Table of Contents

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

The composites industry began to take off in the 1940s and grew rapidly in the 1950s. [TPI Website] A composite is generally any material that is made up of different constituent materials. Composites are often combined in pairs where one material is in the form of a fiber and the other creates a matrix to support the fiber. Composites are engineered materials made from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct on a macroscopic level within the finished structure.

Today, the composites industry continues to grow as a major provider of products. Composite materials are used in a wide range of applications from automotive, aeronautic and sport sectors to construction and architecture. [ALCAN Website] Different manufacturing processes exist depending on the type of application, production rate and size of the components and the technique to produce composite parts include filament winding. The other technique is known as hand lay-up. In hand lay-up, fabric is placed onto a tool where the resin is applied by hand using rollers and squeegees. [Mastbergen, 2007] Then, when more industrialized process began to evolve for the use on aircraft, more process is being created such as Resin Infusion, Resin Transfer Molding process (RTM), Vacuum Assisted Resin Transfer Molding (VARTM), and Seemanns Composite Resin Infusion Molding Process (SCRIMP^{TM}) [Mastbergen, 2007]

Vacuum Resin Infusion is a molding process for the manufacturing a large composite structures. It is considered a closed mold process where a vacuum draws resin into a dry fiber laminate in a one-sided mold and then a film membrane is placed over the top and sealed around the mold. Vacuum Resin Infusion is an environmentally friendly alternative to open mold spraying and this method produces consistent, high quality parts for products like pleasure boats and wind turbine blades.

However, producing a successful part using Vacuum Resin Infusion can be very challenging due to the complex geometry and predicting the flow front through mold is also a difficult problem. This is commonly done by experts who rely much on experience. [Mastbergen, 2007] Furthermore, a trial and error process is also used to detect and eliminate problems involving mold construction. In this trial and error process, the resin is injected partially and slowly to let it set up. Then, this process is repeated using more resin to create a series of parts with a progressing flow front. [Mastbergen, 2007] This process is very useful in identifying where the vacuum need to be located and where more injection resin ports are required to achieve better quality final part.

In wind turbine blade manufacturing, the blade is manufactured using either hand lay-up or Vacuum-assisted resin transfer molding (VARTM) of prepreg in open molds. Several blade manufacturing company for example GE Energy (Atlanta, Ga.), Suzlon Energy Ltd. (Aarhus,Denmark), Nordex AG (Norderstedt, Germany) and LM Glasfiber Group (Lunderskov, Denmark) all use some form of resin infusion, rather than hand lay-up to improve the fiber-to-resin of their all-fiberglass blades. [Hogg, 2007]

More country now invested in installing wind turbine to generate power such as China thus wind turbine blade development become crucial to ensure it works at its best in generating power for respected country. Blades are become longer and thus heavier, so, it needs to be stiffer. Wind turbine blades also will be installed off-shore and that is why the blade must be lighter. [Hogg, 2007]

Benefits of using resin infusion as compared to a non-vacuum bag curing of composite laminates include better fiber to resin ration, thus it can reduce the weight of the composite for the whole blade. Resin infusion also will produce a stronger laminate, low void content, reduced resin usage due to pre-compacted fabric and also faster ply lay-up. These benefits will produce a better quality of the blade.

However, as mentioned before, there will be some challenges in resin infusion in manufacturing blade such as wrinkles, delaminations and dry-spots. Therefore, the excellent distribution channels that cover the whole surface of the complex geometry are very desirable. No models were found that handles this type of process specifically. [Mastbergen, 2007] Thus, the goal of this project is to model an effective resin infusion strategy for wind turbine blade.

1.2 PROBLEM STATEMENT

In resin infusion, complete wetting of the fiber containing preform becomes increasingly difficult as the design getting complex and the cross-sectional thickness of the preform increases, particularly for the layers of the preform centrally positioned within thicker cross-sectional areas of the preform. Moreover, the time required for resin infusion of parts and assemblies increases in a non-linear fashion with cross-sectional thickness of the preform. [Hogg, 2007]

This project is relevant because it is studied and investigated about the infusion strategy of the resin infusion for the close profile. Many trials and researches have been done to the open profile but never for the fully close profile since it is complicated to perform the method for close profile for instance, the thickness of the production will not be uniform due to the many aspects including pressure difference throughout the profile, the position of the resin inlet as well as the vacuum outlet and due to the complicated shape of the mold can effect whether it is successful to achieve the completeness wetting the fiber containing preform during this resin infusion process.

Therefore, a strategy of infusion must be made to achieve an effective resin flow throughout the preform as well as to attain the uniform distribution throughout the design, which is required in order to substantially eliminate voids and bubbles. This infusion strategy is also aimed at achieving complete wetting of all areas within the fiber containing preform, thereby improving the curing process, with resultant greater strength, consistency, and quality control for the parts and assemblies produced.

1.3 OBJECTIVE AND SCOPE OF STUDIES

The objective of this project is listed as below:

1. To investigate the effect of infusion strategy on the filling time and flow of resin.
2. To propose the effective infusion strategy for the wind turbine blade design.

The scopes of study for this project are designing the wind turbine blade. This also includes the study of resin flow characteristic to understand better how resin travels within the wind turbine blade perform. The scope is limit to the usage of glass fibre with latex – epoxy and wood core.

In addition, the strategy of infusion is bound to line feeding and point feeding. More explanations will be provided in the methodology. Once the characteristic of the resin flow has been studied, the material arrangements for performing the project can be easily done. Further investigation will be conducted through this project.

CHAPTER 2

LITERATURE REVIEW

2.1 MANUFACTURING PROCESS

Resin Infusion is one of the manufacturing methods that is widely use nowadays for processing composites material. This method generally involves the use of a mold to enclose one or more fiber containing preforms, a means of imposing a vacuum on the mold, and resin is introduced into the mold for infusion through the preform which infusion is assisted by the draw of the vacuum.

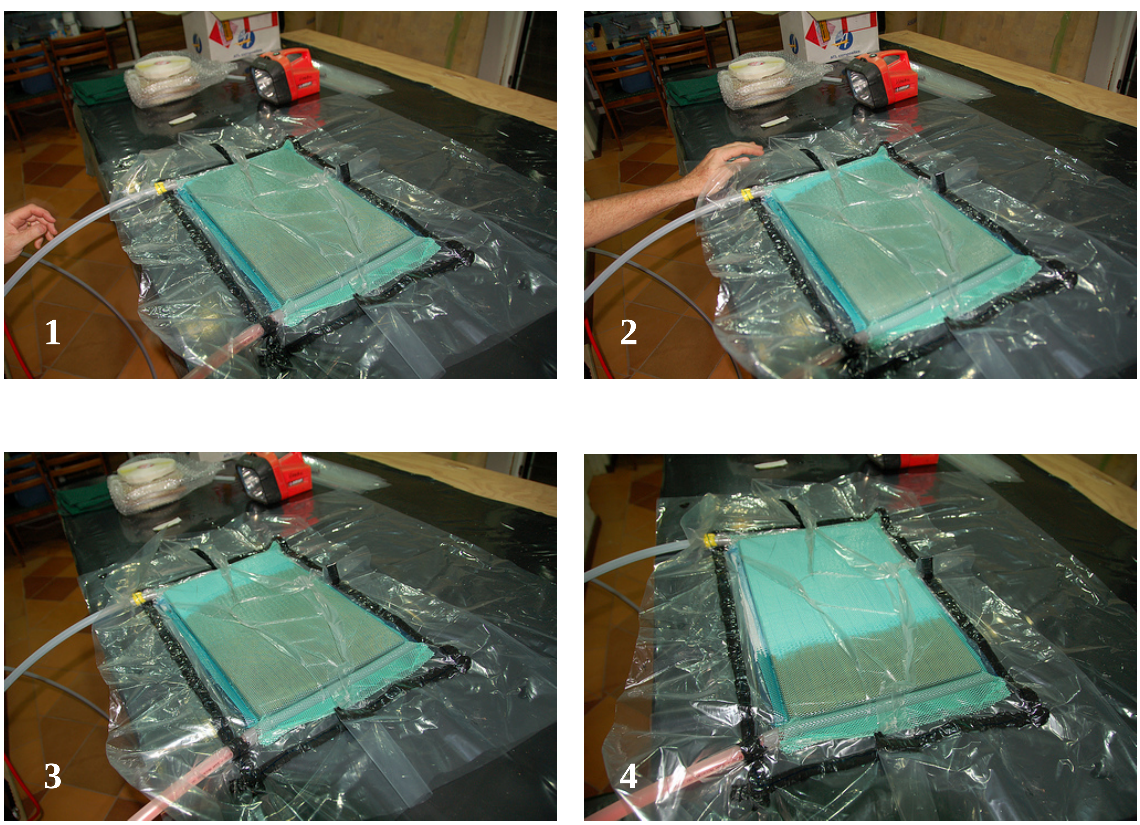


Figure 1: The process of resin flow through the fiber in vacuum resin infusion process

Large and complex structures had to be broken down into multiple pieces of a more simple design for the resin infusion takes place. [Mastbergen, 2007]

The Resin Transfer Moulding Process is using high pressure to bring the resin into the mould. The mould can contain single laminates or sandwich laminates. The high temperature and pressure applied with this process requires higher mechanical and thermal properties of the foam.

On the other hand, Vacuum Assisted Resin Transfer Molding using two-sided mold and a vacuum is drawn on the fabric, while a flexible bagging is forced against the preform at the atmospheric pressure. To deal with the problem of getting the resin to flow large distance through the fabric, a distribution network is used. This distribution network allows the resin to flow through high permeability channels or layers to disperse it throughout the mold. [Mastbergen, 2007]

Vacuum assisted resin infusion under flexible tooling is named because of the flexibility of the plastic bag used in resin infusion - the porosity of the reinforcement and hence permeability depends on the level of vacuum achieved. Just because the permeability measured in a stiff mold cannot be used to simulate the process of the resin filled up the fiber, they using a modified value of permeability in order to reflect the flexibility of the mold cover. [Joubaud, Trochu, Le Corvec, 2002]

There is also SCRIMP™ process where it is characterised by an additional resin flow media outside of the sandwich part. During the infusion process, the resin flow media is distributing the resin quickly over the surface of the part from where it infuses into the sandwich component. Because the resin flow media shall not be part of the sandwich construction, peel ply or perforated foil is placed between the flow media and the surface of the sandwich component. Both layers are designed for one way use and need to be disposed of after curing of the resin. [Mastbergen, 2007]

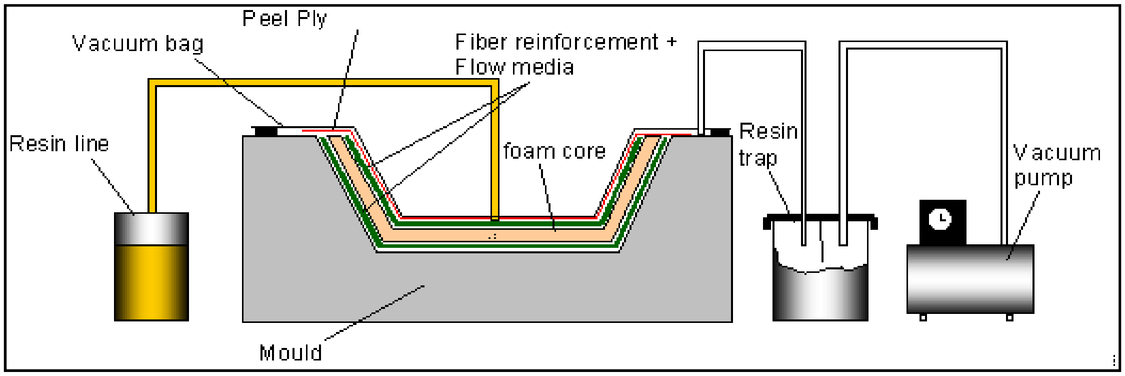


Figure 2: SCRIMP™ Process

A very similar process known as the Fast Remotely Actuated Channeling process (FASTRAC) is a more recent variation of this general principle. The main difference in the FASTRAC and pressure bag molding process compared to SCRIMP™ is that, there is a more refined distribution strategy.

The distribution network is created by a “FASTRAC layer” which is a flexible membrane with tightly spaced channels formed into it. The major difference is that these channels can be collapsed to force the extra resin though the fabric or out of the mold, rather than leaving them attached to the part as in SCRIMP™. [Larson, 2004]

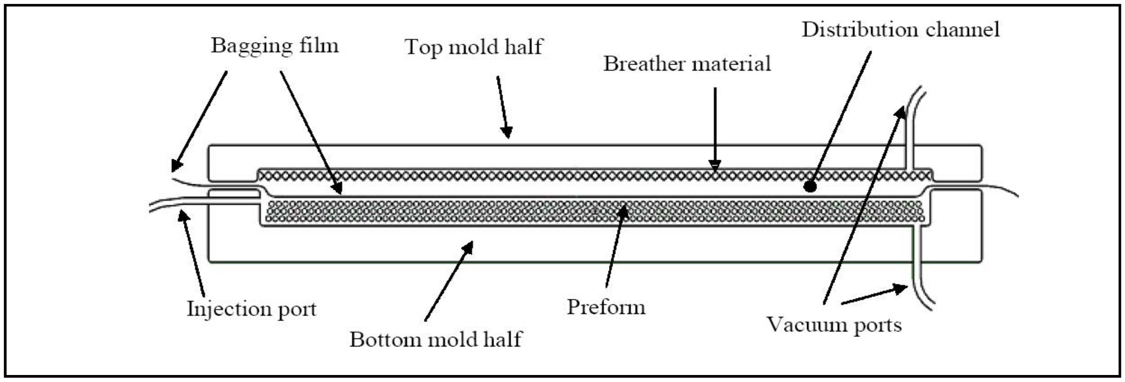


Figure 3: Schematic for pressure bag molding

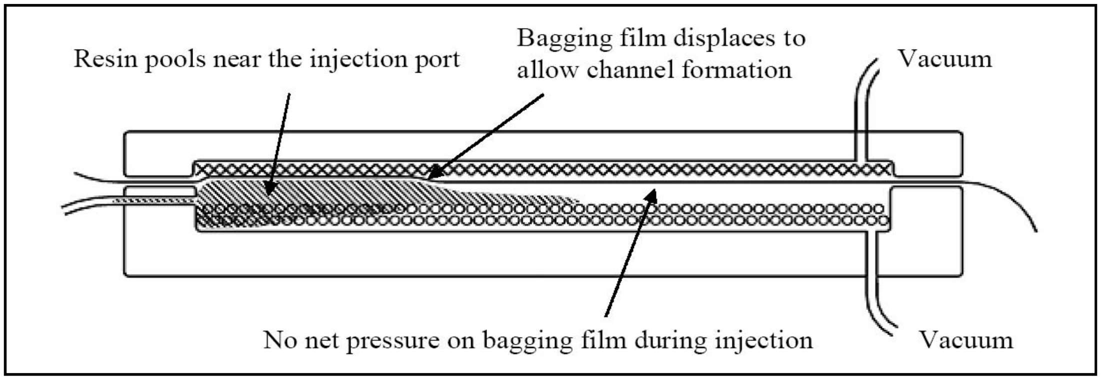


Figure 4: Pressure bag molding process during stage one. [Larson, 2004]

A summary of the manufacturing process are described below taken from Daniel Blair Mastbergen:

Table 1: Summary of manufacturing process.

Process	Basic Principles	Advantages	Disadvantages
Hand Lay-up	Open mold Manual infusion One-sided mold	Low cost Fastest implementation	Volatile emissions Health risks Inconsistent results Less efficient material usage
RTM	Closed mold In-plane resin flow Two-sided mold	Higher dimensional consistency Less volatile emissions Both sides finished	Higher mold cost Resin flow pattern critical Costly equipment required Lowest volume per port
VARTM	Closed mold In-plane resin flow Two-sided mold Evacuated mold	Higher dimensional consistency Less volatile emissions Both sides finished Higher quality products than RTM	Higher mold cost Resin flow pattern critical Costly equipment required Complexity of vacuum porting
SCRIMPTM	Closed mold In-plane resin flow One-sided mold Evacuated mold	Higher dimensional consistency Less volatile emissions Higher quality products than RTM	Propriety process One side finished
FASRAC + Pressure Bag	Closed mold Channel flow One side critical Evacuated mold	High quality High dimensional consistency Less volatile emissions Largest injection volume per port	Added cost of FASTRAC layer or top mold half Highest complexity Possible artifacts from bag Costly equipment required

Patrick J. Thrash et al enclose providing a resin infusion mold tool system with vacuum assisted resin transfer molding that uses a subsequent pressure bleed to achieve high fiber volume fractions on complex composite structures. The mold tool system includes toolings that are positioned under a vacuum bag. The mold tool system and pressure bleed method of the present invention has several advantages which are; large and complex fiber composite structures can be manufactured as a single piece, reduce the cost and labor usage, and the composite structure produced has a high fiber volume fraction.

However, the behavior of the resin during the infusion process is not fully understood yet and the processing strategy used in many applications is not always desirable. Problems of micro-porosity, irregular thickness and defects have been observed locally in parts manufactured by resin infusion. [Joubaud, Trochu, Le Corvec, 2002]

Laurent et al mentioned in their journal of using classical RTM simulation software in investigating and evaluating the difference in the filling behavior between “rigid” and “flexible” molds. By using the RTM simulation software, they can validate and compare the results between the numerical simulation using the software for a complex automobile part manufactured by resin infusion with actual test results obtained at the factory. The result obtained is that the flow fronts in the simulation and in the real infusion are very close during the whole experiments. It is observed that the local differences seen between the actual tests with the numerical may be due to local variations in thickness of the fiber bed. It tends either to be slightly compressed in convex regions or expanded in concave regions.

Unfortunately, referring to Mastbergen and his work in selecting and modeling a process that would be optimal for creating a large wind turbine blade, even using commercially available software can be difficult for complex one-sided molding processes. Some existing finite element programs such as ABAQUS also have porous media fluid elements capable of orthotropic or anisotropic permeability tensors. For closed mold processes, this program could be used to model complex three dimensional geometries with little additional programming. However, for one-sided molding processes there would still need to be a large amount of manual programming.

In this project however, the experiment done is based on try an error since the simulation software is unavailable. By thorough studies, good infusion strategy and better assumptions, a number of trials can be reduced significantly to get much desire results.

There are different ways to do vacuum infusion. They differ in the way the resin is transported through the dry laminate and whether there is an additional pressure on the resin. The table [Matbergen, 2007] below shows the different methods and process parameters:

Table 2: Methods and process parameters

	Vacuum for resin flow	**Pressure on resin**	**Mould closing**
Vacuum infusion with flexible	0.5 – 1 bar	-	Vacuum bag
Vacuum infusion with closed FRP mould (RTM light)	0.3 – 0.6 bar	Up to 1 bar	Vacuum / mechanical
Resin Transfer Moulding (RTM)	Up to 1 bar	2 – 12 bar	Mechanical

This project is using Vacuum Resin Infusion technique where it uses vacuum pressure to drive resin into a laminate. Materials are laid dry into the mold and the vacuum is applied before the resin in introduced. Once a complete vacuum is achieved, resin is literally sucked into the laminate via carefully placed tubing.

2.2 INFUSION CHARACTERISTICS

In the Vacuum Infusion process, a stiff mould half is covered with a stack that includes reinforcement, a bleed out fabric, a resin distribution medium and a breather.

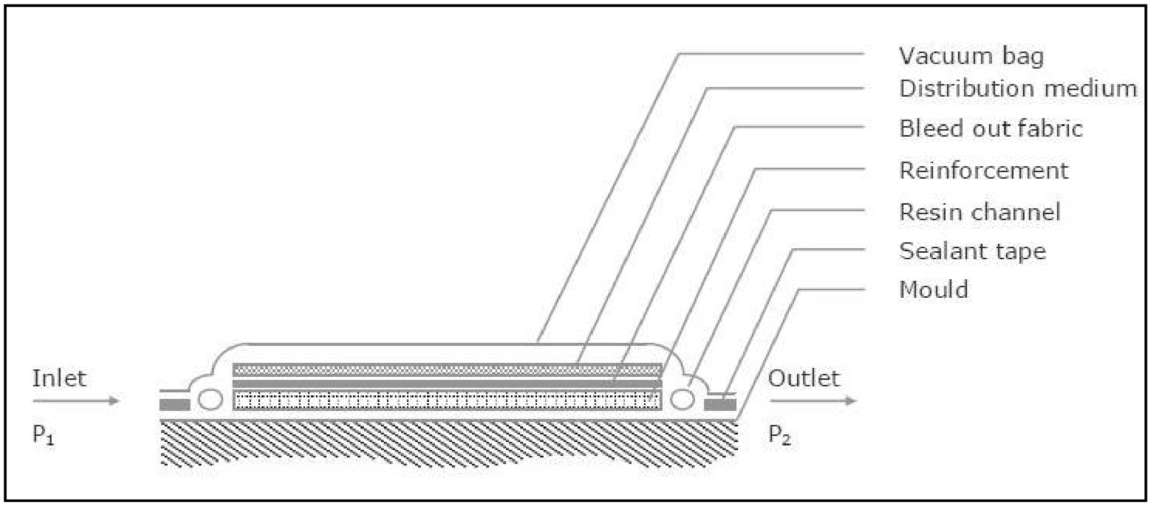


Figure 5: The arrangement of vacuum infusion

An inlet is connected to an atmospheric supply of liquid resin. The outlet is normally connected to a vacuum pump, via resin trap. The cavity is evacuated and resin is admitted. Flow is driven by the pressure difference and when the cavity is judge to be filled, the resin supply is usually cut off. The part is debagged only after resin is cured. The distribution medium modifies the impregnation dynamics and the fluid flows mainly through the thickness of the preform. Depending on the type of fabric infused, this trans-plane flow evolves very differently. [Regondet, 2005]

The resulting distance between the flow front observed on the bag and that observed on the mould is called lead-lad depends mainly on the strategy of infusion, permeability of both the distribution medium and the reinforcement, as well as the thickness of the reinforcement. A problem encountered with the presence of a lead-lag is that the upper side of the preform, in contact with the distribution medium, is fully filled before the rest of the part. When the upper side of the preform is fully filled (distribution medium side), this distance remains dry on the lower side. Resin flows preferentially in the distribution medium, which is fully impregnated and has a higher permeability. Therefore it takes much longer for the remaining dry area to be fully impregnated and large quantities of resin flow through the distribution medium before infusion is complete. If resin starts to gel before the dry area is fully impregnated, a dry patch remains in the laminate. [Ragondet, 2005]

A good strategy must be used to complete the impregnation. In order to optimize the quality of the final component, the strategy of filling the resin and the vacuum outlet must be organized properly.

In order to better understand the impregnation process in vacuum infusion, mould cavity with constant thickness is used as shown in figure. The infusion is conducted under imposed pressure or flow rate. Since the cavity thickness is constant, the permeability of the preform remains constant during the infusion. As described by Darcy's Law:

$$v = \frac{K}{\varepsilon \cdot \mu} \cdot \frac{dP}{dx} \qquad \text{Equation 2.1}$$

Where v is the interstitial velocity, K the preform permeability, ε the porosity, μ the fluid viscosity and $\frac{dP}{dx}$ is the pressure gradient over the flow distance. [Ragondet, 2005] An integration form of Darcy's law shows time as a function of flow front distance squared as described in equation below:

$$t = \frac{\mu \cdot \varepsilon}{2 \cdot K} \cdot \frac{x^2}{\Delta P} \qquad \text{Equation 2.2}$$

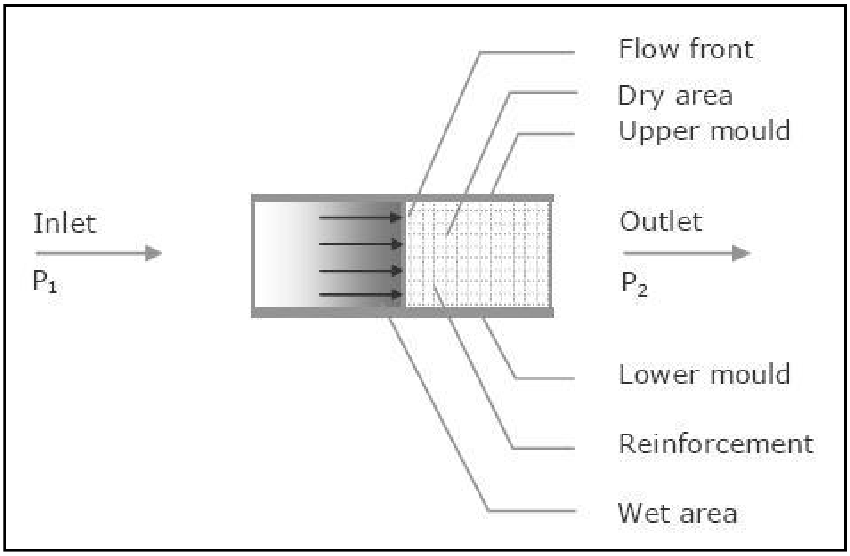


Figure 6: Flow front pattern

In vacuum infusion the upper face of the mould is made of a soft membrane, in this case, vacuum bag. A pressure difference is applied between the inlet of the mould, connected to a resin container under atmospheric pressure while the outlet of the mould is connected to a pump under vacuum. The preform is ready to be infused when the air has been extracted from the cavity, the air tightness of the mould has been checked and the pump has been adjusted to the required level of vacuum. Then the inlet is opened and the resin impregnates the preform. During the infusion, the compaction of the preform grows locally with the pressure gradient and flow front position. [Ragondet, 2005]

Zhou et al mentioning in their paper work the flow in resin injection can be simulated by Liquid injection molding simulation (LIMS) software developed at the University of Delaware. The inputs to the model are the fluid viscocity, the fiber volume fraction within the tows and the overall fiber volume fractions in the mold. The output records the time when each element is completely saturated. This allows one to track and record both the fully and partially saturated flow fronts. At a given instant in time, the fully saturated flow front is defined by the one-dimensional nodes that completely saturated during that time step.

If we use the LIMS output of: (i) time when the first tow near the gate gets saturated and (ii) movement of the unsaturated flow front with time as inputs, we can extract the bulk and tow permeabilities from our analytic solution. This is important because from a real experiment, one can collect the location of the unsaturated flow front without much difficulty but it will be challenging to identify the time when the tows get fully saturated near the inlet with one hundred percent accuracy in a real experiment in the laboratory. However from these two inputs, one can characterize the two permeabilities of a fabric using a constant pressure injection. [Zhou, Alms, G. Advani, 2007]

2.3 INFUSION STRATEGY

There are 4 main strategies of infusion namely as follows:

Point feeding

The feeding point of resin is at the first end. The vacuum line is positioned at the other end of the sandwich part. With this strategy, the resin flow gets slower and slower during the infusion. The resin mass flow keeps constant while more fabric area must be wetted.

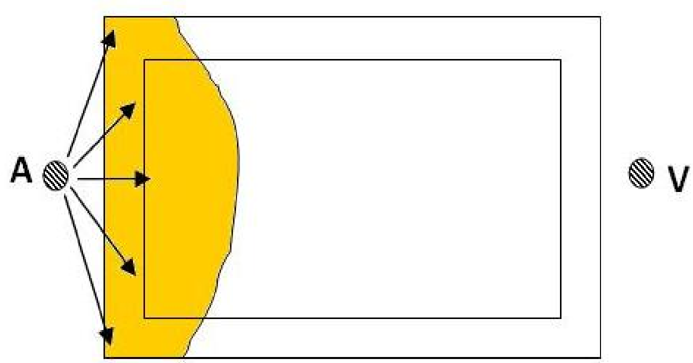


Figure 7: Point feeding

Edge feeding

The vacuum line is placed at the center on the sandwich part. The resin flow starts from the edge of the part. This strategy is very quick and all areas are wetted. Additionally, the waste of resin is reduced.

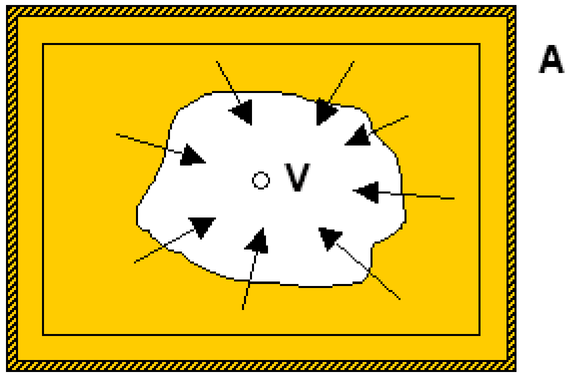


Figure 8: Edge feeding

Line feeding

This is the standard strategy for almost all forms to fill. The distance between the vacuum line and the resin feeding are important for the quality of the infusion. A short distance allows a quick filling of the part. It is recommended not to place the vacuum line more than 50 cm apart of the resin feeding point.

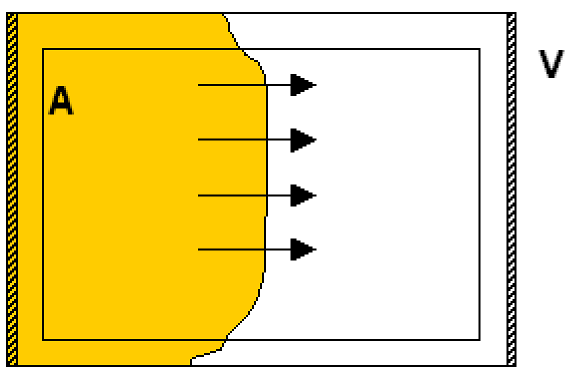


Figure 9: Line feeding

Multiple feeding

This is design especially for larger parts and it is useful to have more then one feeding lines for the resin. The opening of each point follows the flow of the resin. In the example below, first the feeding point A1 is opened until the resin flow reaches point A2. Then A2 will open as well. This strategy can also be used in combination with point feeding.

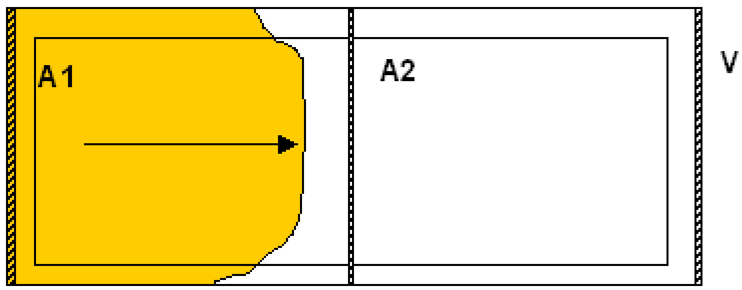


Figure 10: Multiple feeding

The chosen strategy are depends on several different parameters. The edge feeding is very practical for smaller part up to 100 cm in length or size. As for the point feeding, it is useful for the SCRIMP™ process. Line feeding is on first grid if no marks of the feeding points are allowed on the inside of the FRP parts. [ALCAN Composite Website]

2.2 WIND TURBINE BLADE

Wind turbine blade is the design which will be infused later. Like any wind turbine blade, it has aerodynamic shape.

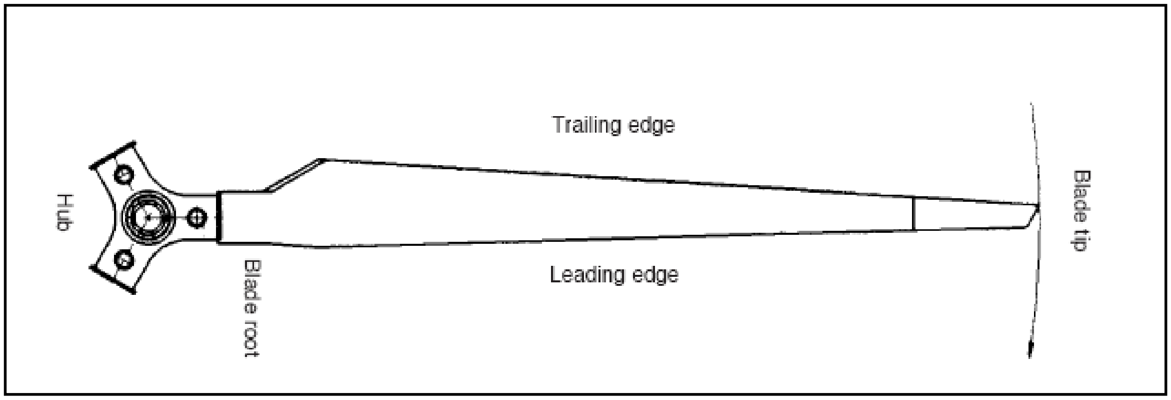


Figure 11: The different components of a wind turbine blade

The front and rear sides of a wind turbine rotor blade have a shape roughly similar to that of a long rectangle, with the edges bounded by the leading edge, the trailing edge, the blade tip and the blade root. If a blade were sawn in half, one would see that the cross section has a streamlined asymmetrical shape, with the flattest side facing the oncoming air flow or wind. This shape is called the blade's aerodynamic profile. [Stiesdal, 1999]

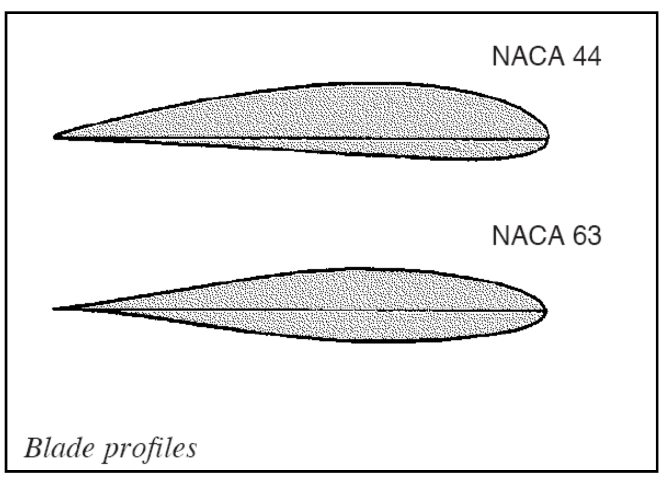


Figure 12: Few examples of blade profile

Producing a successful part using Resin Infusion can be very tough and tricky. Due to complex geometry (wind turbine blade) and the anisotropic permeability of the fabrics used, predicting the flow front though a mold is a difficult problem. A trial and error process is also used to detect and eliminate problems involving mold construction. In one such method a partial charge of resin is flowed and allowed to set up. This is repeated using more and more resin to create a series of parts with a progressing flow front. This process is very useful in identifying where outlet need to be located or where more resin inlet ports are required. [Mastbergen, 2007]

For smaller parts, the cost of doing this may be insignificant as long as a new mold is not required. It is known that resin will only travel in the path of least resistance thus a good strategy is needed to ensure complete wetting of the fiber containing preform in close profile can be achieved.

Optimal injection strategies will be studied and investigate further to reach the desired uniform distribution of the resin to the fiber. The goal of this project is to design an effective resin infusion strategy to achieve the complete wetting of the fiber for the wind turbine blade design.

CHAPTER 3

METHODOLOGY

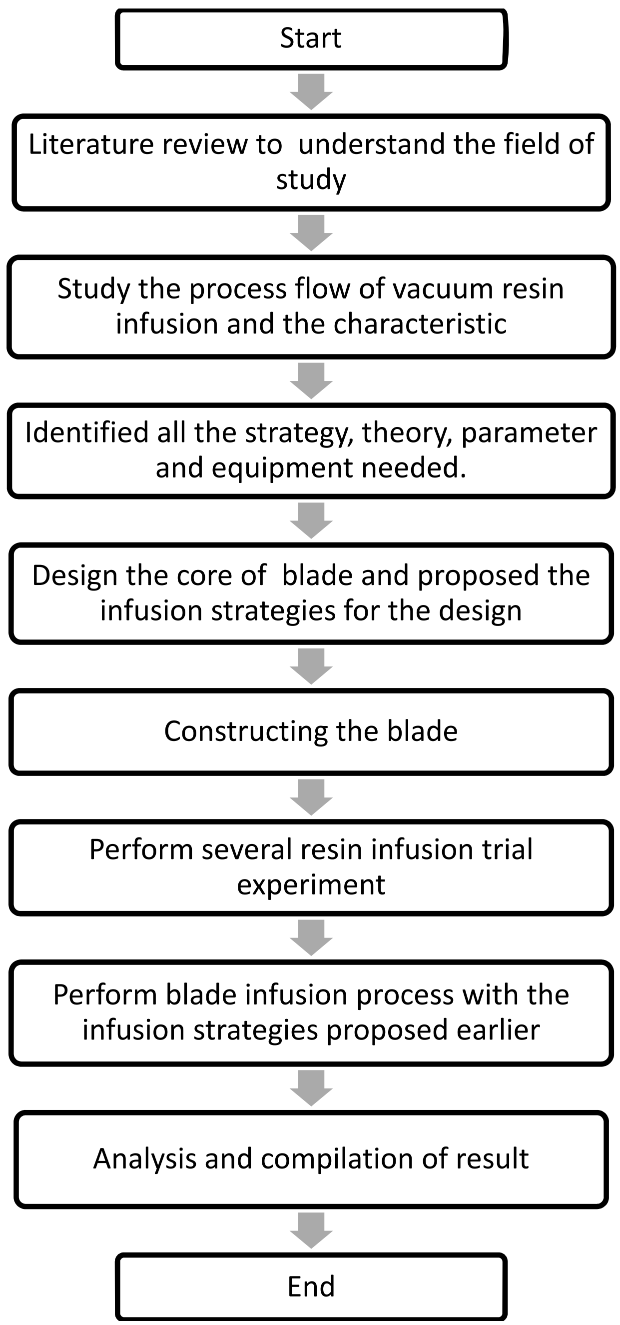


Figure 13: Methodology

3.1 MATERIALS

The material for blade (core) was Damar Hitam wood. Wood may be described as an orthotropic material; that is, it has unique and independent mechanical properties in the directions of three mutually perpendicular axes: longitudinal, radial, and tangential.

The usage of wood as the core has several advantages. Wood has several characteristics/properties that make it the ideal material for this project. In general, the properties of wood include; modulus of rupture whereby this reflects the maximum load-carrying capacity of a member in bending and is proportional to maximum moment borne by the specimen. Wood also has the ability to absorb shock with some permanent deformation and more or less injury to a specimen. In addition to that, wood also characterized by the ability to resist internal slipping of one part upon another along the grain which is termed as the shear stress parallel to grain. Other properties also include tensile stress, compressive stress, hardness and impact bending. [W. Green, E. Winandy, and E. Kretschmann, 1999]

Figure 14: Blade made from damar hitam wood

3.2 FLOW OF PROCESS

3.2.1 Blade Core Construction

Figure 15: The construction of the blade

The blades are made from the standard 1” thick × 8” width wood. The wood is chosen because it is easy to work with, a fine blade can be made from this wood with simple tools fairly quickly. It is also fairly inexpensive. It has an excellent strength/weight ratio, and it stands up to fatigue very well. The blades should be tapered in their width (narrower at the tips than they are near the root) by using a bandsaw. Next, the blades are also tapered in their thickness (they are thinner at the trailing edge than they are at the leading edge) by using power planer. This tool can nicely form the wood to the right shape. For the trailing edge, it need to be nicely rounded, so the conventional planer is used and then do the finishing altogether with sandpaper to get the blade the desired shape and smooth surface.

3.2.3 Resin Infusion trial experiment

i. Set up the experiment

The experiment on sample of resin infusion is conducted to familiarize and to learn the technique of infusion. The equipment for conducting the experiment is set up and listed as follows:

1. E-Glass Fiber
2. Peel Ply
3. Net (flow media)
4. Breather
5. Vacuum Bag
6. Vacuum Pump
7. Vacuum Reservoirs
8. Resin Trap
9. Tube
10. Resin Storage
11. Tacky Tape

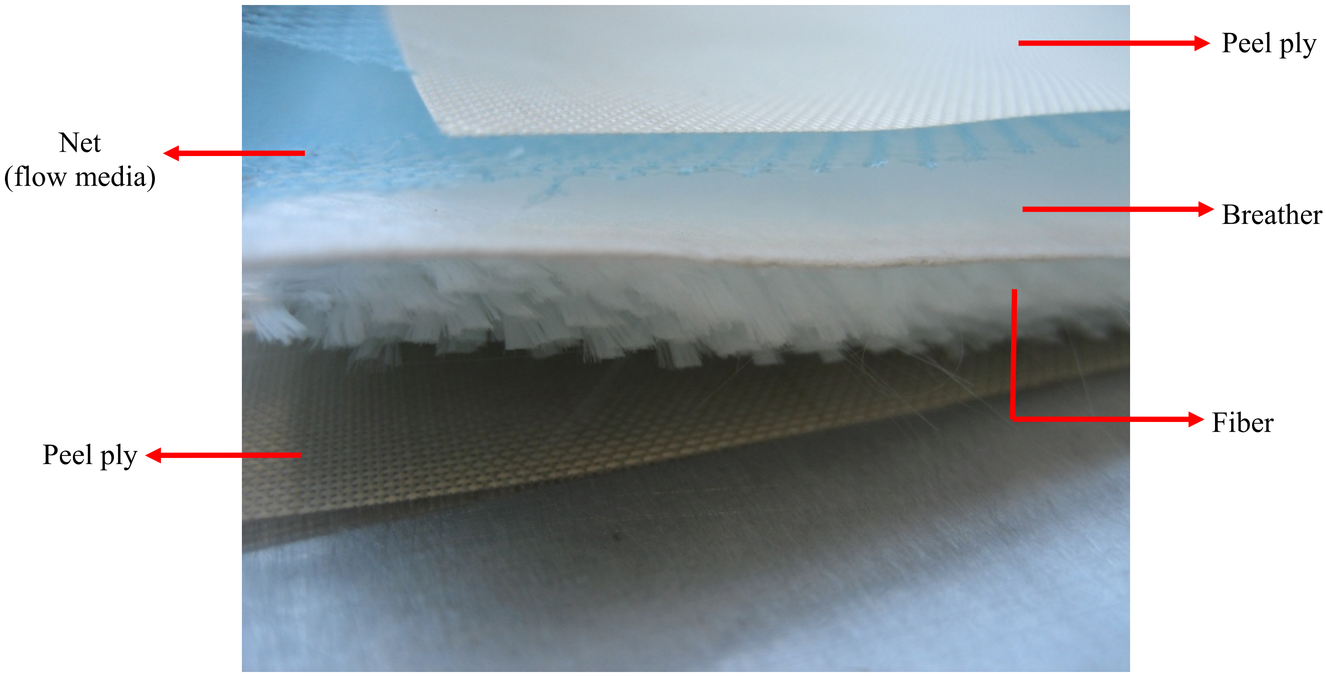


Figure 16: Arrangements of the peel ply, net, breather and fiber

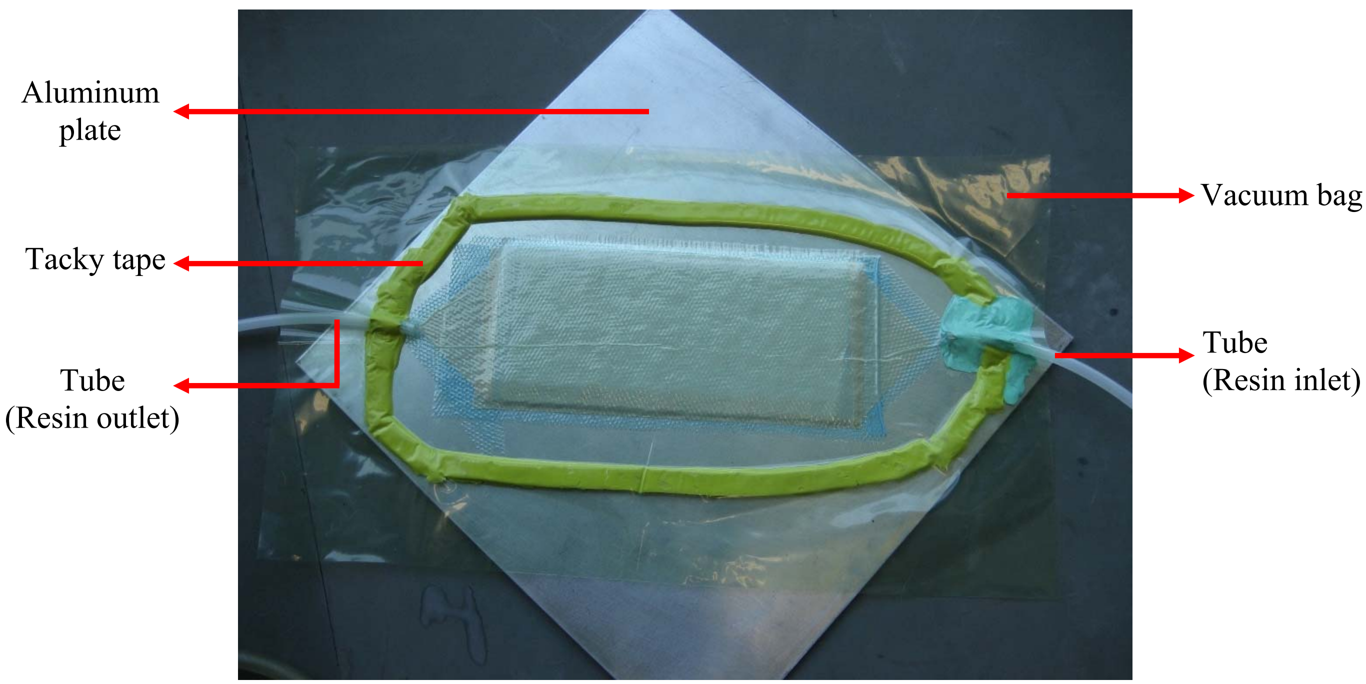


Figure 17: Resin Infusion set up

ii. Mixing of the resin

The experiment has been conducted 3 times. For the first trial, the resin that has been used is vinyl chloride and mixed together with MEKPO (Methyl Ethyl Ketone Peroxide) as hardener and cobalt as promoter and then latex is added as well. The calculation has been carried out to determine the amount of mixing for each material.

<u>Mixing calculation</u>

From the volume of fiber,

$$
\begin{aligned}
V_f &= w \times t \times l \\
&= 80 \times 200 \times 2.0175 \\
&= 32280\ mm^2 = 32.28\ cm^3
\end{aligned}
$$

Since $V_m = V_f$

$$V_m = 32.28\ cm^3$$

$$
\begin{aligned}
W_m &= \rho V_m \\
&= 1.28\ g/cm^3 \times 32.28 cm^3 \\
&= 41.3184\ g \approx 50\ g
\end{aligned}
$$

Thus,

W_m(50g)	-	Latex (5%)	→ 2.5g
	-	Resin (93.8%)	→ 47g
	-	MEKPO (1%)	→ 0.5g
	-	Cobalt (0.2%)	→ 0.1g

Based on the amount above, all the material is mixed.

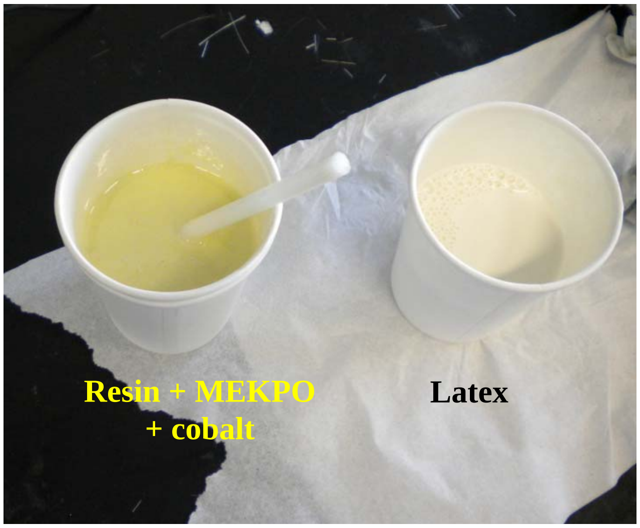


Figure 18: Mixture of the resin

The experiment is conducted three times as follows:

1st trial

1. The fiber, peel-ply, breather, net, and vacuum bag is set up as mentioned.
2. Vacuum pump is started and the air trapped inside the vacuum bag is evacuated.
3. Hissing sound from the seal around the vacuum bag and tube is checked to make sure no leak occur before resin infusion process started.
4. Meanwhile, **47 g Vinyl Chloride, 2.5 g Latex, 0.5 g MEKPO and 0.1 g cobalt** is then mixed slowly and stir properly.
5. The mixture is then degassed to eliminate bubbles for 30 minutes.
6. Then, resin tube is placed inside the mixture. Make sure vacuum pump is off before put the tube inside the mixture.
7. The vacuum pump is started.
8. Time filling is recorded.

2nd trial

1. The fiber, peel-ply, breather, net, and vacuum bag is set up as mentioned.
2. Vacuum pump is started and the air trapped inside the vacuum bag is evacuated.
3. Hissing sound from the seal around the vacuum bag and tube is checked to make sure no leak occur before resin infusion process started.
4. Meanwhile, **47 g Vinyl Chloride, 0.5 g MEKPO and 0.1 g cobalt** is then mixed slowly and stir properly.
5. The mixture is then degassed to eliminate bubbles for 30 minutes.
6. Then, resin tube is placed inside the mixture. Make sure vacuum pump is off before put the tube inside the mixture.
7. The vacuum pump is started.
8. Time filling is recorded.

3rd trial

1. The fiber, peel-ply, breather, net, and vacuum bag is set up as mentioned.
2. Vacuum pump is started and the air trapped inside the vacuum bag is evacuated.
3. Hissing sound from the seal around the vacuum bag and tube is checked to make sure no leak occur before resin infusion process started.
4. Meanwhile, **50 g epoxy and 10.5 g hardener** is then mixed slowly and stirs properly.
5. The mixture is then degassed to eliminate bubbles for 30 minutes.
6. Then, resin tube is placed inside the mixture. Make sure vacuum pump is off before put the tube inside the mixture.
7. The vacuum pump is started.
8. Time filling is recorded.

3.2.4 Epoxy and hardener mixing experiment

Most epoxies come as two-part adhesives, Part A and Part B—the resin with accelerators and the hardener. Mixing them together in specific ratios gives a working epoxy.

In general, the epoxy is colorless although some have a light sheen to them. After the epoxy resin is mixed with the hardener, it usually becomes opaque, but that clears when the mixture has set up. The hardener, part B of the mixture, must be mixed with resin to effect a cure. The reaction creates cross-linked molecular chains that give epoxy its spectacular strength.

Epoxy and hardener is mixed to the proportion of 10:6 ratios and acetone is then added to get the right viscosity and preferred pot-life or cure time. The percentage of acetone added to the mixture of epoxy-hardener is varied to observe the tackiness and cure time for each sample.

<u>1st Sample</u>

1) Mix 40g of epoxy with 24g of hardener and then the time after mixing is recorded.
2) Stir the mixture gradually for 1 to 2 minutes.
3) The mixture is then observed for the tackiness and leaved until it starts to gel.
4) The gel time is noted.

<u>2nd Sample</u>

1) Mix 40g of epoxy with 15% acetone - 15% of epoxy-hardener total weight, which is 9.6g.
2) Stir the mixture of epoxy and acetone gradually for 1 to 2 minutes.
3) 24g of hardener is then added to the mixture and then stir again.
4) The mixture is then observed for the tackiness and leaved until it starts to gel.
5) The gel time is noted.

3^rd^ sample

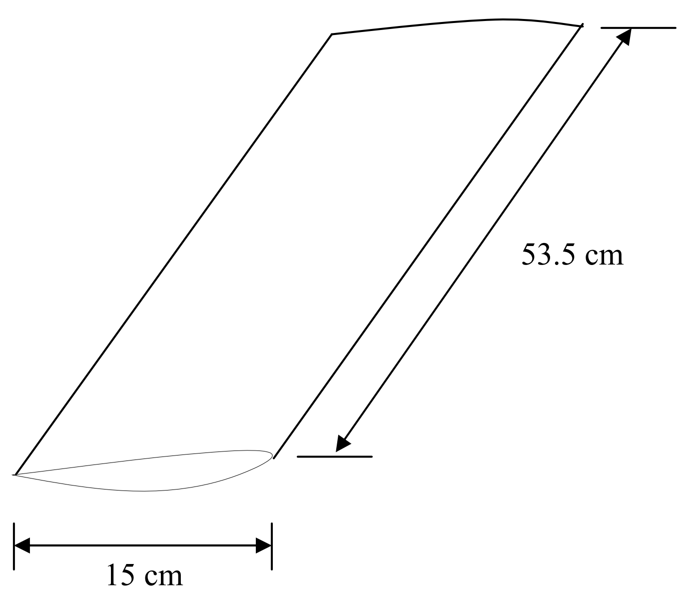
1) Mix 40g of epoxy with 20% acetone - 20% of epoxy-hardener total weight, which is 12.8g.
2) Stir the mixture of epoxy and acetone gradually for 1 to 2 minutes.
3) 24g of hardener is then added to the mixture and then stir again.
4) The mixture is then observed for the tackiness and leaved until it starts to gel.
5) The gel time is noted.

3.2.5 Cardboard blade trial experiment

This is the first trial experiment conducted for blade profile by using cardboard as the core. Cardboard is shaped as a blade and it is used because it is very light, fairly hard and easy to shape.

Cardboard blade dimension

Length : 53.2 cm
Width : 15 cm



Resin usage calculation

After the dimension of the cardboard is determined, the epoxy weight can be calculated using this dimension. Note that the epoxy weight is related with the dimension of the fiber while the fiber dimension is related to the blade dimension. The calculation of the epoxy weight is shown below.

- Fiber will wrap around the blade. Thus, the parameter of the blade is the same with fiber's parameter. It is noted that, the fiber length must have the excess length for infusion set-up later.

  $V_f = w \times l \times \text{thickness fiber}$
  $= 36\text{cm} \times 50\text{cm} \times 1.01\text{cm}$
  $= 181.8 \text{ cm}^3$

  Since $V_f = V_e$, thus

  $W_e = \rho V_e$
  $W_e = 1.24 \text{ g/cm}^3 \times 181.8 \text{ cm}^3$
  $= 225.43 \text{ g}$

  30% excess resin $= 130\% \times 225.43 \text{ g}$
  $= 293.059 \text{ g} \approx$ **300 g**

- The ratio of epoxy : hardener is 10:6, therefore, the amount of the hardener used is **180 g**.
- By using 15% acetone, the amount of acetone will be added later is **72 g**. Then, these amounts of each material are mix together and stir slowly.

Blade set-up for infusion

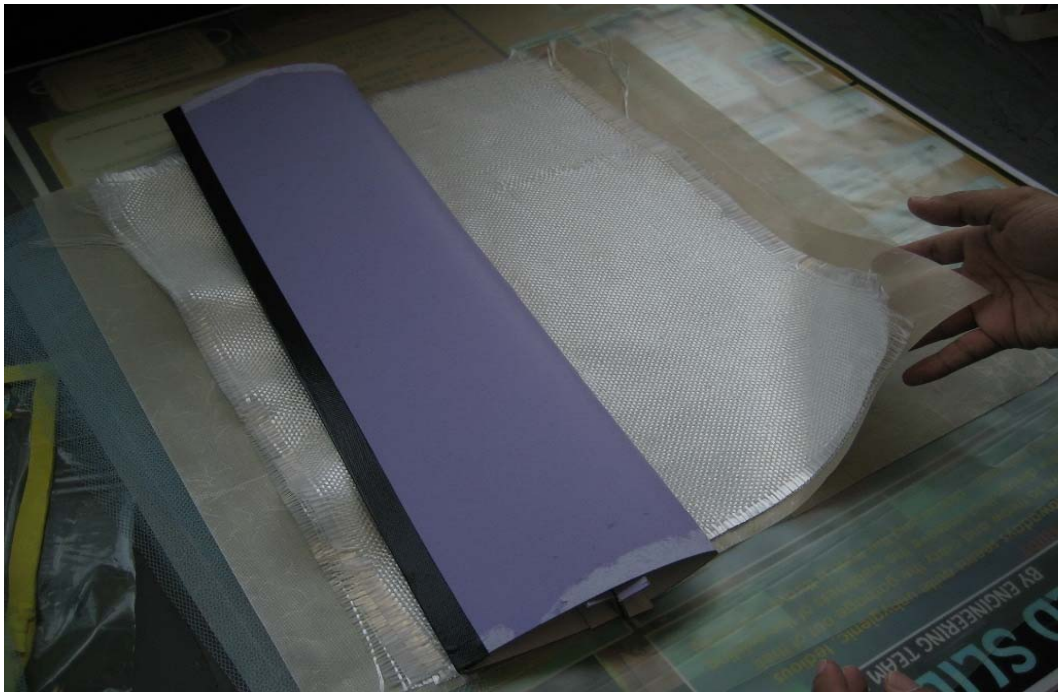


Figure 19: Cardboard blade

The cardboard blade is first been wrapped-up by the fiber (5 layers) and then followed by the peel-ply. The net (i.e. flow media) is laid after the peel-ply and it is noted that the net is not wrap around but applied at the top and the bottom side of the blade. Next, another layer of peel-ply (non-wrap around) is applied on top of the net.

Figure 20: Cardboard blade has been wrap-up

The infusion strategy that is used for this cardboard blade is line feeding, thus the spiral tubing is then placed along the blade's trailing edge and along the leading edge. The spiral tubing acts as the line feeding of the resin and the vacuum line (i.e. resin outlet).

Figure 21: Spiral Tubing (line feeding) at leading edge of the blade

Subsequently, 2 layer of the vacuum bag is applied up and bottom of the blade to ensure its vacuum integrity is maintained for better infusion later. Both layers are then sealed properly and satisfactorily by using sealant tape.

After the bag is fully sealed, the vacuum pump is started and evacuates the air inside. Any leak around the vacuum bag or at sealant tape is observed especially at the place where the sealant tape is joined together. The leaks can be examined by the hissing sound produced during vacuum process takes place. Extra attention and adjustment need to be done at the place where the hissing sound is produced.

After full vacuum is achieved, the resin tube is opened and let the epoxy flows through the fibers preform. When all the fibers preform is satisfactorily is wetted by resin, the vacuum pump is stopped and let the resin cured for 2 days.

3.2.6 Wind turbine blade with infusion strategies experiment

Three experiments have been conducted in investigating the filing time for each strategy namely strategy A, B and C and they are; line feeding from trailing edge to leading edge, line feeding from root to the tip of the blade, and point feeding from trailing edge to leading edge respectively.

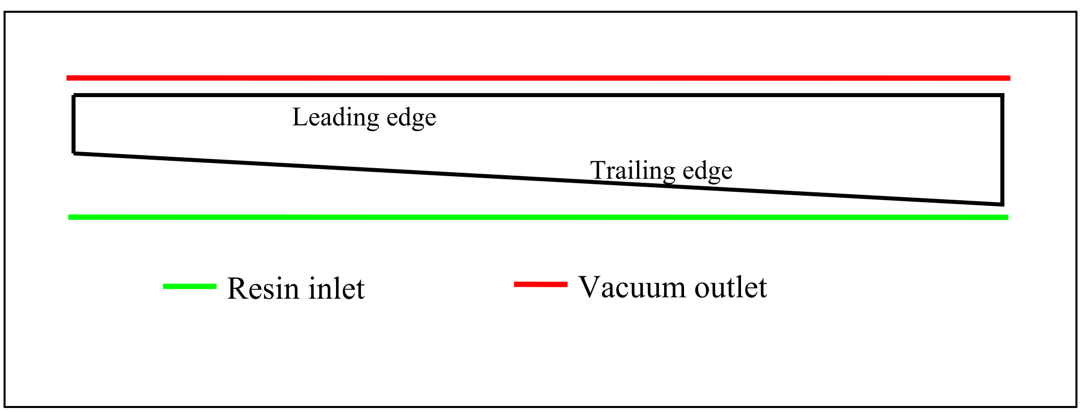


Figure 22: Line feeding from trailing edge to leading edge

For the first experiment, resin inlet line is placed at the trailing edge of the blade while the vacuum line is placed at the leading edge of the blade.

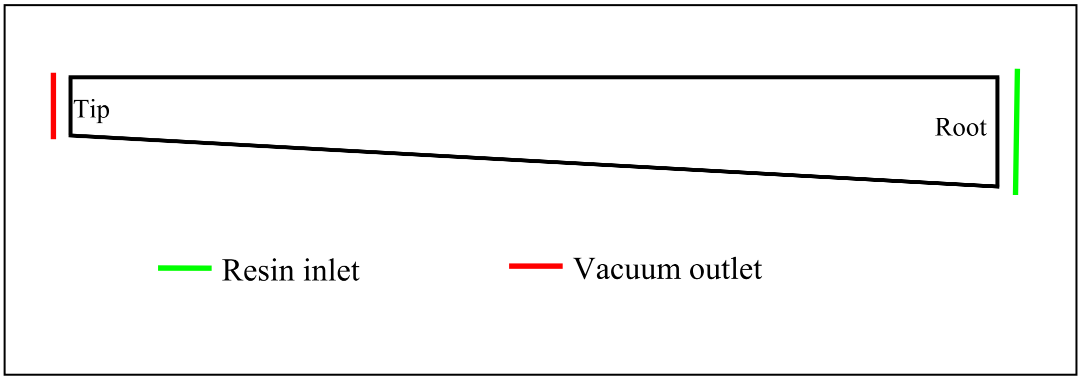


Figure 23: Line feeding from root to the tip

For second experiment, the resin inlet is placed at the root of the blade while the vacuum line is at the tip of the blade.

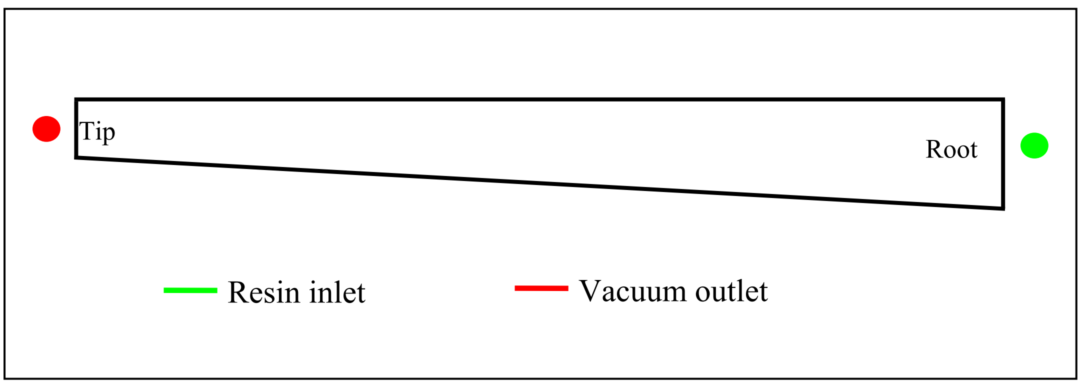


Figure 24: Point feeding from the root to the tip of the blade

For third experiment, resin tube is placed at the root of the blade while the vacuum tube is placed at the tip of the blade.

Resin usage calculation

- Epoxy weight

V_f = w × l × thickness fiber

= 42cm × 94cm × (8 plies of fibers × 0.202cm)

= 638 cm^3

Since V_f = V_e, thus

W_e = ρV_e

W_e = 1.24 g/cm^3 × 638 cm^3

= 791.12 g ≈ **800 g of epoxy**

- Epoxy to hardener ratio is 10 : 6, thus **hardener used is 480 g**

- 15% of total weight epoxy-hardener of acetone is added, therefore **acetone used is 192 g**

i. Strategy A: Line feeding from trailing edge to leading edge of the blade

<u>Blade set-up</u>

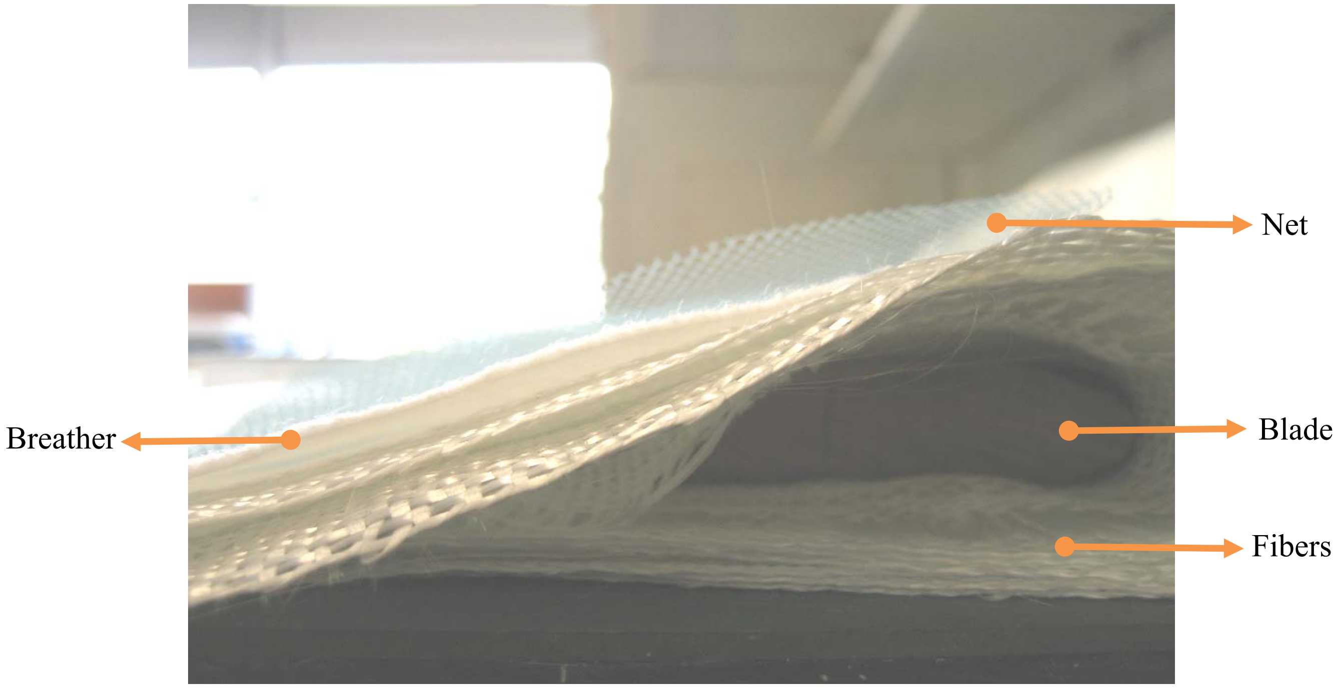


Figure 25: Arrangement of the preform

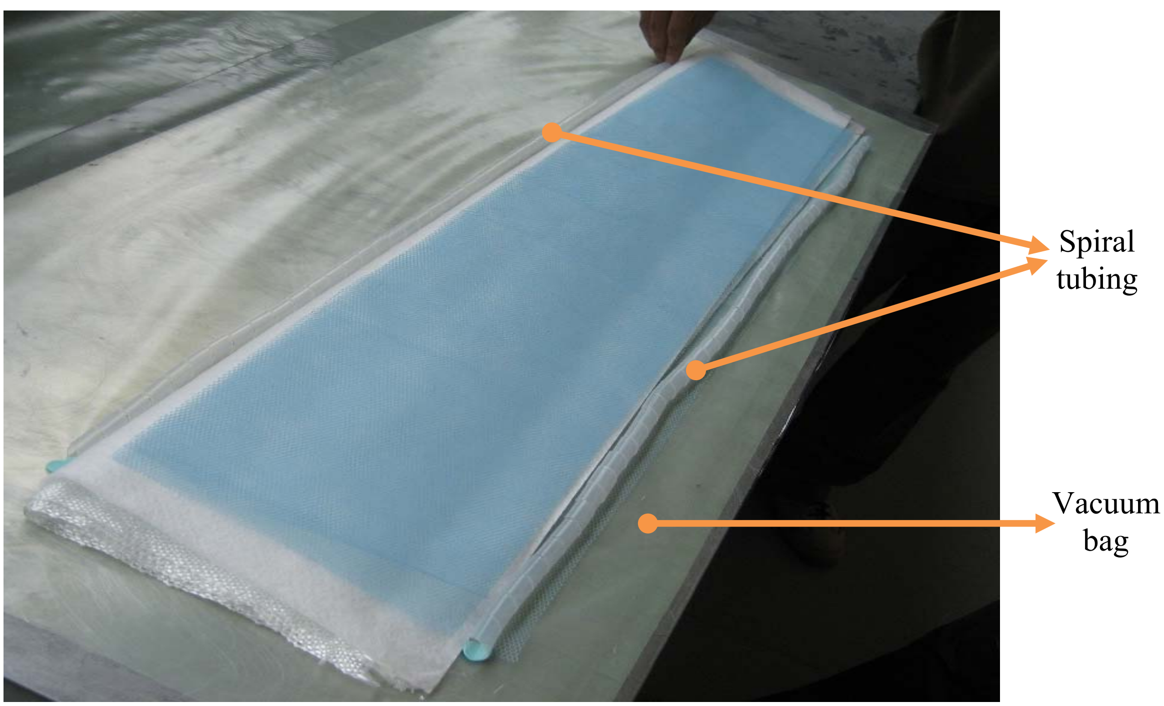
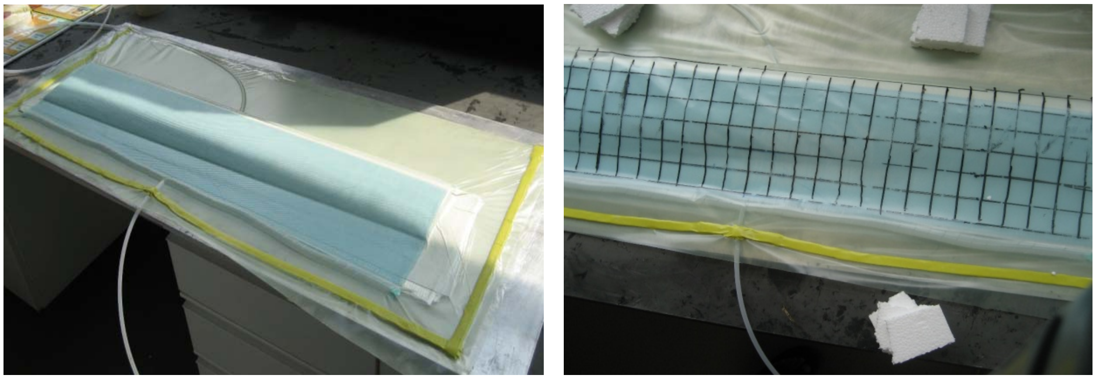


Figure 26: the position of resin inlet and outlet (spiral tubing)



(a) (b)

Figure 27: (a) Complete set up of blade infusion experiment and (b) grid is draw on vacuum bag.

<u>Procedure</u>

1. The blade, fiber, breather, and net are set up as mentioned.
2. First spiral tubing is cut similar length of the trailing edge length and is placed at the trailing edge of the blade. This is the resin inlet line.
3. Second spiral tubing is cut similar length of the leading edge length and is placed at the leading edge of the blade. This is the vacuum line.
4. Vacuum bag is wrapped around to cover the whole surfaces of the blade and then sealed using sealant tape.
5. Vacuum pump is started and the air trapped inside the vacuum bag is evacuated.
6. Hissing sound from the seal around the vacuum bag and tube is checked to make sure no leak occur before resin infusion process started.
7. Grid is draw with the dimension of 28mm × 28mm for analyzing the results.
8. Meanwhile, **800 g epoxy, 480 g hardener and 192 g acetone** is then mixed slowly and stir properly.
9. The mixture is then degassed to eliminate bubbles for 30 minutes.
10. Then, resin tube is placed inside the mixture. Make sure vacuum pump is off before the tube is placed inside the mixture.
11. The vacuum pump is started.
12. Time filling is recorded.

ii. Strategy B: Line feeding from root to tip of the blade

Blade set-up

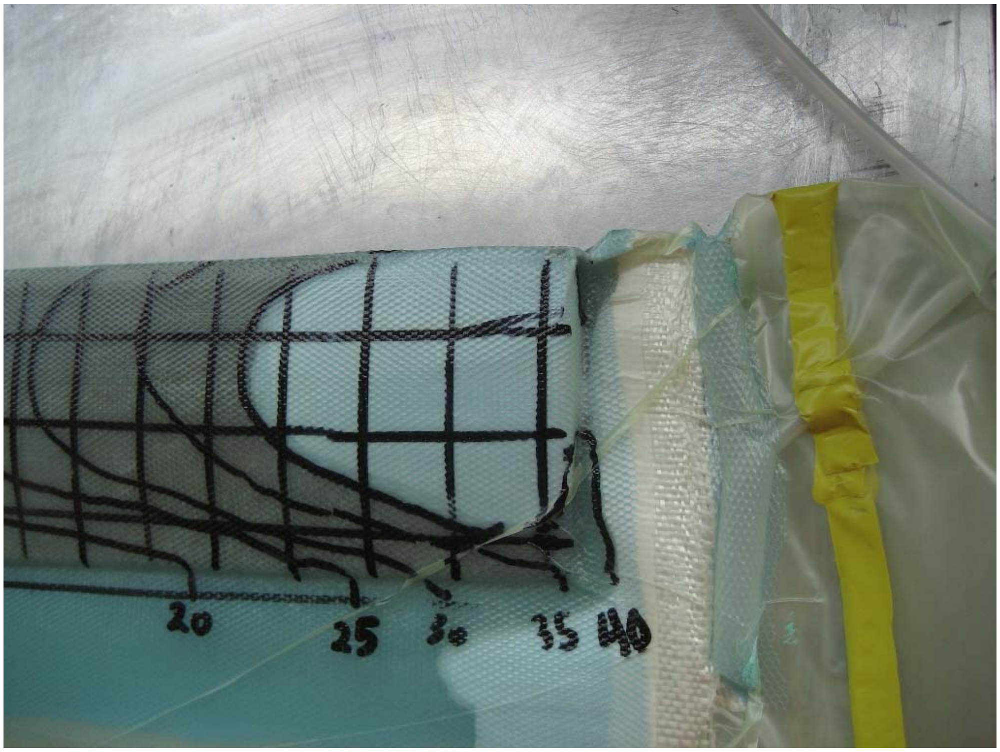


Figure 28: Line feeding set-up

Procedure

1. The blade, fiber, breather, and net are set up as mentioned.
2. First spiral tubing is cut similar length of the root length and is placed at the base of the blade. This is the resin inlet line.
3. Second spiral tubing is cut similar length of the tip length and is placed at the tip of the blade. This is the vacuum line.
4. Vacuum bag is wrapped around to cover the whole surfaces of the blade and then sealed using sealant tape.
5. Vacuum pump is started and the air trapped inside the vacuum bag is evacuated.
6. Hissing sound from the seal around the vacuum bag and tube is checked to make sure no leak occur before resin infusion process started.
7. Grid is draw with the dimension of 28mm × 28mm for analyzing the results.

8. Meanwhile, **800 g epoxy, 480 g hardener and 192 g acetone** is then mixed slowly and stir properly.
9. The mixture is then degassed to eliminate bubbles for 30 minutes.
10. Then, resin tube is placed inside the mixture. Make sure vacuum pump is off before the tube is placed inside the mixture.
11. The vacuum pump is started.
12. Time filling is recorded.

iii. Strategy C: Point feeding from root to the tip of the blade.

Procedure

1. The blade, fiber, breather, and net are set up as mentioned.
2. Resin inlet tube is placed at the root of the blade and then sealed using sealant tape.
3. Vacuum outlet tube is placed at the tip of the blade and then sealed as well using sealant tape.
4. Vacuum bag is wrapped around to cover the whole surfaces of the blade and then sealed again using sealant tape.
5. Vacuum pump is started and the air trapped inside the vacuum bag is evacuated.
6. Hissing sound from the seal around the vacuum bag and tube is checked to make sure no leak occur before resin infusion process started.
7. Grid is draw with the dimension of 28mm × 28mm for analyzing the results.
8. Meanwhile, **800 g epoxy, 480 g hardener and 192 g acetone** is then mixed slowly and stir properly.
9. The mixture is then degassed to eliminate bubbles for 30 minutes.
10. Then, resin tube is placed inside the mixture. Make sure vacuum pump is off before the tube is placed inside the mixture.
11. The vacuum pump is started.
12. Time filling is recorded.

Resin flow front progression was monitored by video camera on the surface of grid is drawn. Times at which the flow front averagely reached lines located at 28mm spacing along the blade were recorded.

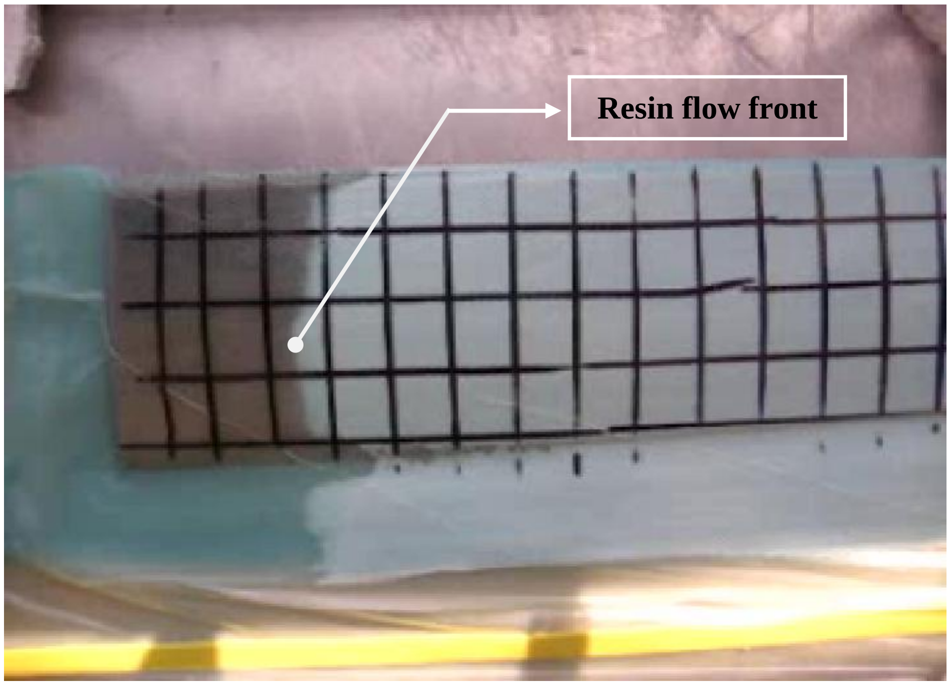


Figure 29: Flow front and grid on infusion process

CHAPTER 4

RESULT AND DISCUSSION

4.1 RESULTS

4.1.1 Resin Infusion trial experiment

<u>1st Trial</u>

The findings during the first trial are, as vacuum pump start to operate, the resin inlet tube is allowed to let resin flow. The flow starts smoothly for the first 5 minutes.

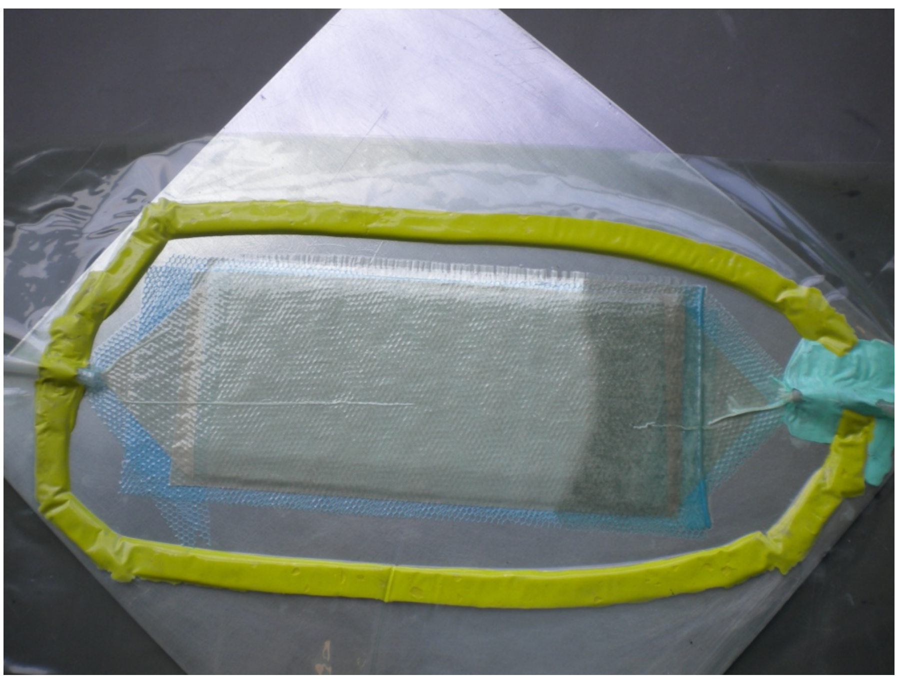


Figure 30: Resin infusion during first 5 minutes. The dark colour indicates the resin is flowing to that area.

As the process is proceeding, no flow of resin is identified for the next 5 minutes. It is found out that the mixture of resin and latex trapped at the resin inlet.

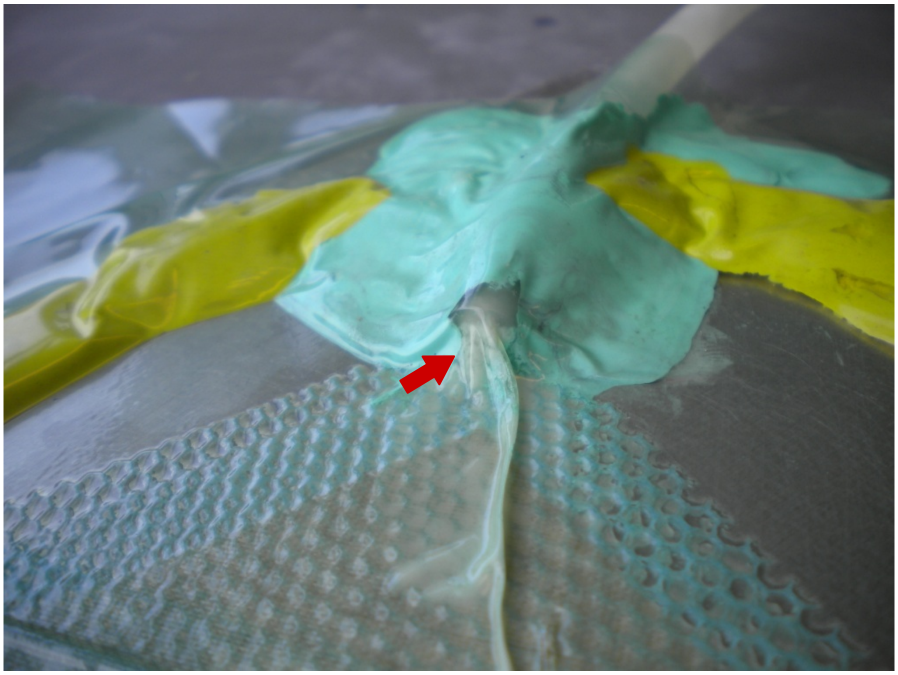


Figure 31: The mixture of resin and latex trapped at resin inlet (red arrow).

After waiting for about 15 minutes, there is still no sign of resin flows. The first trial failed because of the resin is trapped at inlet tube.

2nd Trial

The latex is eliminated for this 2nd trial. Another amount of vinyl chloride with MEKPO and cobalt is calculated similar to the previous calculation and then mix together.

After degassing for about 30 minutes, the mixture is taken out and it is found out that the mixture is starting to gel.

Figure 32: the mixture inside the degassing storage start to gel.

This 2nd trial however, the infusion process cannot be done because the mixture of resin starting to gel before the infusion can takes place. 2nd trial is fail.

3rd Trial

For 3rd trial, epoxy and hardener is used to infuse. The amount of epoxy use is 50g and hardener is 10.5g. Both are mixed together and then the mixture is degassed to eliminate the bubbles.

After the materials have been set-up, the vacuum pump is started. High vacuum (15 in Hg – 20 in Hg)[1] is used to evacuate the air from the vacuum bag and epoxy is pulled into the vacuum bag by the vacuum. Atmospheric pressure on the resin (i.e. epoxy-hardener mixture) feed pushes resin into the bag through an inlet tube. Resin entering the bag encounters the net used to channel the resin to the basic fiber preform. Resin flows laterally through the flow media over the preform and, subsequently, downwardly into

[1] the highest pressure it can achieve

the preform. The preform has the lowest permeability to flow (i.e., the highest resistance to the flow of resin).

The finding is that the resin is successfully infused to the whole fiber. Time filling are noted, that is 43 minutes for the resin distribute to the whole fiber.

After the fiber cured 2 days later, the vacuum bag, peel ply and the tubes are released and it is found out that the composite now is nicely cured.

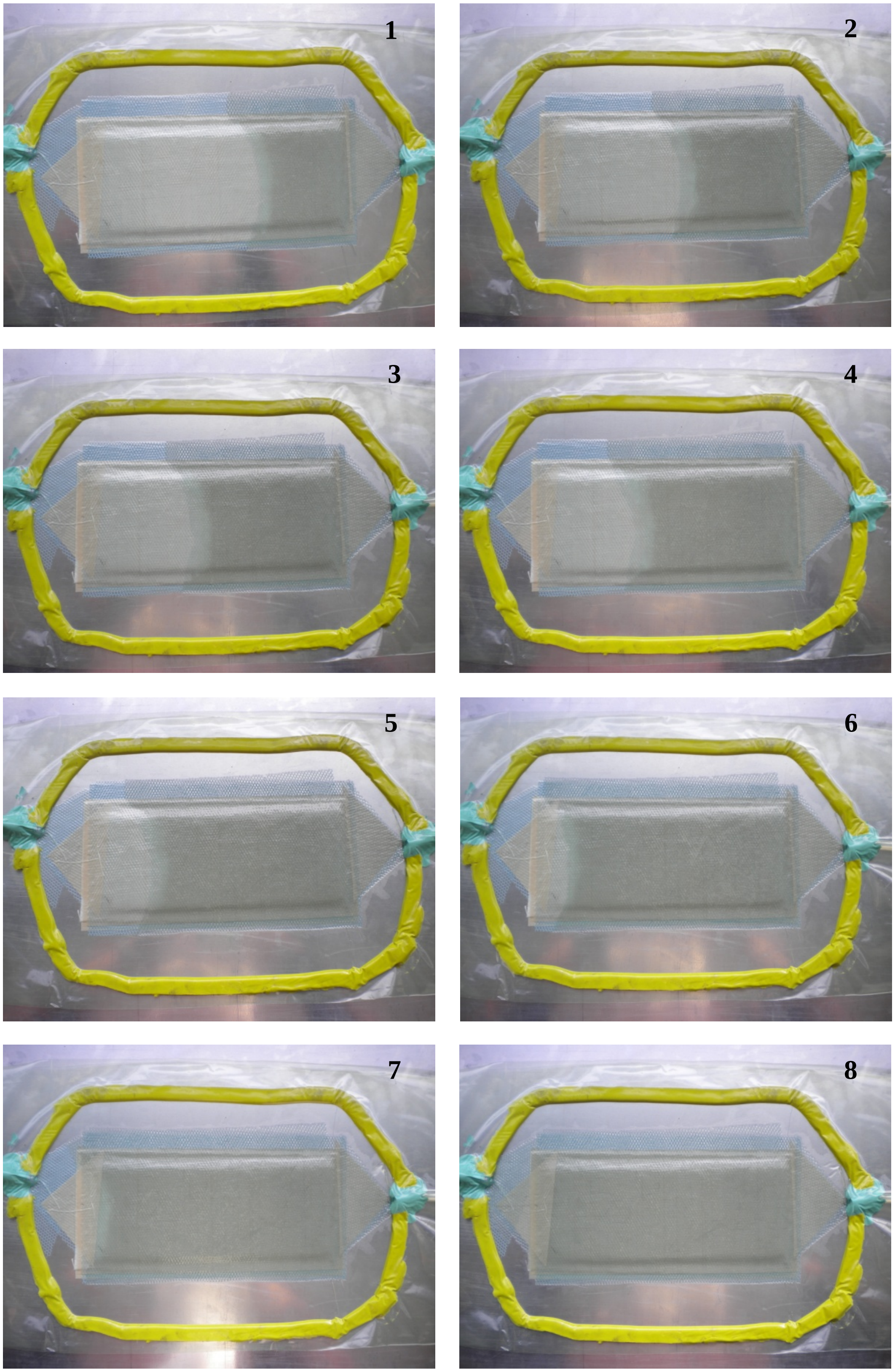


Figure 33: 3rd trial resin infusion filling process in time interval 5 minutes.

Figure 36: Process of peeling to take out the composite.

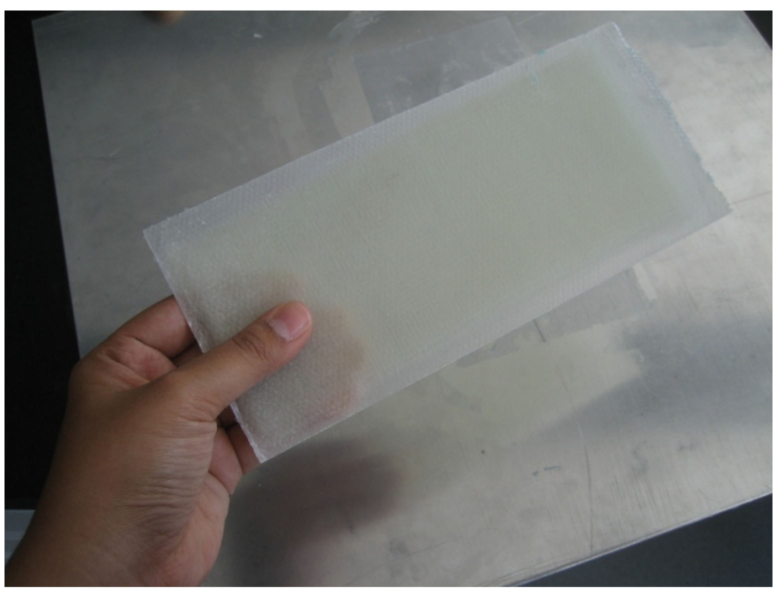


Figure 35: Finish product (composite)

4.1.2 Epoxy and hardener mixing experiment

Result:

Table 3: Summary of results for 3 samples

Number of sample	Mixtures	Viscosity	Gel time
1	40 g epoxy + 24 g hardener	Too high	57 minutes
2	40 g epoxy + 24 g hardener + 15% acetone	Moderate	1 hour 40 minutes
3	40 g epoxy + 24 g hardener + 20% acetone	Good	>2 hours

From the above result, the proportion of mixture that will be used for resin infusion process throughout the actual experiment later is the 2nd sample, which is by using 15% acetone of the total weight of epoxy-hardener. Acetone is added to provide a right viscosity for the resin to flow smoothly and to adjust the epoxy-hardener cure time.

4.1.3 Cardboard blade experiment

When the vacuum pump starts, all the air is evacuated. Any leaking is sealed properly to make sure no vacuum loss. Once the vacuum is reached, it is observed that the cardboard is crushed at the thickest part of the blade (leading edge to the ribs)[2] (see Figure 31) caused by the pressure differential between inside the vacuum bag and atmospheric pressure. It is also observed that the cardboard blade cannot sustain the pressure up to 20 in Hg.

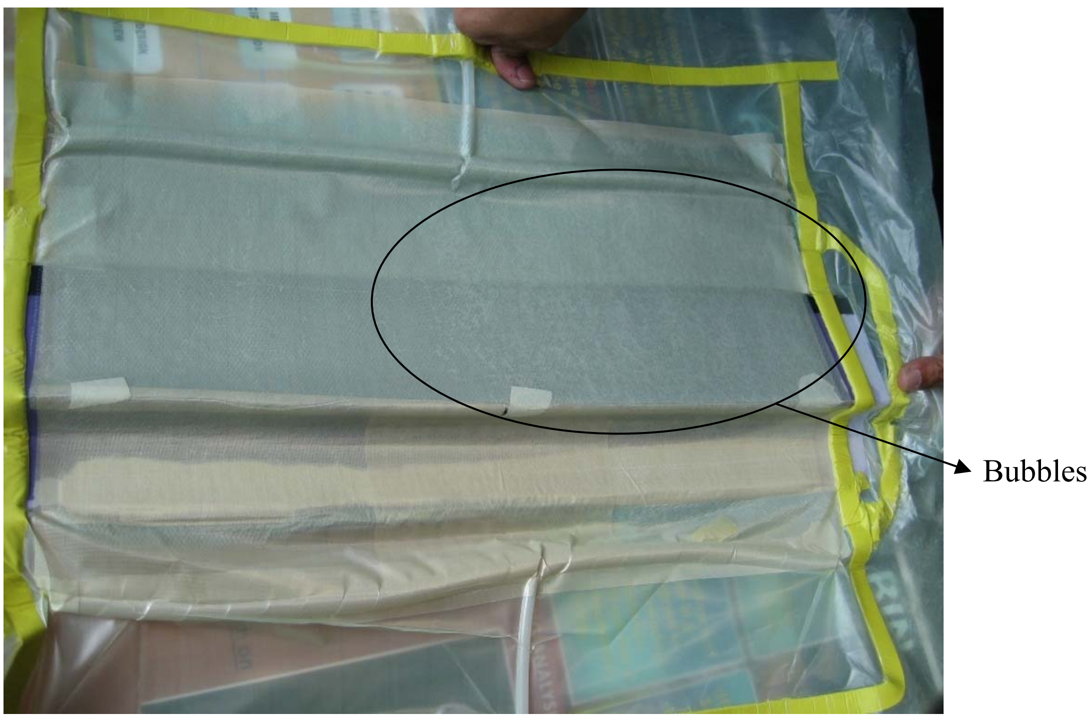


Figure 37: Resin flows during resin infusion experiment

After full vacuum is achieved, the resin tube is opened and let the resin flows through the fibers preform. It is observed that the bubbles formed quickly as of the air trapped and it flows through the fiber following the direction of the resin. Resin flows quickly at the flat profile and getting slowly at the edge where the blade is crushed.

[2] Rib is the beam placed at the center of the blade to support the blade.

After the blade cured 2 days later, it is found that the fiber is not achieving complete wetting at the bottom side. The resin is impossible to flow to all area due to the shape of the blade that is changing due to compression during vacuum process.

4.1.4 Wind turbine blade with infusion strategies experiment

All three experiments are using the same mixture of resin (15% acetone and epoxy-hardener[3]), the same arrangement of the preform, and the wood as the core. The main variable is the infusion strategy whereby it is the location of the resin inlet and vacuum outlet. The infusion processes were all conducted with a pressure at 20 inHg. The data obtain are the flow front position from the first grid and time taken for the flow front to reached at certain grid. Note that the trend of the graph from these three experiments almost met the trend from the graph by using LIMS (refer to Appendix A).

i. ***Strategy A: Line feeding strategy from trailing edge to leading edge of the blade***

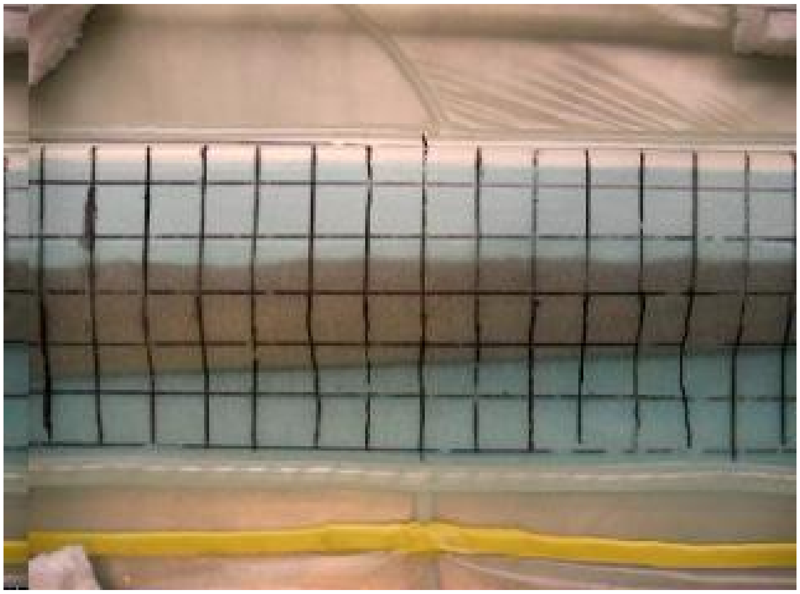


Figure 38: Resin flow during line feeding from trailing to leading edge

[3] Epoxy-hardener in ratio of 10:6

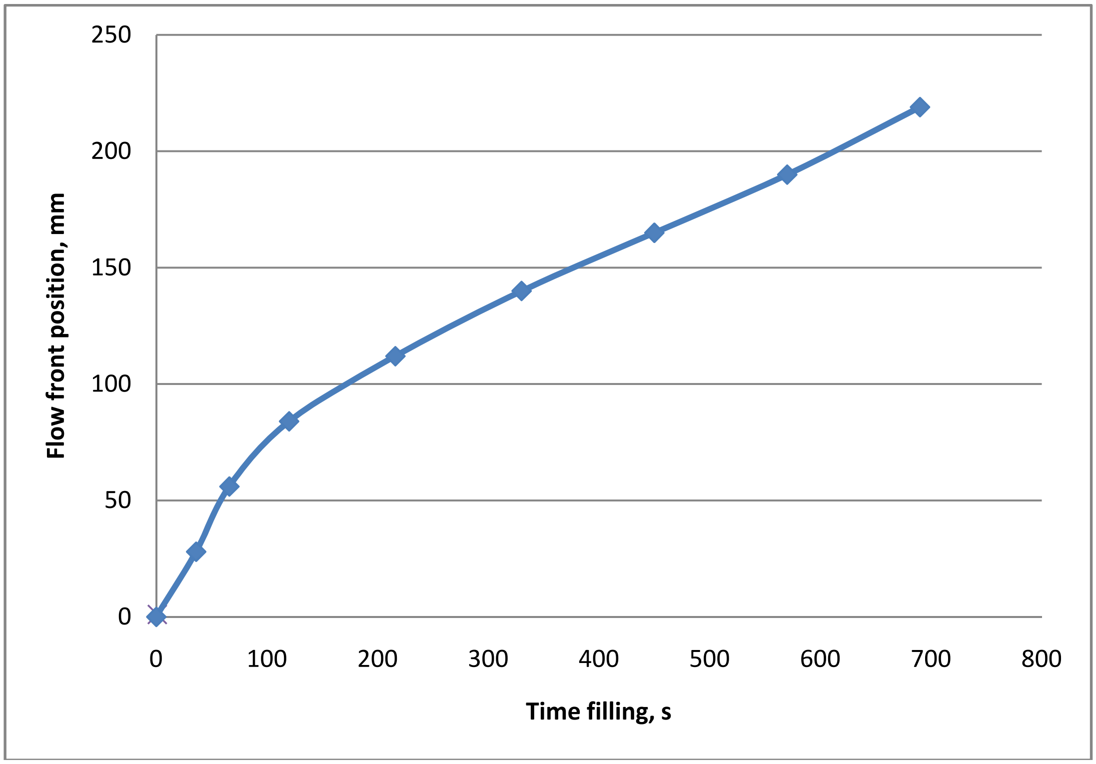


Figure 39: Evolution of flow front versus time filling at strategy A

This graph shows the infusion time for 224 mm length of flow front progression. The time filling for strategy A is 11 minutes and 30 seconds. This is the shortest infusion time were recorded and this is due to the shortest distance resin needs to travel from the resin inlet to the resin outlet (i.e. vacuum outlet). The use of spiral tubing at the trailing and leading edge increase the flow enhancement by providing large area for both discharge and suction of resin. However, during the process takes place, vacuum cause the spiral tubing at the leading edge compacting the layer of the preform and the problem is only realize after the resin is cured and the part is debagged to get the final product. The folded line along the leading edge the result by this problem. It is also observed that the bubbles form mostly at the spiral tubing at resin inlet side.

ii. Strategy B: Line feeding strategy from root to the tip of the blade

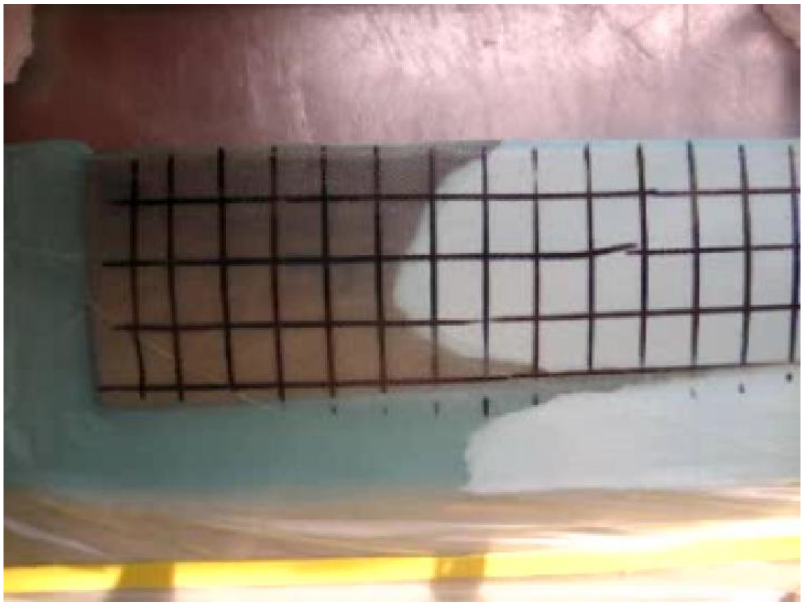


Figure 40: Resin flow during line feeding from root to the tip

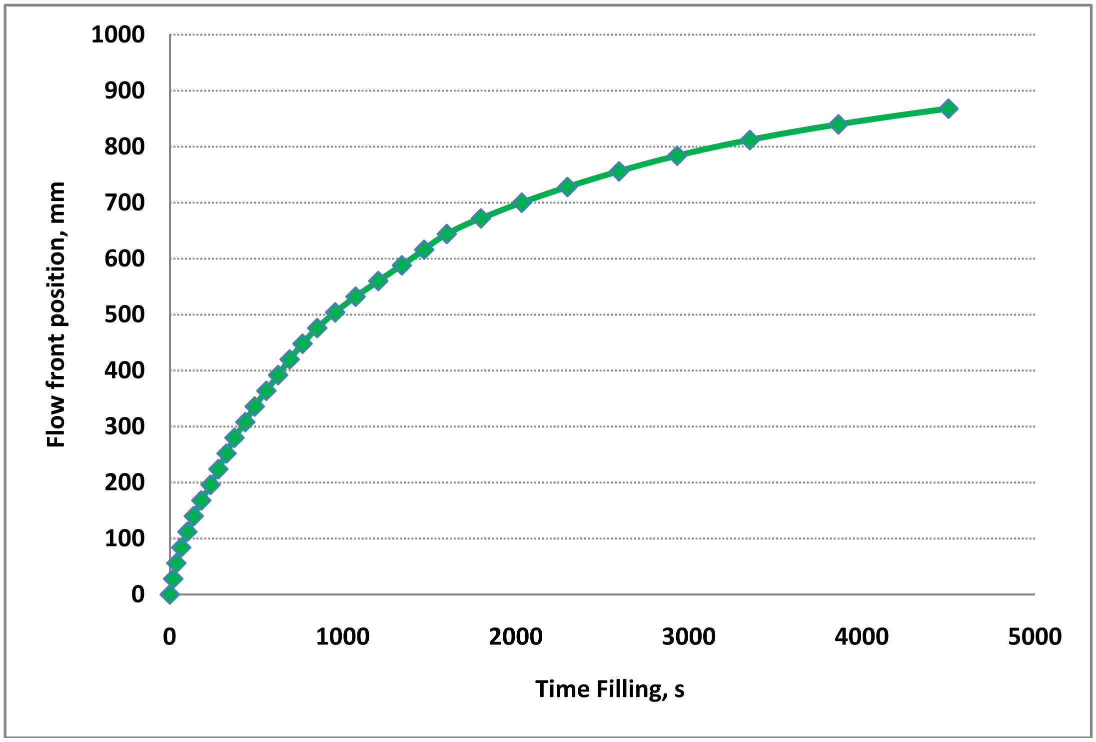


Figure 41: Evolution of flow front versus time filling at strategy B

The above graph shows the 868mm length of flow front progression. The time filling for strategy B is 1 hour and 15 minutes (4500 seconds). The longer distance of resin needs to travel from inlet to outlet is the reasons why the filling time is much longer. The farest resin is travel, the longer the time needed for resin to complete wetting all area. By virtual inspection, the bubbles form at the spiral tubing at inlet is insignificant compared to strategy A. This is because spiral tubing used is shorter than that in strategy A thus creating less bubbles.

iii. Strategy C: Point feeding from root to tip of the blade

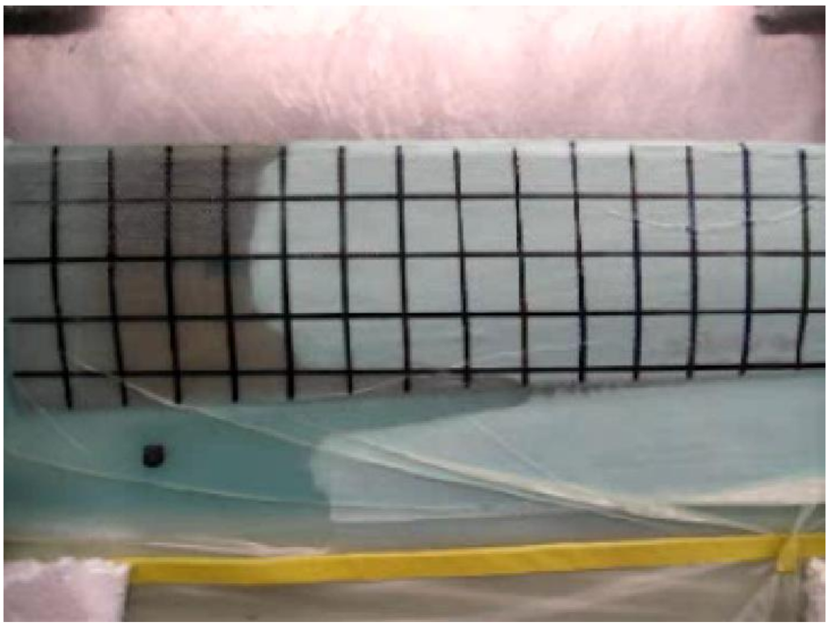


Figure 42: Resin flow during point feeding from root to tip

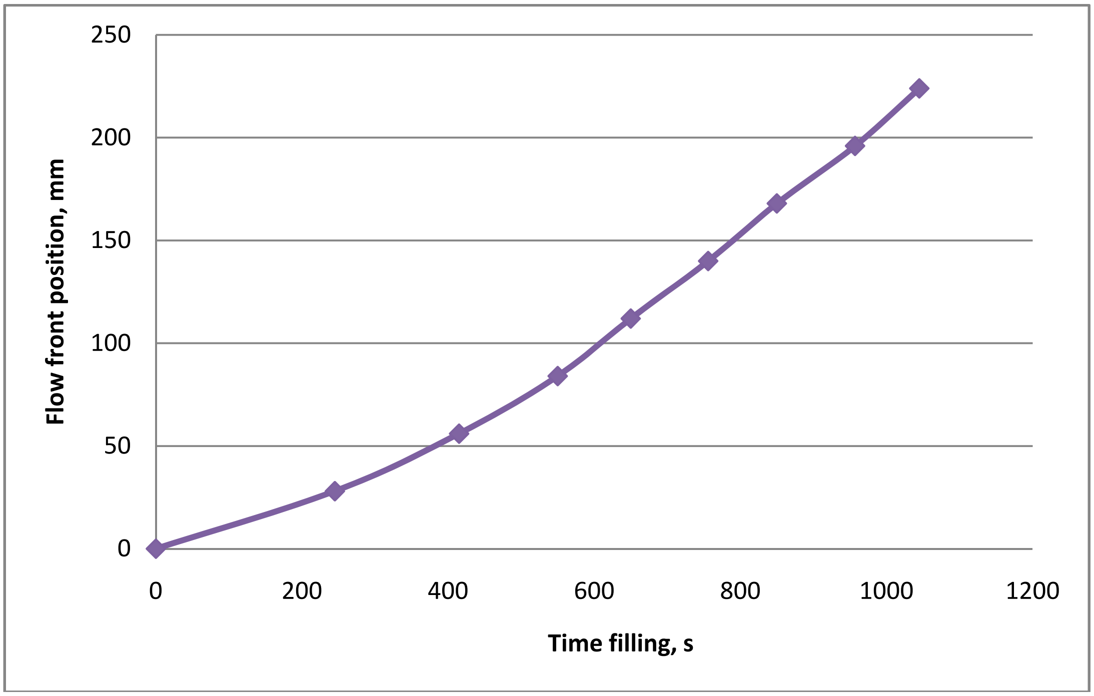


Figure 43: Evolution of flow front versus time filling at strategy C

The above graph shows less than the half of 868 mm length of flow front progression using point feeding. The time filling for strategy C is however cannot be recorded because the flow progression is too slow due to the leak at vacuum bag and cannot be completed. The leak cause the pressure inside the vacuum bag increased and full vacuum is not achieve. Due to the slow flow progression of the resin, the resin started to gel on the 25% of of the process.

Data Analysis

Comparison in time filling between strategy A and strategy B is made to observe the time taken in each strategy for certain percentage of filling.

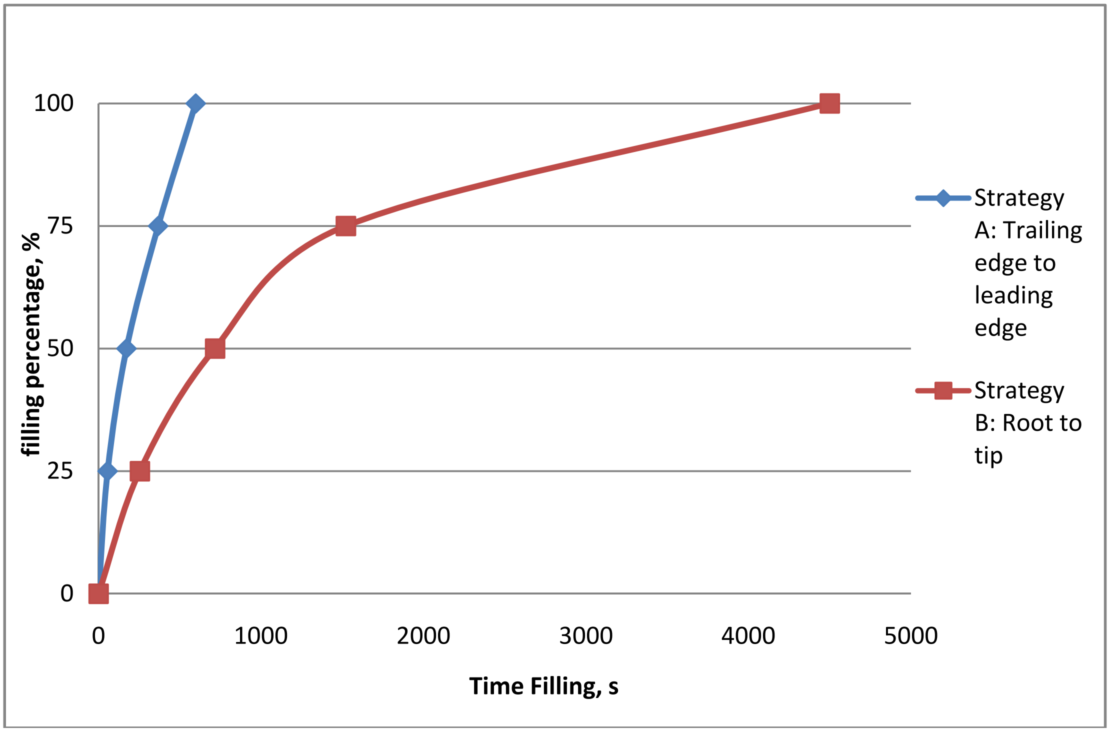
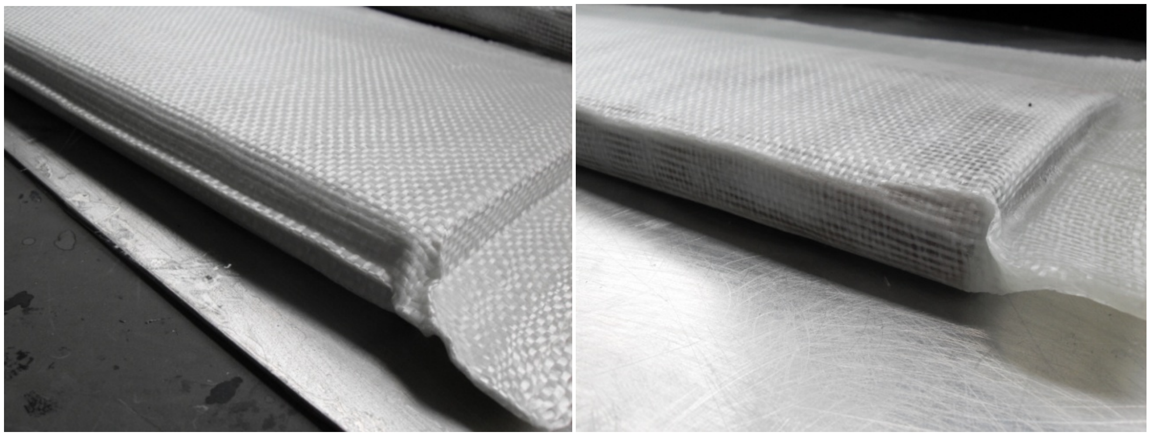


Figure 44: Filling percentage versus time filling for strategy A and B

Based on this graph, the flow progression for both strategies is faster initially and become slower as the distance getting larger. It is observe that strategy A record a shortest time filling compared to strategy B at 25% of filling. Later, strategy A finishes completing the whole preform area at less than 1000 seconds while strategy B reaches up until 4500 seconds to complete wetting the whole area.

This shows that strategy A is much more desirable for wind turbine blade infusion process in terms of time filling.

The finish product of strategy A and B is compared.



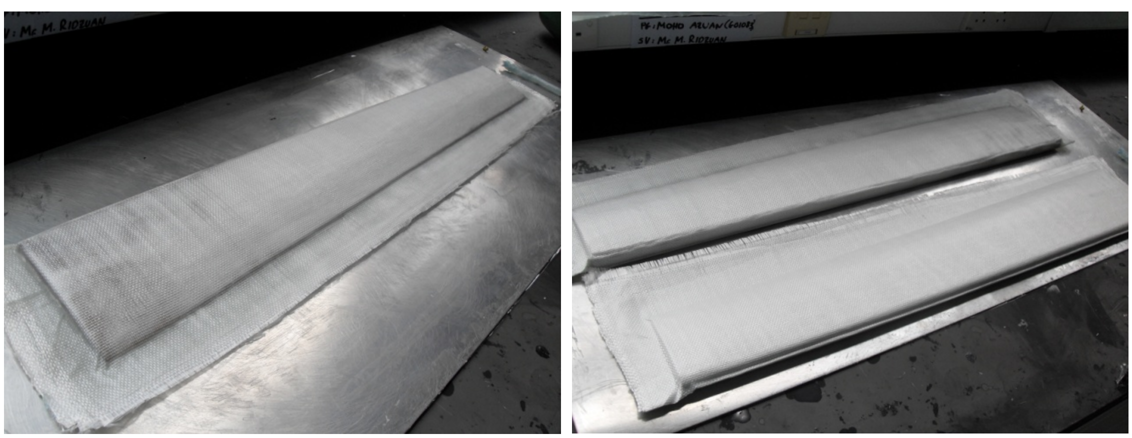
(a) **(b)**

Figure 45: Finish products from (a) Line feeding from trailing edge to leading edge and (b) line feeding from root to tip

Referring to (a), spiral tubing along the trailing edge cause the fibre of that area is compacted and folded at the time of vacuum is applied to the set-up resulting in straight contour along the trailing edge of the blade.

As of (b), the finish product has smooth shape of fibre similar to blade profile. Line feeding from root to tip does not affect the finish product profile in the end.

<u>Final Product</u>



(a) **(b)**

Figure 46: Finish products (a) and (b)

4.2 DISCUSSIONS

4.2.1 Resin Infusion Trial Experiment

1. For 1st trial, it is found out that vinyl chloride does not mix well with latex. The latex form tiny particles of supple solid when mix with vinyl chloride. This small particle gets stuck at the resin inlet during the mixture flows. The flow getting slower as more small particles trapped and block the inlet.

2. As for the 2nd trial, the mixture of vinyl chloride, MEKPO and cobalt starting to gel before the infusion process could take place. It is noted that gel time for vinyl chloride is 45 minutes. Mixing and degassing this mixture are time-consuming causes this resin to gel.

3. Degassing process is time-consuming since the process cannot perfectly done due to the low pumping pressure of the vacuum pump. The pressure noted is approximately 80 kPa. Moreover, leakage is occurring at the valve cause the desired pressure is unattainable.

4. 3rd trial is successful, the infused fiber is leave for 2 days to cure. After the composite is taken out, it is found out that the breather is infused together. This might due to the unsuitable breather used or the arrangement of the breather and peel ply is incorrect. Further studies will be conducted later.

4.2.2 Epoxy and hardener mixing experiment

1. 15% of acetone creates a thinner mixture of the epoxy- hardener. This is very desirable since the resin will flow smoothly into the fiber.

2. The time for this mixtures starts to gel is fairly precise and appropriate since the gel time is very crucial. Furthermore, the other works - set-up the equipment, degassing the resin, and time filling of the resin during the infusion process must not exceed the gel time. For jobs that require the application of large areas of epoxy, a moderate hardener helps to coat the surface, apply the laminate and get the job set up before the epoxy starts to cure.

3. The experiment is needed with mixing the fast and moderate hardeners to adjust the cure rate. If the job starts to cure before all the materials are in place, the best option is to remove the partially cured material, let the cure finish, sand everything back, and start over.

4. Since the manufacturer has provide the mixing ratio of the epoxy and the hardener is 10:6, the best way to adjust its cure time (i.e. gel time) and viscosity are by using acetone. The amount of acetone mixed is varied to determine the most appropriate cure time and viscosity produced by each mixture.

4.2.3 Cardboard blade experiment

1. The new profile has sharp edges which is inappropriate for resin infusion process since the resin only flow in the less resistant area. This cause the infusion process is unsuccessful and the bubbles forms hastily during infusion (see Figure 31, circled).

4.2.4 Wind turbine blade with infusion strategies experiment

1. The graph shows the resin flow depends much on the distance of the resin from the inlet line to the vacuum line. The bigger the profile to infuse the longer time needed to complete the infusion time.

2. Spiral tubing usage as the resin line and vacuum line however has its disadvantage. Spiral tubing tends to gather the resin and fill itself first before the resin can flow out to the preform. This cause a pretty lot of resin wastage.

3. Any leakage at the vacuum bag must be eliminate completely as it will affect greatly on the infusion process. It will form bubbles rapidly and time taken for resin to travel will much longer due to partial vacuum achieved inside the vacuum bag.

4. This leads to the conception of infusion strategies in order to make the infusion process much easier and less time-consuming. That is why in hull construction, they use multiple feeding of resins so that more resin is injected at the same time and can distribute evenly to the whole area of the hull in lesser time.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

In resin infusion system the harder part is to guess the right amount of resin flowing at the same rate to all directions. As the design is a close profile, the infusion strategy must be conducted in its most effective ways to prevent a lot of trials and errors experiments later.

After conducted three blade resin infusion experiment, it can be conclude that the shortest distance between the resin line inlet and vacuum line outlet will lead to a shorter time filling. However, the experiment is limit to the infusion strategy, thus, another parameter such as the thickness of the preform, the usage of flow medium and pressure difference can also affect the time filling of resin infusion process and this does not cover inside this project.

For wind turbine blade profile, the ideal strategy to infuse is line feeding from the trailing edge to the leading edge of the blade.

5.2 RECOMMENDATION

1. Re-do strategy C to observe the effect of point feeding to the blade. Another strategy such as multiple feeding should be tested as it is assume to give better time filling with better resin to fiber ratio.

2. Degassing time should increase to enhance in eliminating bubbles from the resin mixture before infusion process takes place.

3. The vacuum pump with high efficiency is needed for better degassing process later.

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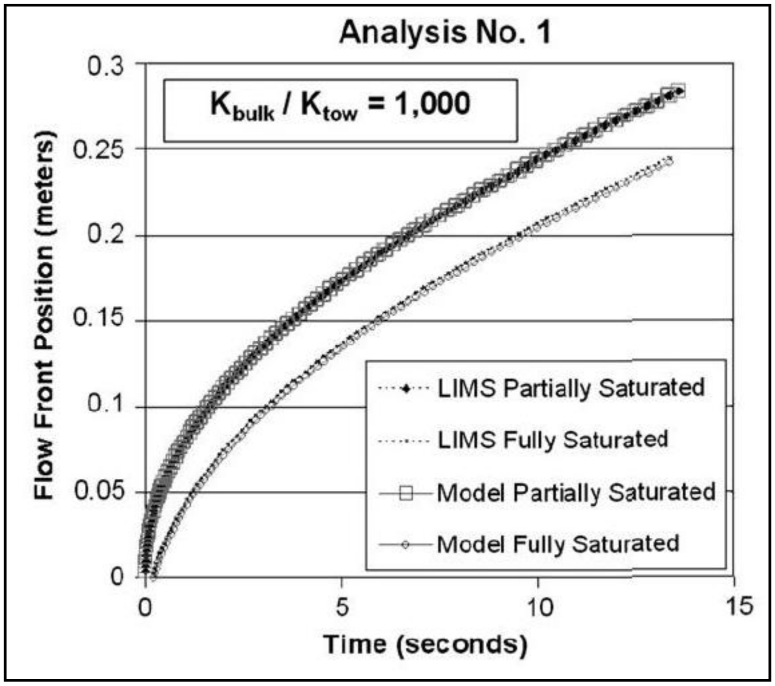
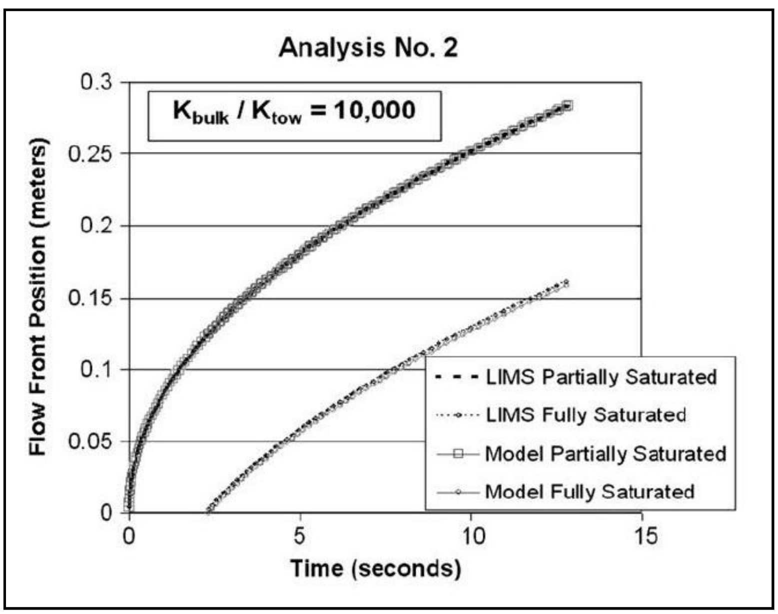
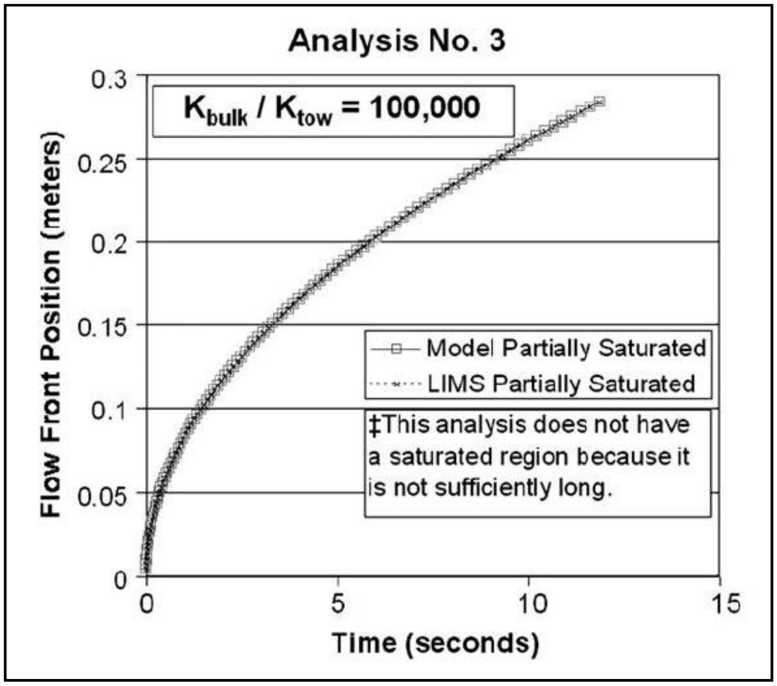
APPENDIX

Appendix A







Appendix A: Graphical comparison of fully and partially saturated flow front position (m) versus time (s) of analytical and numerical solutions using LIMS.