systems pass through high temperature post curing treatment.

The system, which is used in textile composite products and doesn’t require any high temperature use requirement, is the, polyester resin system. It comparably less expensive or cheap, it has a good flow and good quality of fibre surface wetting because of low viscosity as well as it is curable at low temp it is very sensitive or responsive towards heat therefore some of its drawbacks are poor strength, to poor impact performance and quality of excessive shrinkage at high temp but, neglecting its negative quality, polyester resin system is widely used in many textile composite application from
many years and has been successful in generating confidence in users to get a desirable
or expected result

There is another resin system, called epoxy resin system, which is used broadly in textile
composites products, which have high temperature requirements. It bears qualities like
higher strength, curable at low temperature, less shrinkage and less evidence of creep
as compared to polyester resin system because it is less sensitive towards heat some of
its negative qualities are higher cost and toxicity, lack of toughness, it reduces its
strength at high temperature on balance it is the best system available to use in high
temperature composite application, in which toughness is not an important issue.

Another form of resin system are self-reinforcing plastics or liquid crystals, they have
capability for textile structural composite application and are in development stage. It
has been seen that this there is no fibre requirements here liquid crystal technology will
be used to develop self-reinforcing plastic system. In the future, it will be a main
contender, but the prime candidates for textile structural composite in up coming years
will be thermoplastic epoxy and elasticized epoxy resin system.
Various Manufacturing processes

- Auto clave moulding
- Wet lay up
- Press moulding
- Pressure bag moulding
- Vacuum Resin infusion
- Filament welding
- VARTM

INTRODUCTION TO VACUUM RESIN INFUSION

Definition ....

The technique which uses the vacuum pressure to run the resin into the laminate is vacuum resin infusion process (VRIC). In this process before introducing the resin, materials are first laid up they are kept dry into the mould then vacuum is applied through a external pump the pump sucks all the air inside the system. When complete vacuum stage is achieved then the resin is sucked inside the laminate by the vacuum pressure this is done by arranging the tubes carefully. This practice is aided with a group of supplies and materials. In a usual hand lay-up, reinforcements are laid into a mould physically by hands using brushes, rollers or any other means. Any other improvements which can be made in this process is the use of vacuum bag to suck extra resin out of the laminate fiber to resin ratio is significantly improved by doing this vacuum bagging, and this results in a stronger and lighter product. “Vacuum bagging equipment and
technique for room temperature application “is a brochure which is recommended to those, who are new with vacuum bagging because VIP requires practice or understanding in this area and uses several types of same principles. These principles have been built upon by vacuum infusion parallel providing additional improvements to the lamination method.

**VIP setup and Equipment**

Before understanding the experiment with infusion, it is very essential to be familiar with some common concepts which give information about material and its arrangement point to be considered is that every project is irreplaceable and this guide is not plan to impart the only available options. This report will discuss some variations further .firstly the following diagram illustrates sequence of series of procedures that comprises vacuum infusion.

(https://fibreglast.com/downloads/vacuuminfusion) Figure 3 showing VI set up
According to the principle from the following fig, focus will be on one general setup idea with the concept that, in the laminate, resin is infused in the center point after that from there resins will be pulled outwards through vacuum pressure. The following diagram shows the final arrangement of the material.

Note FOR showing the inside process the vacuum bag is eliminated from the figure.

Going in detail, let’s discuss step by step procedure of “what materials are used and how to go about using them”. There are seven steps involved they are as follows.

**Step 1 Preparing the Mold**

Preparation of the mould and selection of the flow media for the reinforcement.
Step 2 Prepare Vacuum Lines

Selection of resin feed lines and vacuum lines

Step 3 Generating vacuum Bag

Allow for prohibiting resin from entering the vacuum, Building the vacuum bag

Step 4 Preparing Vacuum Pumps

Attaching the vacuum pump so that proper vacuum is ensured

Step 5 Ready for Infusion

Selection of resin and the setup of resin vessel or bucket

Step 6 Starting resin Infusion

Catalyzing resin and Clamp off resin line to allow it to start infusing

Step 7 Check and analysis for perfection

Making it better by trying some variation
STEP1

In this step process like preparation of mould, selection of reinforcement as well as selection of core material or flow medium is done for the lamination process. Good quality mould is required, similarly for vacuum infusion similar quality mould I used. It should be rigid as well as high gloss finish it should also have flange by 6 inches which will be used in placement of sealant tape and spiral tubing. Mould release agent is applied on the mould when it is properly cleaned.

Selection of the reinforcement

One of the important decisions for any laminate is choosing its reinforcement, but there are further considerations while choosing reinforcement for infusion. While all fabrics will patiently infuse, flow rated can be altering by different material and weave style. Following are some common guidelines for selecting material, though entity experiences may change.

a) Fiber glass – It is the most commonly used reinforcement in vacuum infusion, most fiber glass fabric suggests high permeability, allowing resin to effortlessly flow through. In general, loser weaves tend to infuse better as there is a less crimping of strand. While using a non woven mat, continuous strand mat will show superior infusion as compared to chopped strand. While both show high permeability, resin flow gets binder in chopped strand mat. This problem can be avoided by continuous strand mat (#251). Due to their construction neat fabrics often used for infusion. To avoid crimping caused by weaves they are knit together instead of weaving. The knit fabric boosts resin flow as well as adds strength and bulk very quickly.

b) Carbon fiber (graphite) and Kevlar – infusion rate in this reinforcement is very slow but then also this reinforcement can be used in the vacuum infusion
process. To neutralize this, both #1110 vinyl Easter and epoxy resins are used for creating successful part and also by using them infusion rates can be increased to a great extent. In order to achieve best results it is better to do some experiments with these materials before applying it to the actual flow rate.


It is seen that when vacuum infusion is applied to a more complex shape mould, it is difficult to keep the dry reinforcement flat on the surface this may create anarchy in the mould while experimenting.

To overcome such problems

Super 77 spray adhesive (#1404) can be used as the best solution before laying down the reinforcement on the surface of the mould a light layer of this adhesive is sprayed. Through this process, enough adhesive is provided for holding the material in proper place tightly. The process of curing and resin infusion is not affected by Super 77 adhesive when used reasonably.
Flow Media

The design of the flow media is the unique concept to vacuum process. In VIP, the resin entering the laminate must be directed properly at a fixed point or (points). Least resistive path is always chosen by the resin, for travelling in VIP. Unfortunately a great deal of resistance, through which the resin flow is prevented, is provided by most of the reinforcements. The job of flow media is to add flow to the resin. Infusion of resin into reinforcement is also possible with any addition of flow media, but it is rarely successful. For providing easy flow channel for resin the flow media is characteristically laid as a sole layer, between the layers of the reinforcements. Ultimately this material turns out to be part of the laminate.

There are various manner of flow media three of them are as follows.

a) **Lantor soric XF (#1409)**

   Maximum comfort ability is provided by this kind of flow media. This material can perform task of both flow media as well as bulker. For rapidly moving the resin through the laminate it consists of hexagonal flow channels, while the thickness is added concurrently 35% less resin preservation is experienced normally by the laminates integrating Soric compared to all glass laminates. Any kind of considerable structural properties are not provided by Soric; even it is used as a core.

b) **Enka Fusion Nylon Matting (#1401)**

   Quicker infusion time is granted by this flow media. Resin can move as fast as it can be fed, by the use of this media, because it is constructed of erratically oriented, entangled nylon filaments.

c) **Divinymat Sandwich core (#1024).**
This acts as both a flow media as well as structural core. The properties of this material is indistinguishable to the traditional Vinyl Foam Cores, but it contains grooves, perforations, and scores in the core material through which strength and rigidity is added to the laminate concurrently it also helps in resin pass through. In addition, this material is on a scrim backing to assist conformability.

**Step 2**

Vigilant deliberation must be taken in order to setup resin and vacuum lines, before closing the vacuum bag.

On the whole a bucket or a standing source is used to fed the resin, before closing the bag the lines (or spiral tube) have to be installed. The tubing which is used for providing vacuum inside the bag can also be used for feeding the resin inside it.

Following are some unique material for VIP projects which helps in directing the resin flow accurately.

**a) Spiral tubing (#1043)**

It is also known as spiral wrap. it is a tube shaped plastic ribbon which has been coiled like spring as its design propose that air can freely pass through inside or outside from its walls on its entire length.

The above properties of the spiral tubing makes it ideal for the use in VIP projects for feeding resin or for vacuum. It allows resin to travel freely and quickly through tube but concurrently seep out along the way, through which the laminate gets quickly we along a long stretch, but one thing have to be considered is that the spiral tube has to be
wrapped in peel ply so that it can be easily removed.

b) **Enka fusion filter jacket**

This system is mostly used in all VIP projects this material is applied on the top of the laminate and at the time of separating from mould this is removed from the laminate. Removable material is also provided by it which can be used for anchoring the T fitting which joints the resin and vacuum lines.

Enka fusion filter jacket is 4 inch wide. It is a flow channel over the length of the laminate. It is just like the nylon matting only the difference is in the shape it’s narrow and is contained within a fabric “sock”. Until the entire length of the laminate I filled with resin it helps in holding the resin. When this laminate is used as a surface media the thing that has to be kept in notice is that peel ply has to be used below the filter jacket, otherwise the laminate will be enduringly attach to it.
Enka fusion filter jacket is shown in the above diagram which will be used as a resin feed line.
As the schematic suggests, this filter jacket is placed on the top of the T joint to prevent shifting and to increase or confirm the steady flow rate.

Fig 1 shows the process how to achieve that and
Fig 2 shows the finished product how it will look like after the process has been done.

Selection of resin feed lines and vacuum lines.

For absorption of surplus resin and driving vacuum through laminate a breather / bleeder material is commonly used in traditional vacuum bagging, but for the resin infusion these are not characteristically used.
In VIP, within the sealed bag vacuum lines are extended. The best material for this
purpose is spiral tubing. All the corners have to be filled with resin to achieve complete
infusion. Preferably center of the laminate is used for infusion but typically spiral tubing
is used around the flange.

Spiral tubing have the tendency to curl and whirl, so you may face some problems in
placing them into the proper place, were is has to be .For avoiding this sealant tape can
be used to attach them in proper place for securing their position.

Add Vacuum Lines

https://fibreglast.com/downloads/vacuuminfusion. } figure 8 spiral tube

Step 3

Building the vacuum bag

After the set up of all the dry material in the proper place, now it’s time for vacuum bag
.the dimension of the vacuum bag should be proper not very big or very small this may
result in pooling of resin or improper infusion. The bag should have plenty of room to keep all the materials inside and also it has to be tight.

After the bag is built, cuts are made for attaching the tubes to the bag for resin flow and vacuum. The cuts have to be carefully made as it may lead to leakage. The resin line has to be clamped before switching on the pump, before the introduction of resin vacuum is drawn. The resin tube has also temporary leak. A flow regulator can be useful for that purpose.

**Allow for prohibiting resin from entering the vacuum.**

**Resin trap.**

It is a kind of an air tight container placed between the circuits. It prevents the vacuum pump from destroying as it holds the excess resin which can flow to the pump and can damage it. During the VI process, many times the resin is fully drawn into the laminate and sometime it stays partial it is normal and there is no way to cure that except continuous flow of resin. When this is done resin trap plays an important role by catching all the excess resin drawing through the laminate, also if there is any air bubble it will be sucked and pushed into the pump for reflow.

For bigger project more than one trap can be used as soon as one is filled other can be used. One important thing that has to be kept in account is that before its application the tank has to be polished with some wax for easy removal of the resin from the tank.

**Step 4**
Vacuum pump

Now when all the setup is done it’s time to attach the vacuum pump to the system, as vacuum is required for feeding the resin this pressure is generated through pump. The specification of the pump has to be proper to generate a good vacuum, and to match the requirements for better infusion.

Ensure proper vacuum

Once the pump is attached, switch it on then it will create vacuum, as the biggest problems inside any infusion are leaks. Even a smallest leak can create disturbance in the process or can ruined the whole process, so make sure all the leaks are cured before infusing. For avoiding this problem a cheap means can be used that is the stethoscope, through which the sound can be heard from the air which is leaking and than it can be cured. Another tool which is more precise and expensive is ultrasonic leak detector by the use of it; it can detect even a slight vibration made by air leakage. A led light is used to know that vibration it is attached to the sensors of the ultrasonic detector and when it senses any vibration by the leak it glows and the leak can be cured.

Step 5

Prepare for infusion

Select your resin

Selection of the resin is also one of the important aspects of the VIP. There is not any specific type of resin that has to be used for the process any kind may be used, only the thing that has to be noticed is the viscosity, as the viscosity of resin is low it will give
good result. As it will flows easily. This is not that his viscous resin will not be used it will require special attention and more flow media. This is not that viscous resin will not be used it can also be used it will require special attention and more flow media following are some types of resin.

**Vinyl Easter**

Most commonly and frequently used at a viscosity of 275 centipoises.

**Polyester resin**

Infuse quite readily at 475 centipoises viscosity

**Epoxy (system 2000)**

Its viscosity depends upon the hardeners choice. Through this high quality parts are created. It’s a slow infusion resin. It is used between viscosities of 900-975 centipoises.

**Resin bucket set up**
For the proper VIP there should not be any air flowing through the resin flow pipe as it may lead to improper result. To avoid that a proper set up has to be made. For this a bucket, resin holder, zip strips and spring clamp are required as we can see from the schematic that the resin line holder is attached to the tube with zip strips, it helps to avoid the curling of the tube as it may lead to air suction and also through which end side of the pipe is kept angled

If it is not like that it will stuck to the bottom of the bucket and will not allow the resin to flow. Once this step is done the pipe is then clamped and ready for procedure.

**Step 6**

**Resin infusion**

**Catalyze and allow infusing.**

When all the steps are done now mix the resin but give a final check before infusion that all setup is proper if it matches accuracy then unclamp the resin inlet and allow the resin to completely flow. Continue the flow until the entire laminate is covered. It is visible to see that.

**Clamp off resin line**

Once the laminate is fully filled with resin and no further resin is required now clamp off
the resin line to avoid excess flow and to stop. If the resin gets over in between then clamp off the tube before that to avoid air bubble to enter and then fill the bucket again with resin.

Once the resin infusion is complete the pump has to be kept running for a while to maintain the vacuum pressure and to avoid the air to enter and if there is any bubble of air the pump will suck it off.

**Step 7**

**Check and analysis for perfection**

Some helpful materials that can be used to save time and improving the results are follows.

**Thermal gun**

This device can be used to determine the temperature. It can be sued by pointing to any object and it will show its temperature reading. Through which the temperature of the resin and the setup can be calculated and by which we can see that it has reached the curing temperature or not this will save extra time for which the setup is placed even after curing.

**Stopwatch and marker**

These can be used to see the flow rates and paths this may lead for better practice and can be helpful in further project attempts. It is done by recording the flow rate through stopwatch and marking the area with the marker on the laminate to record low rate.

**Variation in the experiment**
In the above figure a gind of variation made to the spiral tubing is shown.

https://fibreglast.com/downloads/vacuuminfusion

figure 10 variation
EXPERIMENTAL WORK

VACUUM INFUSION EXPERIMENT PERFORMED FOR TWO DIMENSIONAL FLAT PLATES.

A vacuum infusion experiment has been performed for making a two-dimensional flat plate model, whose samples were used for further testing in three-point bend test and torsion test.

The step-by-step procedure is shown.
Figure 3.1

This experiment has to be performed on a flat clean surface so that at the end a proper result can be obtained. As shown in the figure glass plate was used for this experiment. There were some dirt’s on the surface of glass plate, which was removed, with the help of a piece of clay from the glue tape.

Figure 3.2

Now PVA release agent was applied as it indicates a harmful sign on the bottle so safety gloves were used to avoid any skin damage.
Figure 3.4

As from the picture it can be seen that a piece of breather (cotton cloth) was used to apply the release agent. 3 to 4 layers of this release agent were used so that the mould can be easily removed from the glass surface.
Figure 3.5
Now the reinforced have been cut in rectangular pieces and 12 sheets were used in the experiment to get proper thickness for performing tests.
After cutting the reinforcement they were laid one over another by the orientation of 0, 90 degrees as shown in the figure.
Now a peel ply was cut according to the dimension and placed over the reinforcements firmly. Peel ply is used so that the mould setup can be removed easily from the glass plate.
Figure 3.8

Breather was placed over the peel ply so that the resin could be applied evenly and it should split everywhere like gel over the reinforcements.
Figure 3.9
Now bleeder was placed at the top and it was fixed with sealant tape. Bleeder is not compulsory but a try was given to see the difference in the results. Bleeder allows the resin to flow properly at all areas inside bag.
Boundary conditions were made through clay tapes, so that the plastic bag can be placed on the top and vacuum can be generated.
Figure 3.11
The above figure shows the spiral tubing setup and the use of T joint tube used for proper flow of resin through out.
Figure 3.12

The overall setup before vacuum looks like the above fig and it shows the inlet pipe arrangement of resin infusion and the outlet pipe for vacuum and to suck extra resin.
The above figure shows a catch tank used for catching the extra amount of resin flowing at the time of experiment. A proper layer of release film has been applied inside that so that it can be cleaned easily and hard resin can be removed.
Figure 3.14

This is a picture of the pump whose end is attached with the catch tank and which is used for sucking the air from the vacuum bag to generated vacuum.
Figure 3.15

From the above fig it can be seen that vacuum has been properly generated and the set up is now ready for infusion.
Figure 3.16

These are the glass epoxy resin and hardener which has been mixed in the ratio 100 : 26 as indicated on the bottle for making the resin for infusion.
Figure 3.17
Infusion has been started and it is shown how the resin is flowing through the reinforcements
Figure 3.18

This shows the container from which the resin was sucked inside the vacuum bag for process.
This figure shows the successful completion of the resin infusion, which was further, placed like that for 8 hrs at the room temperature for curing and then has given the heat treatment for again 8 hrs to get the final mould.
Figure 3.21

This figure shows the final product, which was obtained after the experiment.
VACUUM INFUSION EXPERIMENT PERFORMED FOR THE THREE DIMENSIONAL MODELS (HEMISPHERE):

It can be seen from the above figure 1.1 that a flat surface is required for the experiment and for this experiment a glass plate has been used further the step by step procedure with pictures is explained.
As there were some defects in the hemispherical model in the form of holes on the surface figure 1.2. This has been eliminated by filling car body filler in the workshop. Following are the procedure adopted to perform vacuum infusion experiment, which has been describe according to the steps and their figures:
• Figure 1.3- Sealant tape has been used to make the model perfect or perfectly remove the error.
• Figure 1.4- Now it’s time to apply the release agent on the surface of glam plate, so, that after experiment, the model can be separated from the glam easily (PVA release agent).
• Figure 1.5- For safety purpose hand gloves has to be used, to prevent any skin change or allergy.
• Figure 1.6- A piece of cotton breather is used for applying the PVA release films mostly, three to four layers.
• Figure 1.7- After applying release film, the hemispherical model has been placed on the glass surface as shown in the figure and to make it steady on its place, some sticky tape has been used.

• Figure 1.8- As from the figure it is shown that the tape has been applied covering all the areas on the surface, so, that it can be perfect and air could not move inside the hemisphere.
Figure 1.9- Small stick has been used to make an air tight sealing and to flat the bumpy areas. In this experiment I used a piece of a stick to fix that or any other means can be used.
• Figure 1.10- After applying the sticky tape or clay I have used the sealant tape to make the model perfect as if there is any air leakage that can be cured by applying this.
Figure 1.11- Now after the setup of hemispherical model has been done its time to again apply the release agent on the surface of hemisphere, so, that the final model after the experiment can easily be removed.
• Figure 1.12- As three, four layers has been applied on the surface; it's time to prepare the reinforcement. These play important role in infusion experiment. In this experiment I have used eight layers which has been cut (can see in following fig).
Figure 1.13- After cutting, these have been laid one by one on the surface by the orientation, 0 to 90 degrees.
Figure 1.14 – Now, after the lay-up of the reinforcement’s boundary has been created by spiral tubes through which resin can run evenly and vacuum can be generated properly inside. For avoiding any movement of the tubes, a sealant tape has been used.
Figure 1.15- Now it’s time to put peel ply on the surface. It’s a kind of orange colour cloth used for separating the final product from the model easily. This has been cut according to the size for laying.
Figure 1.16- When the peel ply has been placed, now, a breather has to be placed over that. It’s a white colour cotton type cloth which is used for holding the resin, like a gel, so, that we can get proper shape after the experiment.
• figure 1.17 Now over the breather, bleeder has been placed so that the resin should be evenly spread. In this case because of the complicated shape of the hemispherical model I have cut those into 4 triangle shaped for making proper alignments at the time of placing.
• Figure 1.18 when all these set up was made a boundary condition has been applied through sticky clay tape which is used for sticking the plastic sheet for creating vacuum bag for the experiment.
Figure 1.19 now the plastic bag was cut according to the size of the boundary made by the clay tape.
• Figure 1.20 when the plastic sheet has been cut now it is placed in such a manner that it should make an air tight sealing so that no any air could enter inside the bag, after that vacuum has been created inside the bag for this a pump has been used. For suction of air from the bag a small cut has been made on the top surface and a pipe has been inserted as well as fixed with the clay to secure the vacuum. Now the resin has been prepared. In this experiment I have used glass epoxy resin and the ratio of resin to the hardener is 100:26.
Figure 1.21 when the resin was prepared a checkup has been performed to the setup as there is any air leakage or not and if it is so that has to cured and everything was perfect. Infusion has been done through the other pipe whose one end is inside and one outside of the vacuum bag. It has been fixed with clay so that vacuum condition can be maintained. This pipe was clamped before the infusion so that no any air enters inside. When infusion was successfully done the set up was kept like that at room temperature for at least 8 hrs for curing.
Figure 1.22 a and b when 8 hrs has been completed the set up was ready to give a heat treatment before the final stage for this the whole set up was placed inside oven for again 8 hrs at temperature between 70 degrees after heat treatment it was ready to separate as it can be seen from the figure that this experiment failed because there was not proper vacuum and the resin has traveled inside the hemispherical model.
THE THREE DIMENSIONAL EXPERIMENT AGAIN PERFORMED BY USING A CART WHEEL MODEL.

When the hemispherical model failed then this cart wheel model was used to perform the same experiment and the steps are as follows.

![Cart wheel model](image)

*Figure 2.1*

From the above figure it can be seen that the cartwheel model is placed on the flat surface (glass plate) same as in hemisphere also the use of sticky clay was use to ensure vacuum so that sir could not pass inside the cart whell model which can disturb the experiment and also sealant tape were to use for final adjustments. As it can also be seen that this model was also having some holes on the top which has been covered with tape and plastic (from a disposable cup) to avoid errors in experiment.
Figure 2.2

When the initial set up was made then reinforcements were placed in the form of layers, for this eight rectangular shaped parts are used and they are laid according to the orientation 0, 90 degrees. Spiral tubes are also set up in this step and their position is secured by using sealant tape and also the pipe for resin infusion can be seen which is glued with clay on the surface.
Now as the figure shows same procedure was adopted like hemispherical model and the peel ply, breather and bleeder were placed accordingly then the boundary is made through sticky tapes and it is covered with plastic bag to make vacuum. Pump has been started and vacuum was generated as seen in figure.
Like in the hemisphere again a cut has been made on the top of the plastic bag to suck the excessive resin and to generate vacuum for which a pipe has been used and it is further connected with a catch tank, basically what catch tank does is it collects the extra amount resin from the system to make proper alignment in the experiment. One thing has to be noticed that some release agent has to be applied on the inner surface of the tank so that resin could be removed easily from it after the experiment.

Figure 2.4
when proper vacuum was checked then resin mixture was prepared and again glass epoxy resin has been used for the experiment with the same resin - hardner ratio as was in hemispherical model i.e. 100 : 26 as shown in figure then it is mixed and ready for infusion then infusion was made and kept for 8 hrs in room temperature for curing.
Figure 2.6
The above figure the set up is shown after curing and heat treatment. Heat treatment was given for 8 hrs in the temperature 70 degrees. This treatment was given by placing the whole set up inside an oven in the workshop.
Figure 2.7

Now the model has been separated from the mould and as from the diagram it can be seen that it was successfully removed from the cartwheel. Now the actual part has to be removed. It required a lot of effort for removing the mould from the peel ply and safety gloves were used to avoid any injuries and this has been done with the help of 2 people.
Figure 2.8

As shown in figure that mould was successfully removed and the rest of the setup looks like this.
Figure 2.9

This is the final version and it was nice results at the end. the inner portion can be seen from the figure.
Figure 2.10

The back part of the mould without any bump or damage it was perfect this sample will be there in the work shop for those who are interested.
Rule of Mixtures for composites

Rule of Mixtures is a method to predict the properties of composite materials, based on an assumption that a composite property is the volume weighed average of the phases or its properties of the dispersed phase and matrix phase.

Through rule of mixtures we can find the following properties of a composite material.

- Tensile strength
- Shear modulus
- Modulus of elasticity
- Poisson’s ratio
- Density
- Coefficient of Thermal expansion

Tensile Strength

For long-fiber reinforced composite in longitudinal direction

\[ \sigma_c = \sigma_m \times V_m + \sigma_f \times V_f \]

Where

\( \sigma_c, \sigma_m, \sigma_f \) – tensile strength of the composite, matrix and dispersed phase (fiber) respectively.

For short-fiber composite in longitudinal direction
(Fiber length is less than critical value $L_c$)

$$L_c = \sigma_f \frac{d}{\tau_c}$$

Where

$d$ – Diameter of the fiber;

$\tau_c$ – shear strength of the bond between the matrix and dispersed phase (fiber).

$$\sigma_c = \sigma_m V_m + \sigma_f V_f (1 - L_c / 2L)$$

Where

$L$ – Length of the fiber

For short-fiber composite in longitudinal direction

(Fiber length is greater than critical value $L_c$)

$$\sigma_c = \sigma_m V_m + L \tau_c V_f / d$$

Shear modulus

$$G_{ct} = G_t G_m / (V_f G_m + V_m G_t)$$

Where:

$G_t$ – shear modulus of elasticity of fiber material;

$G_m$ – shear modulus of elasticity of matrix material;

Modulus of Elasticity
Long align fibers

Modulus of Elasticity in longitudinal direction ($E_{cl}$)

$$E_{cl} = E_m * V_m + E_f * V_f$$

Modulus of Elasticity in transverse direction ($E_{ct}$)

$$1/E_{ct} = V_m/E_m + V_f/E_f$$

Short fibers

$$E_{cl} = \eta_0 \eta_L V_f E_f + V_m E_m$$

$$\eta_L = 1 - 2/\beta L \tanh(\beta L /2)$$

$$\beta = \sqrt{8 G_m / (E_f D^2 \ln(2R/D))}$$

where:

$E_f$ – modulus of elasticity of fiber material;
$E_m$ – modulus of elasticity of matrix material;
$G_m$ - shear modulus of matrix material;
$\eta_L$ – length correction factor;
L – fibers length;
D – fibers diameter;
$2R$ – distance between fibers;
$\eta_0$ - fiber orientation distribution factor.
$\eta_0 = 0.0$ align fibers in transverse direction
$\eta_0 = 1/5$ random orientation in any direction (3D)
$\eta_0 = 3/8$ random orientation in plane (2D)
\( \eta_0 = 1/2 \) biaxial parallel to the fibers
\( \eta_0 = 1.0 \) unidirectional parallel to the fibers

**Poisson's ratio**

\[ \mu_{12} = \nu_f \mu_f + V_m \mu_m \]

Where:

\( \mu_f \) – Poisson's ratio of fiber material;
\( \mu_m \) – Poisson's ratio of matrix material;

**Density**

\[ d_c = d_m * V_m + d_f * V_f \]

Where

\( d_c, d_m, d_f \) – densities of the composite, matrix and dispersed phase respectively;

\( V_m, V_f \) – volume fraction of the matrix and dispersed phase respectively.

**Coefficient of Thermal Expansion**

in longitudinal direction (along the fibers)

\[ \alpha_{cl} = (\alpha_m * E_m * V_m + \alpha_f * E_f * V_f) / (V_m * E_m + E_f * V_f) \]

Where

\( \alpha_{cl}, \alpha_m, \alpha_f \) – CTE of composite in longitudinal direction, matrix and dispersed phase (fiber) respectively;
$E_m, E_f$ – modulus of elasticity of matrix and dispersed phase (fiber) respectively.

*in transverse direction (perpendicular to the fibers)*

$$\alpha_{ct} = (1+\mu_m) \alpha_m V_m + \alpha_f V_f$$

Where

$\mu_m$ – Poisson’s ratio of matrix.

**Poisson’s ratio** is the ratio of transverse contraction strain to longitudinal extension strain in the direction of applied force.

Through this following figure it is obtained that rule of mixture is the better option to get the experimental data.
Fig 10 graph for rule of mixtures

Through the above equations the calculation for glass epoxy has been done which can be seen from the following table.

Table 1a Lamina properties
Table 1b Lamina properties

<table>
<thead>
<tr>
<th>Materials</th>
<th>P</th>
<th>E</th>
<th>G</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-Glass</td>
<td>2.55</td>
<td>8.00E+10</td>
<td>5.00E+10</td>
<td>0.2</td>
</tr>
<tr>
<td>Matrix</td>
<td>1.144</td>
<td>3.50E+09</td>
<td>2.92E+09</td>
<td>0.4</td>
</tr>
<tr>
<td>Fv</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Where p is in grams per centimeter square and E and G are in giga Pascal's.

Also help of HALPIN TSAI EQUATION has been taken.
TEST AND RESULTS

Three point bend test and torson test have been performed with the samples obtained with the flat 2 dimensional plate which looks like this.

These are the samples which were used for the three point bend test.
These are the samples used for torsion test.

The results obtained from the test are shown in the form of graph.
This graph shows the 3 point bend test on the samples which were not exactly up to the standard because the dimension of the samples were not perfect according to the test machine.
The above graph shows the torsion test performed and which is also not up to the mark because of the samples dimension which was found after cutting but further analysis will be carried on in these results.

After converting the above graph into Stress-Strain curve and finding the E for 3point bend and flexural test by its gradient then it has been compared with the value of E calculated with Halpin- Tsai equation. If the value of the E from the gradient is equal to half the value of E from Halpin Tsai then test results were assumed to be good.

Stress-Strain curve for 3 point bend test
Graph for sample 1 and 2 (3pt test)

Graph for sample 3 and 4 (3pt test)

Stress-Strain curve for Tension test
Graph for sample 1 and 2 (tension test).

Graph for sample 3 and 4 (tension test).

From all the charts shown above the gradient has been calculated like E₁, E₂, E₃, E₄ for 3 point bend (Eflexural) and e₁, e₂, e₃, e₄ for tension test (ETension) and they are:

E₁ = 196, E₂ = 160, E₃ = 140, E₄ = 135
And e₁ = 7000, e₂ = 13000, e₃ = 10000, e₄ = 9000.
If the values are compared with the value of $E$ from Halpin Tsai Equation so it is not equal to half of the value so it is concluded that the test were not so good.

RESULTS OF VI PROCESS

The experiment has been performed various times to understand the concept and to get better result at last so after performing some experiments in two dimensional and in three dimensional following results are obtained.

These figures show the successful but not the perfect sample obtained.
The above picture shows the failure result of the two dimensional plate because the resin was unable to flow properly and evenly at every area and the middle portion was left like that only.

Above pictures show the result obtained from three dimensional test of the hemispherical model which was failed because shape of the model. It was very difficult to stop the resin to flow inside as it can be seen in the figure that the resin has flown inside of the modal and now it can be separated from the model it has to be cut in the work shop.

The above are the results obtained from the cart wheel modal and which shows the satisfactory result because the shape was perfect for the experiment starting from the
initial layup to the final result there were no any disturbances found and got good results.

**DISCUSSION AND CONCLUSION**

**DISCUSSION**

In this project various set of experiments have been performed to understand vacuum infusion process and to work for how to make it better, so for that the proper setup and variations have been discussed on the literature review of this report by following that better results can be obtained and also 3pt bend and tension has been performed and by converting the results sin stress – strain form compared with the value of E obtained from HalpinTsai equations.

**CONCLUSION**
This project has given the brief introduction and overviewed about textile composites and described the vacuum resin infusion process for manufacture through textile composites.

It has established an understanding of the VI manufacturing process and reviewed the difficulties occurred at the time of experiment. By doing this a better platform has been generated which will allow future progress on this.

It has been seen after doing the VI experiments that there is no any specific kind of set up for this experiment and it can be performed according to the results wanted. The results can be made better only by using some means like thermal gun, Enka fusion resin jacket etc which will lead to proper results and also different variations can be used to get result according to the demand.

Finally three point bend test and torsion test have been done with the samples of the 2d and 3d models which were not up to the standards.

Unfortunately the FEM test (simulation) was not completed by the end of this project this was due to the partial knowledge of the software ABAQUS which took some time to understand.

With more time on this project further testing and simulation would have been performed and by matching them a better conclusion have been made.
Also more detailed testing and calculation would have been written with larger allowances of pages.

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APPENDICES
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
ACE/64, 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 responsibility 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

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BS EN 2746:1998

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Aerospace series — Glass fibre reinforced plastics — Flexural test — Three point bend method
## En 2748:1998

### Foreword

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

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 EACMA, 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, Ireland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Swedan, Switzerland and the United Kingdom.

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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 27148, Aerospace series — Reinforced plastics — Standard procedures for conditioning prior to testing.
EN 2823, Aerospace series — Fibre reinforced plastics — Test method for the determination of the effect of exposure to humid atmosphere on physical and mechanical characteristics.

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.

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, r₁, of the loading nose and the radius, r₂, of the supports shall be as follows:

\[ r_1 = (d \pm 0.1) \text{ mm}; \]
\[ r_2 = (2 \pm 0.2) \text{ mm}. \]
It shall be possible to adjust the span (see Figure 1).
6 Specimens

6.1 Dimensions
- Thickness: "A": (3 ± 0.2) mm
- Width: "B": (15 ± 0.5) mm
- Length: "L": (20 × A) ± 1 mm

NOTE: If it is impossible to obtain specimens from the finished component, prepare test panels according to EN 2748 or a suitable method agreed 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:

\[ r_2 \geq 1.5 \times h \]

6.2 Number:
Minimum of five.

7 Procedure

7.1 Conditioning
EN 2748 for tests in the initial state.
EN 2408 for tests after immersion.
EN 2523 for tests after exposure to humid atmosphere.

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

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

\[ L = (16 \times h) \pm 1 \]

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 \( V \):

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

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

\[ V = K \frac{h}{h} \]

where:
- \( V \) is the test speed, in millimetres per minute;
- \( K \) is the thickness of the specimen, in millimetres;
- \( h \) is 0.5 mm⁻¹.

7.5 Test atmosphere

Carry out the tests at (23 ± 2) °C and (50 ± 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

\[ \sigma_i = \frac{3FL}{2bh^2} \]

where:
- \( \sigma_i \) 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:

\[ \sigma_i = \frac{3FL}{2bh^2} + \frac{4d}{E} \]

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.
EN 2746:1998

\[
\begin{align*}
E_t &= \frac{P}{b h^2} \\
\Delta F &= \frac{DN}{h} \\
\Delta d &= \frac{\Delta F}{E_t}
\end{align*}
\]

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.

8.8 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.

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.
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 etc.

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

METHOD OF CLEAN UP
RECOVERY
Spread sand
Collect the product in a container pending future destruction
MANUFACTURE OF ADVANCED TEXTILE COMPOSITES

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), SCRMIP™ and RIF (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 (50°C) postcure, offering the finished laminate properties that lie between hard 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 geltime of the resin to be more closely matched to the required infusion time for any particular size of moulded part.

Extensive testing at SP have shown that PRIME™ 20LV with Slow and Extra Slow Hardeners provide an excellent bond to certain types of vinyl ester resins. 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 hull/keels 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.
Manufacture of Advanced Textile Composites

Table 1. Component Properties

<table>
<thead>
<tr>
<th>Mix Ratio by Weight</th>
<th>UV Resin</th>
<th>Hardener Fast</th>
<th>Hardener Slow</th>
<th>Hardener Extra Slow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mix Ratio by Volume</td>
<td>100</td>
<td>26</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>Viscosity 80°C (cP)</td>
<td>1010</td>
<td>31.4</td>
<td>31.4</td>
<td>31.4</td>
</tr>
<tr>
<td>Viscosity 80°C (cP)</td>
<td>1010</td>
<td>20-27</td>
<td>19-24</td>
<td>18-18</td>
</tr>
<tr>
<td>Viscosity 60°C (cP)</td>
<td>600-840</td>
<td>20-02</td>
<td>15-17</td>
<td>13-15</td>
</tr>
<tr>
<td>Viscosity 60°C (cP)</td>
<td>380-410</td>
<td>16-18</td>
<td>13-14</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>1</td>
<td>Clear</td>
<td>1</td>
</tr>
<tr>
<td>Mixed Colour (Gardener)</td>
<td>-</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>1.123</td>
<td>0.903</td>
<td>0.936</td>
<td>0.931</td>
</tr>
<tr>
<td>Mixed Density</td>
<td>-</td>
<td>1.059</td>
<td>1.084</td>
<td>1.083</td>
</tr>
<tr>
<td>Hazard Category</td>
<td>XI 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 : 28 (by weight)
- 100 : 31.4 (by volume)

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 : 28 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 60°C or 16 hours at 50°C. Ambient temperature (15-25°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. 35-40°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 – Tcmax 150g 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>0:35</td>
<td>0:28</td>
<td>0:23</td>
</tr>
<tr>
<td>Latest flow under vacuum (theoretical, thin film, hr : min)</td>
<td>3:50</td>
<td>3:10</td>
<td>2:40</td>
</tr>
<tr>
<td>Earliest vacuum off time (theoretical thin film) (hr : min)</td>
<td>8:10</td>
<td>4:15</td>
<td>3:20</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, see “Rontemted Products Technical Characterisation” which can be found in the “Materials and Process” section on the website. www.gft.com. All figures quoted are indicative of the properties of the product concerned. Some batch 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 (Mettler Toledo DSC302iE), and Dynamic Mechanical Thermal Analysis (Rheodyne Thermal Analyser MDIII) 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>18hrs 50°C</td>
<td>18hrs 50°C</td>
<td>18hrs 50°C</td>
</tr>
<tr>
<td>Tg (DMTA - peak tan δ)</td>
<td>62.9</td>
<td>62.6</td>
<td>62.9</td>
</tr>
<tr>
<td>TgUH (DMTA)</td>
<td>74-76</td>
<td>87-89</td>
<td>90-92</td>
</tr>
<tr>
<td>Tg1 (DMTA)</td>
<td>68-70</td>
<td>69-70</td>
<td>69-71</td>
</tr>
<tr>
<td>JM – 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>18hrs 50°C</td>
<td>18hrs 50°C</td>
<td>18hrs 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>1.1</td>
<td>3.5</td>
<td>3.1</td>
</tr>
<tr>
<td>Moisture Absorption (%)</td>
<td>1.1%</td>
<td>1.1%</td>
<td>1.1%</td>
</tr>
<tr>
<td>Cured density (g/cm³)</td>
<td>1.53</td>
<td>1.44</td>
<td>1.32</td>
</tr>
<tr>
<td>Linear Shrinkage (%)</td>
<td>1.83%</td>
<td>1.76%</td>
<td>1.54%</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>18hrs 50°C</td>
<td>18hrs 50°C</td>
<td>18hrs 50°C</td>
</tr>
<tr>
<td>Compr. Strength (MPa)</td>
<td>473</td>
<td>492</td>
<td>456</td>
</tr>
<tr>
<td>LSSS (MPa)</td>
<td>47.6</td>
<td>47.0</td>
<td>62.6</td>
</tr>
<tr>
<td>LSSS wet retention (%)</td>
<td>1.1%</td>
<td>1.1%</td>
<td>0.5%</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
Manufacture of Advanced Textile Composites

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Gurit (UK) Ltd
St Cross Business Park
Newport, Isle of Wight
United Kingdom PO30 5WU
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,
More Vale, 2163 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,
Mapogu, (Québec) J1X 5G9, Canada
T +1 819 847 2182
F +1 819 847 2572
E info-na@gurit.com
W www.gurit.com