A COMPARATIVE STUDY BETWEEN TWO RESIN INFUSION STRATEGIES IN THE MANUFACTURING OF POLYMER COMPOSITE WIND TURBINE BLADE VIA RESIN INFUSION PROCESS

by

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfillment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(MUHAMAD RIDZUAN BIN JEMAAT)

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ABSTRACT

This report explains about the project entitled Resin Infusion Strategies for Wind Turbine Blade. The proposed design for this project is wind turbine blade which will be infused later. The goal of this project is to investigate and determine the effective infusion strategy for the wind turbine blade in order to achieve uniform resin distribution in shortest time throughout the wind turbine blade design. One of the most important parameter in Resin Infusion process is the strategy of filling. The location of the resin start to penetrate and the vacuum will be applied is much depends on the design to infused. There are several strategies, namely point feeding, edge feeding, line feeding and multiple line feeding. As the design getting more and more complex, the complete wetting of the fiber by resin will become increasingly difficult and the resin flow front progression will become slower. The proper infusion strategy and good technique is needed to achieve a better fiber-to-resin ratio for the final product and good filling time taken for infusion process to complete. Trial and error experiments need to be conducted several times to learn the technique and familiarize with the resin infusion process and thus can decrease unsuccessful experiments later on. After conducted two blade resin infusion experiments, it can be conclude that the shortest distance between the resin line inlet and vacuum line outlet will lead to a shorter time filling.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Vacuum infusion (also known as resin infusion) technique has become common among the industrial applications nowadays. Carbon fiber fabric and fiberglass, along with resins and epoxies are common materials laminated together with a vacuum bag operation. The technique has been used in many applications such as in making the wind blades, hull of boats, gun shields, and even in aerospace applications. The processing technique is simple yet capable enough to produce high quality composite products with higher mechanical strength in less manufacturing cost.

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. [1] 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. [1] This process is very useful in identifying where the vacuum need to be located and where reinforced composite material with higher mechanical strength [2].

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.

In typical vacuum infusion process (VIP), a dry reinforcement will be placed in mold. A laminate bag is then laid onto the reinforcement and properly sealed to avoid any leakage during suction process. Then, the vacuum pressure is introduced to pull the resin (mixture) into the lamination. Once a complete vacuum is achieved, the resin is literally sucked into the laminate thorough the inlet pipe and distributed through the composite material section assisted with resin distribution mesh act as flow media. As the penetration process goes on, the remaining resin will then sucked by the vacuum (usually using pump) and discharged into the outlet basin. The process will continue until the complete infusion is obtained. The result is a

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. [4] 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 [2].

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.

Previous work has mainly focused on open profile such as flat plate and U-shaped channels. The current work involves a closed profile with meeting flow fronts. The closed profile is more complex and complicated because there is a need to consider many factors. For instance, the thickness of the production will not be uniform, varying pressure difference throughout the profile, the distance of resin inlet and outlet from the profile, and 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:

i. To investigate the effect of infusion strategy on the filling time and flow of resin.
ii. To propose the effective infusion strategy for the wind turbine blade design with a better quality.

The scopes of study for this project are to reinforce and manufacture the wind turbine blade using resin infusion process using fiberglass. This also includes the study of resin flow characteristic which involves the flow front progression and the filling time to understand better how resin travels within the wind turbine blade perform.

Besides, the strategy of infusion is bound to line feeding and more explanation will be mentioned in the methodology section. 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, 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.

Resin Transfer Molding process (RTM) is a particular useful manufacturing process processes that use liquid resin to impregnate the stationary fibrous preform. During the RTM process, the preform is placed into the mold cavity, the mold is closed and the resin is injected into the cavity under pressure. The mold with the preform is often put under vacuum so that the vacuum removes all the entrapped air in the preform and speeds up the RTM process. Once the liquid resin fills the mold cavity, it cures, during which the resin hardens due to the formation of polymeric network forming the matrix of the composite, allowing the part to be de-molded. Typically thermoset polymers of Epoxy, Vinyl Ester, Methyl Methacrylate, Polyester or Phenolic are used with fiberglass, carbon fiber and synthetic fibers reinforcements either individually or in combination with each other.

This technique is well known and has been traditionally applied to moderately large parts in various application. It allows one to obtain even very complex neat-shape parts with good surface finish, in many cases at reasonable production rates. The fiber architecture, permeability of the preform and the fabric crimps, resin viscosity, temperature of operation, have an influence on the wetting of the fabric. Careful process design is needed to obtain a repeatable high quality product.

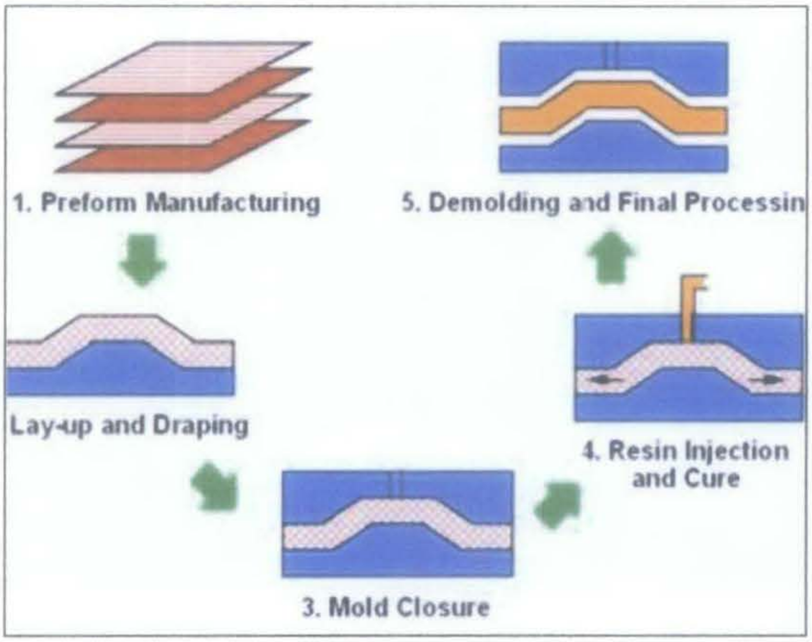

Figure 1 : Resin Transfer Molding process (RTM)

(Source : http://www.jjmechanic.com/process/rtm.htm)

Vacuum Assisted Resin Transfer Molding (VARTM) is a single sided molding process where the dry preform (reinforcement or coring materials) is placed into the mold, a cover (or a vacuum bag) is placed over the top to form a vacuum-tight seal. A distribution medium (a mesh) is used and laid on top of the top release fabric to help maintain an even distribution of resin and facilitate the flow of resin through the thickness of the panel. The low viscosity resin typically enters the preform through resin distribution and vacuum distribution lines with the aid of vacuum. In VARTM process, the flow of resin occurs in plane as well as in the transverse directions to the preform. The permeability of the preform, fiber architecture and fabric crimp have an influence on the wetting of the fabric.

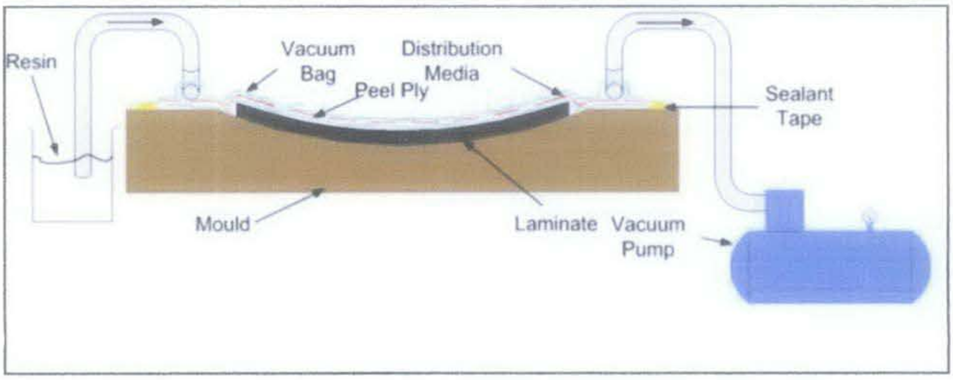

Figure 2 : Vacuum Assisted Resin Transfer Molding (VARTM)
(Source : http://polynovacomposites.blogspot.com/)

Vacuum assisted resin infusion under flexible tooling (RIFT) 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.

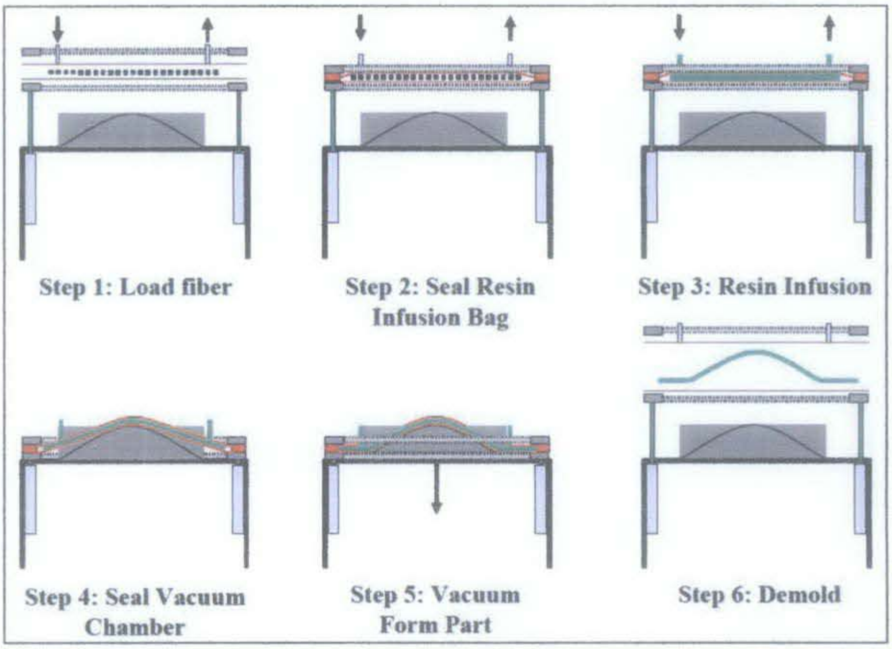

Figure 3 : Vacuum assisted resin infusion under flexible tooling (RIFT)
(source : http://www.scribd.com/doc/46441166/Fiberglass-Vacuum-Infusion)

2.2 INFUSION CHARACTERISTIC

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.

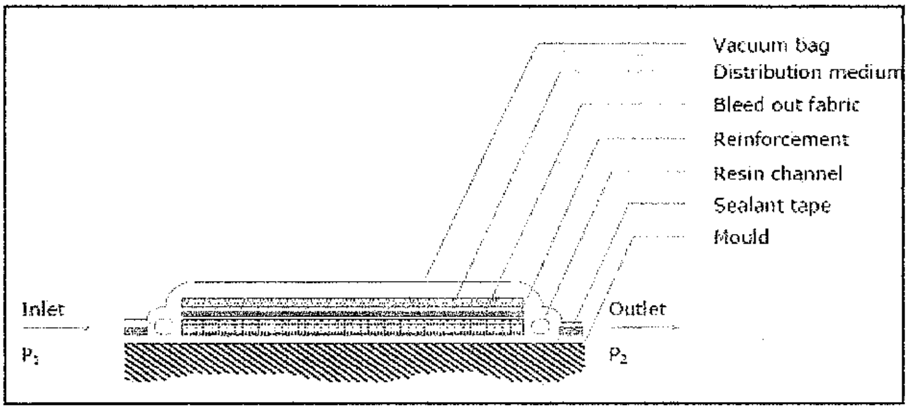

Figure 4 : The arrangement of vacuum infusion

(source : http://web.mit.edu/windenergy/windweek/Presentations/Nolet_Blades.pdf)

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.

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.

An integration form of Darcy's law shows time as a function of flow front distance squared as described in equation below:

$$\text{Fill time, (t)} : \frac{\text{Viscosity, Pa.s } (\mu) \times \text{Flow length,m } (d)^2}{\text{Permeability,m2 (K)} \times \text{Pressure gradient}(-\Delta p)}$$ **(Equation 1)**

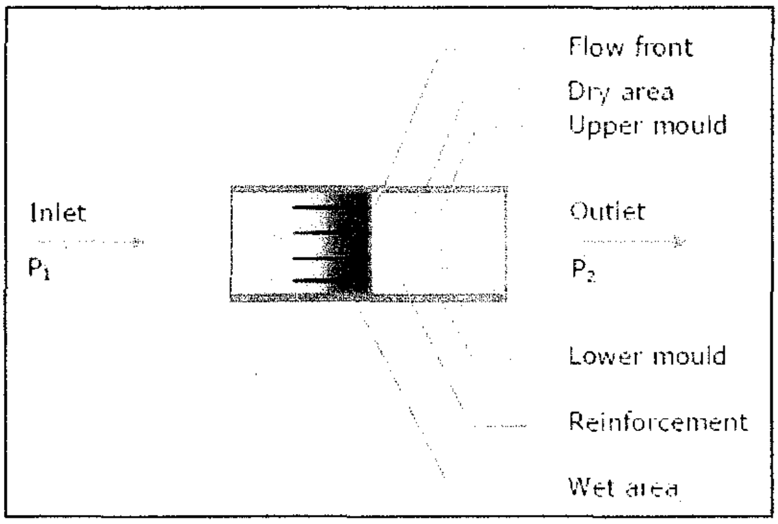

Figure 5 : The arrangement of vacuum infusion

(source : http://web.mit.edu/windenergy/windweek/Presentations/Nolet_Blades.pdf)

A pressure difference is applied between the inlets 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 [4].

Resin flows preferentially in the distribution medium, which is fully impregnated and has a higher permeability. Therefore it takes 14 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 [4].

2.3 INFUSION STRATEGIES

There are 3 main strategies of infusion namely as follows:

Line feeding

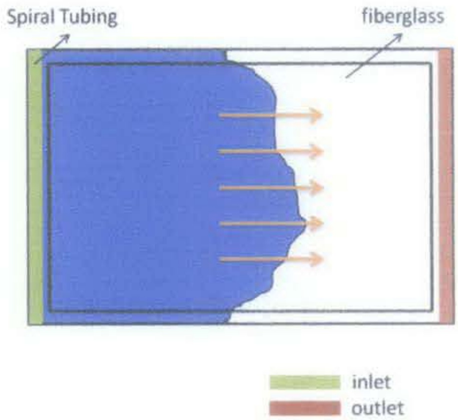

Figure 6 : Line Feeding schematic diagram

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 30 cm apart of the resin feeding point because it might affect the filling time and it is better if both inlet and outlet be 0.5-1 cm closed with the fiberglass.

Point feeding

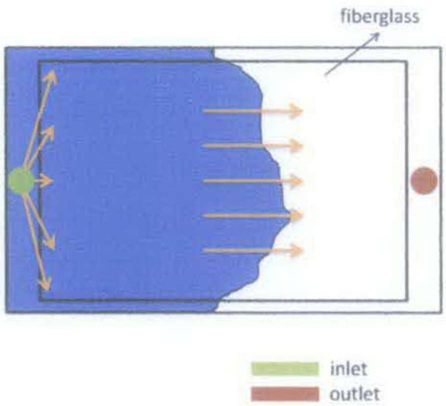

Figure 7 : Point Feeding schematic diagram

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.

Edge feeding

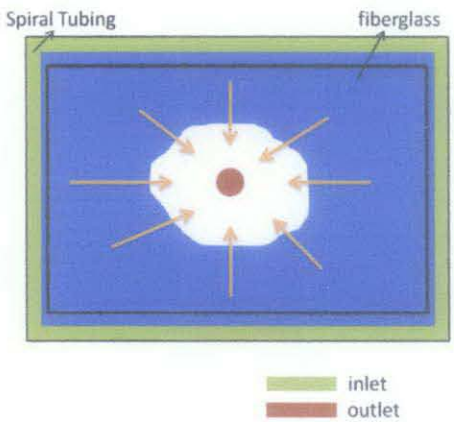

Figure 8 : Edge Feeding schematic diagram

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.

CHAPTER 3

METHODOLOGY

This chapter will cover the details explanation of methodology that is being used to make this project complete and working well. The method is use to achieve the objective of the project that will accomplish a expected result and fulfill the characterization of flow front progression and the filling time. In order to accomplish the objective of this project, the methodology generally based on this flow as shown below:

3.1 PROCESS FLOW

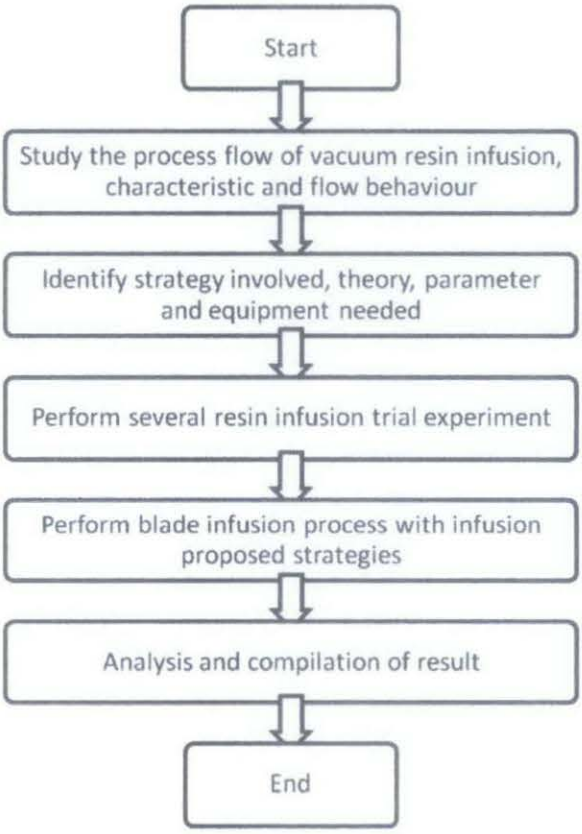

Figure 9: Process Flow of the project

3.2 INFUSION STRATEGIES

In designing the single infusion process, the main parameters of the resin infusion should be carefully investigated by the support of experiment where the flow front characteristic of the resin used will be highly focus on. Below are the two different infusion strategies on the wind blade that need to accomplish:

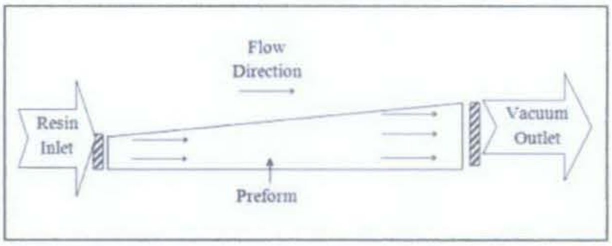

Figure 10: Strategy A (Line feed type, from tip to root)

This strategy involves the line feeding which being positioned at the tip as the resin inlet and root of the blade as the vacuum outlet. The flow of the resin would be from the inlet to the outlet and by doing the meshing grid, the author would be able to track the filling time and mapping the flow of the resin.

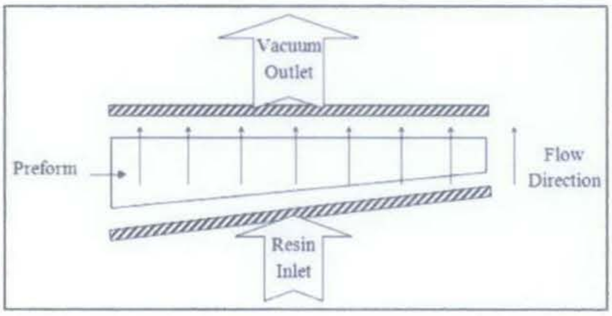

Figure 11: Strategy B (Line feed type, from trailing to leading edge)

This strategy involves the line feeding which being positioned at the trailing edge as the resin inlet and leading edge of the blade as the vacuum outlet. The spiral tubing at the trailing edge will follow the shape/angle of the blade. The flow of the resin would be from the inlet to the outlet and by doing the meshing grid, the author would be able to track the filling time and mapping the flow of the resin.

3.3 RESIN INFUSION EXPERIMENT

3.3.1 Setting up the equipment

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

i. Fiberglass
ii. Peel Ply
iii. Net Cloth (flow media)
iv. Vacuum/Laminating Bag
v. Vacuum Pump
vi. Vacuum Reservoir
vii. Resin Trap
viii. Spiral Tubing
ix. Resin Storage
x. Tacky Tape/Sealant

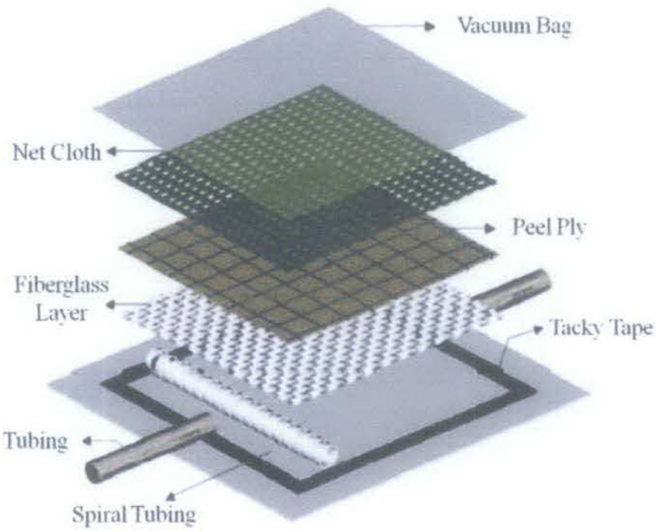

Figure 12: Arrangement of equipment/apparatus

(source : http://www.jjmechanic.com/process/rtm.htm)

3.3.2 Preparation for Dry Lay-Up for Trial Experiment

This preparation involves experiment with different dimension of fiberglass and also the layer of fiberglass. The dry lay-up consist of glass fibers, peel plies, net, and breathers (alternative). The peel ply is functioning as a protective layer for the glass fibers. By putting the peel ply above and bottom of glass fibers, it protects the glass fibers from sticking to the mold plate and the net. The peel ply also helps in the permeation of resin into the fiber. The net is used as a flow medium for the resin to travel along the fibers.

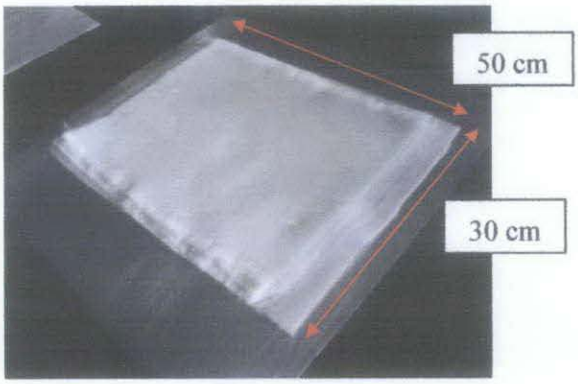

Figure 13: Fiberglass Dimension

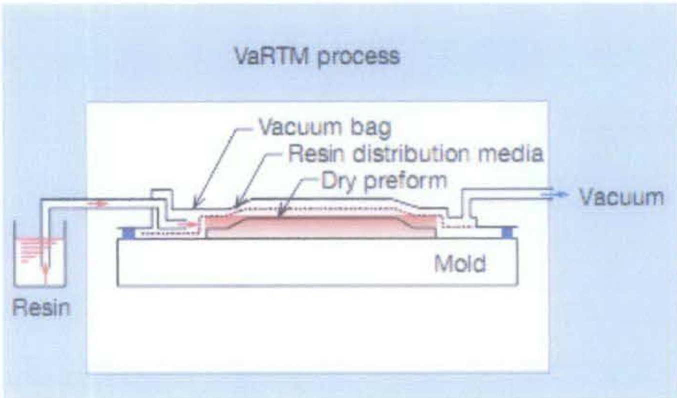

Figure 14: Schematic diagram of resin infusion

(source : http://www.jjmechanic.com/process/rtm.htm)

Preparation for matrix (mixing)

The matrix consists of epoxy resin, hardener, and acetone. The ingredients were mixed manually by using spoon or mixer. During the mixing process, acetone was firstly mixed with the epoxy before putting the hardener. This step is to ensure complete dilution of epoxy and to avoid any unexpected gelling to occur. The stirring took about five to seven minutes, until all the contents mixed.

Below is the calculation of matrix for experiment conducted previously:

Volume of fiberglass (8 plies) = width x thickness x length

= 300mm x 1.616mm x 520mm

= 252 000 mm³

Assuming that same volume of matrix will permeate in the fiberglass:

$$V_m = V_f \quad = 252.0 \text{ cm}^3$$

To find the weight of matrix needed, using $w_m = \rho v_m$

$$w_m \quad = 1.12 \text{ g/cm}^3 \times 252.0 \text{ cm}^3$$

$$= 282.3 \text{ g}$$

Considering that wastage of resin will happen due to sticking of material to the tubes and container, 30% extra matrix is concluded. Thus, the optimum amount of resin needed to use was

$$= 30\% (282.3) + 282.3$$

$$= 367 \text{ g} \approx 370.0 \text{ g}$$

Then, apply to mixing ratio of **epoxy: hardener (10:6)** and **10% acetone**

Total Mixture Mass

= 370.0 g (resin) + 222.0 g (hardener) + 60.0g (acetone)

= **650.0 g**

Before begin the experiment, the mixtures are being tested as to its gelling time and it should not gel before 40 minutes. It is important to determine the time taken for the mixture starts to gel as it can reduce the changes of resin flow failure or maybe it can affect the filling time as flow might be stopped during the infusion.

Data Recording Method

As stated in the methodology chapter, before conducting experiment using wind blade, there are several experiments need to be done to get familiar with the apparatus, equipment and the most important is the exposure of how the resins are flowing and distributing along the sample. For this target to be accomplished, we need to have effective data recording by using meshing and video recording. The time starts when the resin starts entering the rectangular portion after filling the spiral tubing. Meshing is one of the method mapping rectangular/square shapes onto the laminating vacuum bag so that we can see clearly the flowing of resins throughout the process. By having video recording, the flowing process can be reply back to get the clear view on time taken for data recording

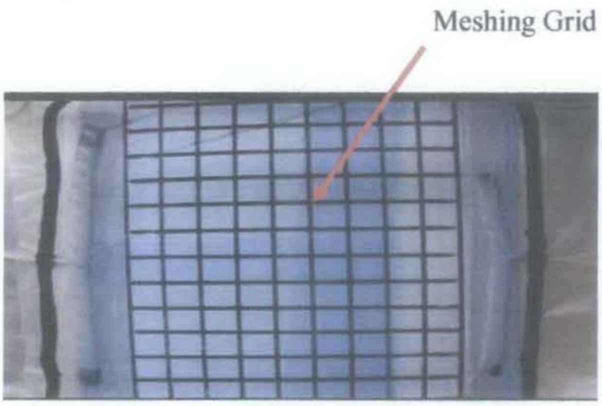

Figure 15: Meshing on the laminating vacuum bag

3.3.3 Vacuum Infusion Process

In the process, the pump suction was maintained at vacuum pressure of 75 kPa to 80 kPa. The infusion was stopped when all the glass fibers have been completely infused. Before the infusion is started, it is important to make sure that all the pipes connection are well sealed and the pump is in good condition. The minor leakage potentially happens at the connection joints and almost cannot be detected. Besides, the issue of vacuum integrity also applies to the preparation of reinforcements especially between the vacuum bag and infusion plate. Therefore, it is very crucial to have a thorough check along the sealing section.

Below is the procedure for experiment for using 8 pliers rectangular shape fiberglass:

i. The fiber, peel-ply, breather, net, and vacuum bag was set up as mentioned.
ii. Vacuum pump was started and the air trapped inside the vacuum bag was evacuated.
iii. Hissing sound from the seal around the vacuum bag and tube was checked to make sure no leak occur before resin infusion process started.
iv. Meanwhile, 370 g Epoxy, and 60 g Acetone were then mixed slowly and stir properly.
v. After mixing the epoxy and acetone, 222 g Hardener were then added to the mixture and stir properly.
vi. The mixture was then degassed to eliminate bubbles for 20 minutes.
vii. Then, resin tube was placed inside the mixture. Make sure vacuum pump was off before put the tube inside the mixture.
viii. The vacuum pump was started.
ix. Time filling was recorded.

3.3.4 Experiment based on different position of inlet and outlet

This experiment involves the different position of inlet and outlet whereby the inlet and outlet in located at the different length and width to get to know the distribution trends and time taken for the sample to complete the filling.

There are several parameters need to be set to be same throughout the experiment:

Table 1: Parameters of resin infusion trial experiments

Parameters	Description
Fiberglass Layers	8 Layers
Fiberglass Dimension	50cm x 30 cm
Fiberglass Thickness	0.202 cm

The position of the tubing spiral as the resin distribution inlet and outlet:

1st Trial Experiment:

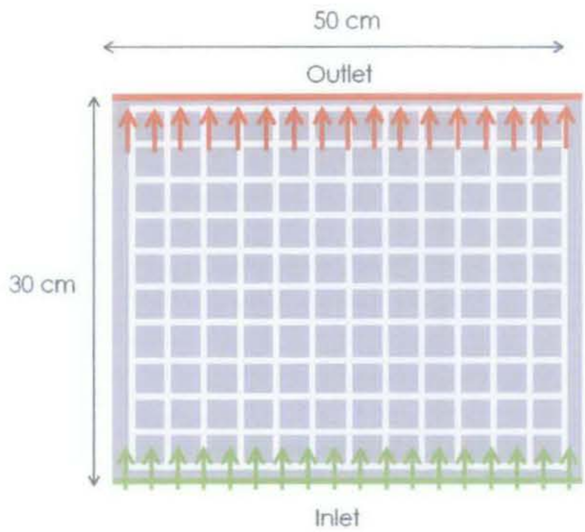

Figure 16 : Inlet and outlet position for experiment

In this experiment setup, the inlet will be at the length of 50cm and based on the schematic diagram, the resin will flow through distance of 30cm.

2nd Trial Experiment:

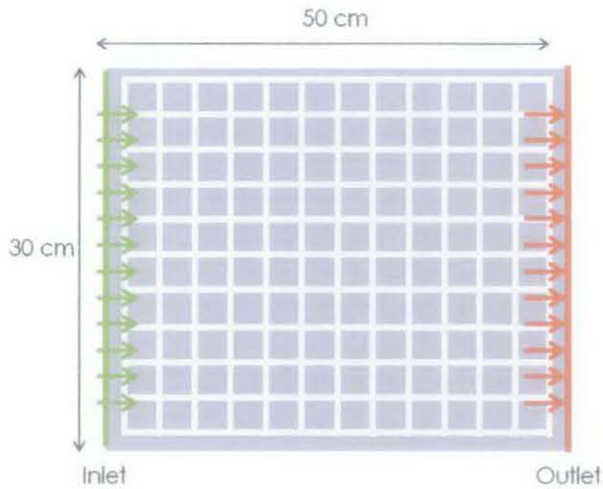

Figure 17 : Inlet and outlet position for trial experiment

In this experiment setup, the inlet will be at the length of 30cm and based on the schematic diagram, the resin will flow through distance of 50cm.

Based on the figure above, the inlet and outlet is at different position because want to the effect of resin distribution with respect to area covered. From this experiment, we would able to observe which of these strategies will fully infuse in shorter time.

Record the Filling Time

In the process, the pump suction was maintained at vacuum pressure of 75 kPa to 80 kPa. The infusion was stopped when all the glass fibers are completely infused. But, before the infusion started, it is important to make sure that all the pipes connection are well sealed and the pump is in good condition. After completing the infusion, the specimen need to be mapped with line indicate the flow of particular time interval for future reference.

3.3.5 Wind turbine blade with infusion strategies experiment

Two experiments have been conducted in investigating the filing time for each strategy namely strategy A and B, they are line feeding from:

i. Trailing edge to leading edge by following the line of trailing edge
ii. Tip to the root of the blade

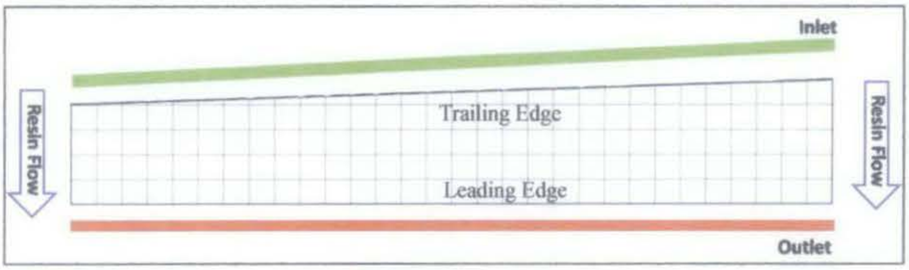

Figure 18: Strategy A (Trailing edge to leading edge)

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.

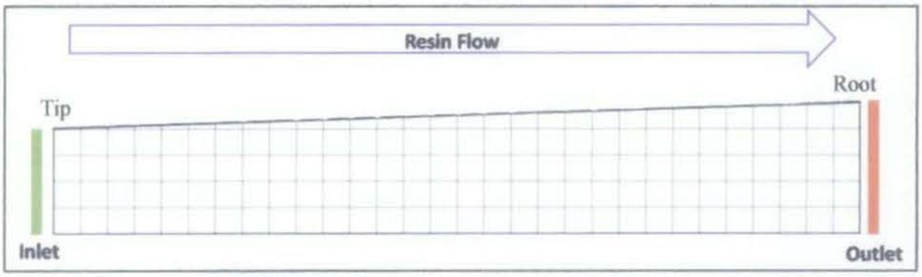

Figure 19: Strategy B (Tip to Root of the blade)

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

3.3.6 Resin usage calculation

Epoxy Weight:

Volume of fiberglass (8 plies) = width x length of blade x thickness fiber

$\mathbf{V_f}$ = 42 cm x 94 cm x (8 plies x 0.202 cm)

= 638.0 cm³

Assuming that same volume of matrix will permeate in the fiberglass:

$\mathbf{V_f = V_m}$ **= 638.0 cm³**

To find the weight of matrix needed, using $\mathbf{W_m = \rho V_m}$

w_m = 1.24 g/cm³ x 638.0 cm³

= 791.1 g ≈ 800 g of Epoxy

Considering that wastage of resin will happen due to sticking of material to the tubes and container, 10% extra matrix is concluded. Thus, the optimum amount of resin needed to use was

= 10% (800) + 800

= 880 g

Then, apply to mixing ratio of **epoxy: hardener (10:6)** and **10% acetone**

So the weight of:

i. **Resin = 880 g**
ii. **Hardener = 528 g**
iii. **Acetone = 140 g**

3.3.7 Strategy A : Line Feeding from Trailing Edge to Leading Edge

Blade Setup

Figure 20: Arrangement of the preform

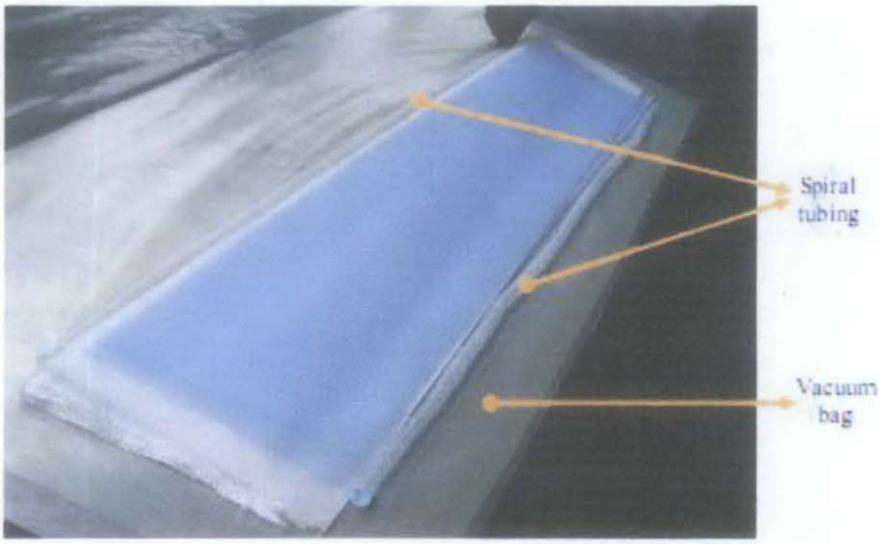

Figure 21: Position of resin inlet and outlet

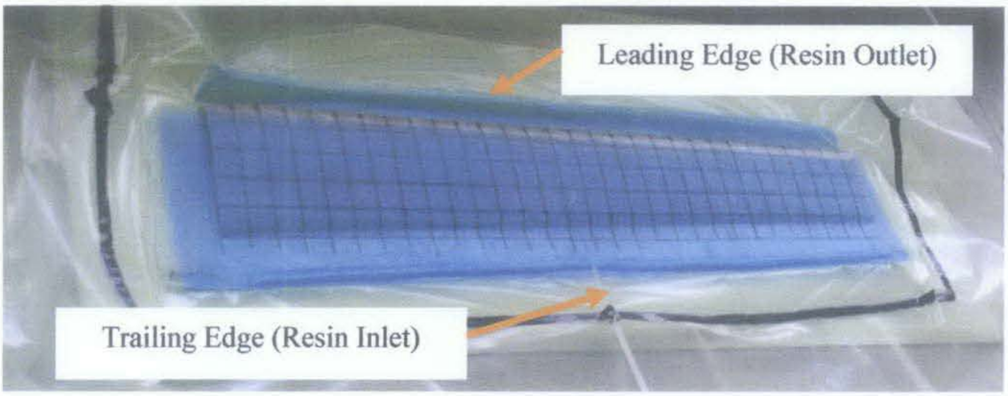

Figure 22: Complete set up of blade infusion experiment and grid is draw on vacuum bag (Strategy A)

Procedure

i. The blade, fiber, breather, and net were set up as mentioned.
ii. First spiral tubing was cut similar length of the trailing edge length and placed at the trailing edge of the blade (resin inlet line).
iii. Second spiral tubing was cut similar length of the leading edge length and placed at the leading edge of the blade (vacuum line).
iv. Vacuum bag was wrapped around to cover the whole surfaces of the blade and then sealed using sealant tape.
v. Vacuum pump was started and the air trapped inside the vacuum bag was evacuated.
vi. Hissing sound from the seal around the vacuum bag and tube was checked to make sure no leak occur before resin infusion process started.
vii. Grid was draw with the dimension of 30mm × 30mm for analyzing the results.
viii. Meanwhile, 880 g epoxy, 524 g hardener and 140 g acetone were then mixed slowly and stir properly.
ix. The mixture was then degassed to eliminate bubbles for 20-30 minutes.
x. Then, resin tube was placed inside the mixture. Make sure vacuum pump was off before the tube is placed inside the mixture.
xi. The vacuum pump was started.
xii. Time filling was recorded.

3.3.8 Strategy B : Line Feeding from Tip to Root of the blade

Blade Setup

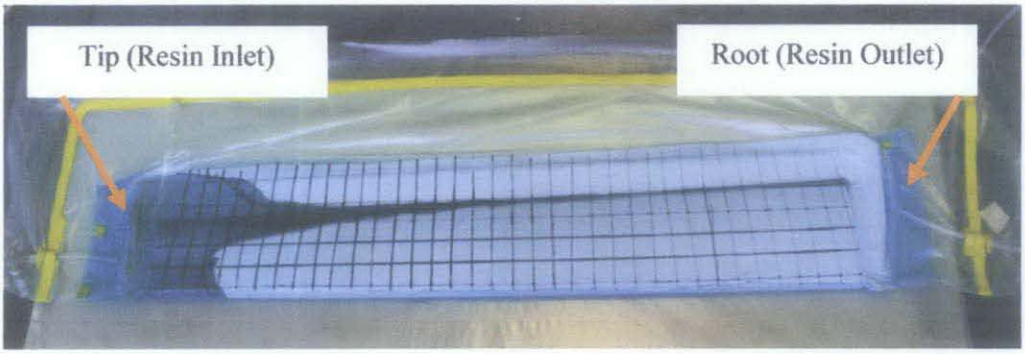

Figure 23 : Complete set up of blade infusion experiment and grid is draw on vacuum bag (Strategy B)

Procedure

i. The blade, fiber, breather, and net were set up as mentioned.

ii. First spiral tubing was cut similar length of the tip length and placed at the tip of the blade (resin inlet line).

iii. Second spiral tubing was cut similar length of the root length and placed at the root of the blade (vacuum line).

iv. Vacuum bag was wrapped around to cover the whole surfaces of the blade and then sealed using sealant tape.

v. Vacuum pump was started and the air trapped inside the vacuum bag was evacuated.

vi. Hissing sound from the seal around the vacuum bag and tube was checked to make sure no leak occur before resin infusion process started.

vii. Grid was drew with the dimension of 30mm × 30mm for analyzing the results.

viii. Meanwhile, 800 g epoxy, 480 g hardener and 192 g acetone was then mixed slowly and stir properly.

ix. The mixture was then degassed to eliminate bubbles for 30 minutes.

x. Then, resin tube was placed inside the mixture. Make sure vacuum pump was off before the tube was placed inside the mixture.

xi. The vacuum pump was started.

xii. Time filling was recorded.

Data Recording Method for Wind Blade Infusion

For this target to be accomplished, we need to have effective data recording by using meshing and video recording. The time starts when the resin starts entering the rectangular portion after filling the spiral tubing. Meshing is one of the method mapping rectangular/square shapes onto the laminating vacuum bag so that we can see clearly the flowing of resins throughout the process. By having video recording, the flowing process can be reply back to get the clear view on time taken for data recording. Besides, we also can take pictures for every 5 minutes to get the resin dispersion throughout the blade. 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.

CHAPTER 4

RESULT & DISCUSSION

4.1 RESULTS

This section will be discussed the experiment result and that have been conducted and how the data be analyzed. In the first part of this chapter, it will explain about how data is being collected from the experiment and second part of this chapter will explain about the finding from the experiment.

4.1.1 Resin Infusion Trial Experiment

Based on the data recording, the author able to get the result from the experiment which is the time taken for the resins to have a complete distribution for all areas from input to output. Below is the chart with filling time and percentage distance of resin taken to complete the flow along the traveling distance:

1st Trial Experiment:

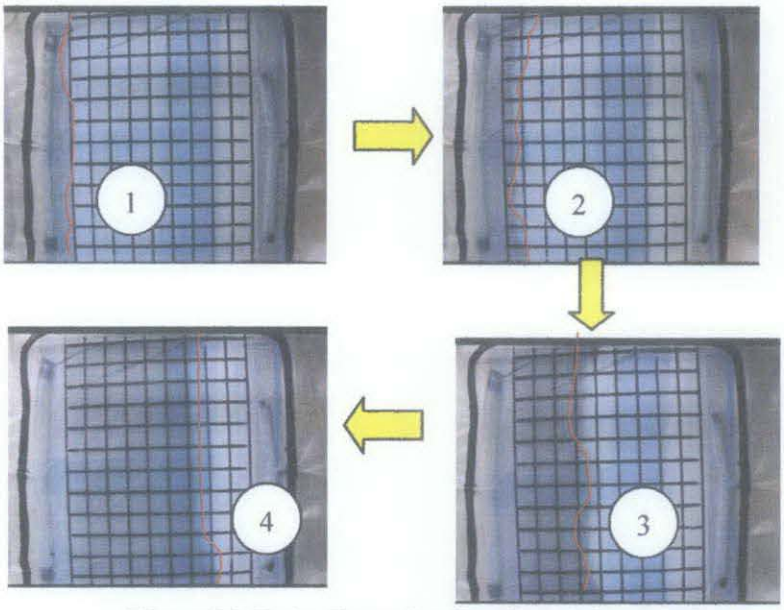

Figure 24: Resin dispersion flow from inlet to outlet

Above experiment data can be shown in graph presentation:

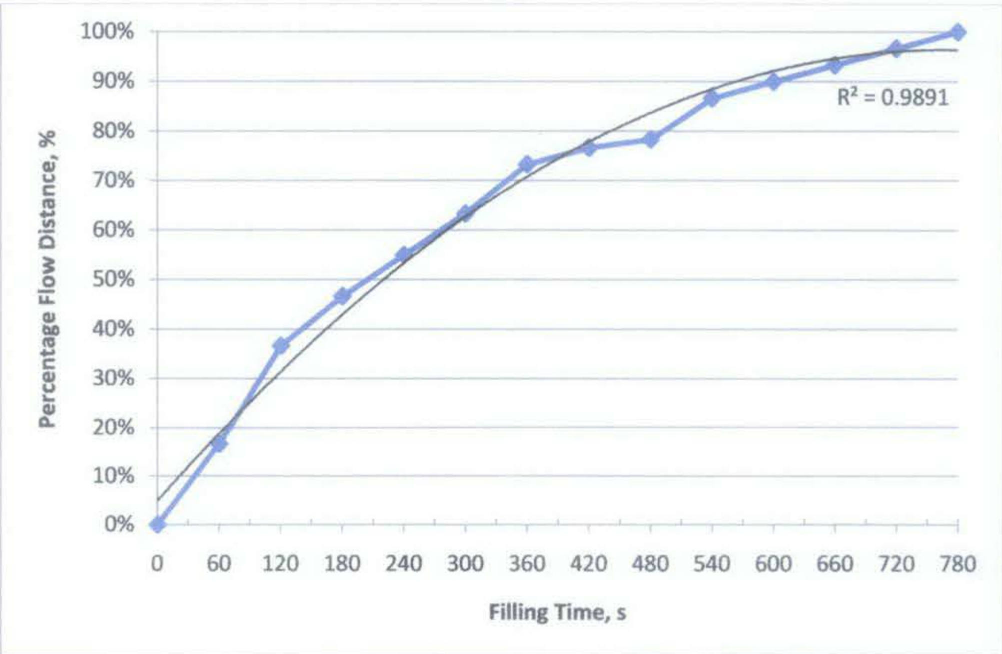

Figure 25: Percentage of flow distance versus filling time for trial experiment 1

This graph shows the infusion time for 30 cm length of flow front progression. The full time filling for this first experiment is 780 seconds (13 minutes). The trend line is set on the graph to view the best line for the graph recorded. This is the shortest infusion time recorded and this is mainly due to the shortest travel distance which resin needs to travel from the resin inlet (resin source) to the resin outlet (vacuum outlet). The use of spiral tubing at the width side of the fiberglass 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 inlet 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. It is also observed that the bubbles form mostly at the spiral tubing at resin inlet side.

2nd Trial Experiment:

The experiment data can be shown in graph presentation:

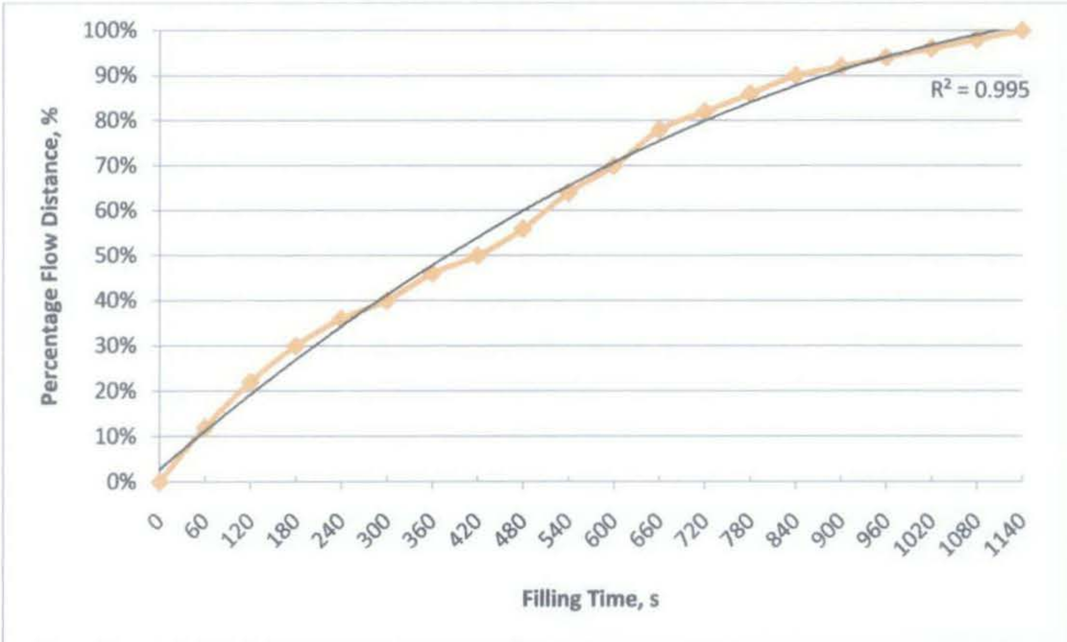

Figure 26: Percentage of flow distance versus filling time for trial experiment 2

The above graph shows the 50 cm length of flow front progression. The time filling for second experiment is 1200 seconds (120 minutes). The longer distance of resin needs to travel from inlet to outlet is the reasons why the filling time is much longer. The farthest 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 first experiment. This is because spiral tubing used is shorter than that in first experiment thus creating less bubble.

Permeability Data Analysis:

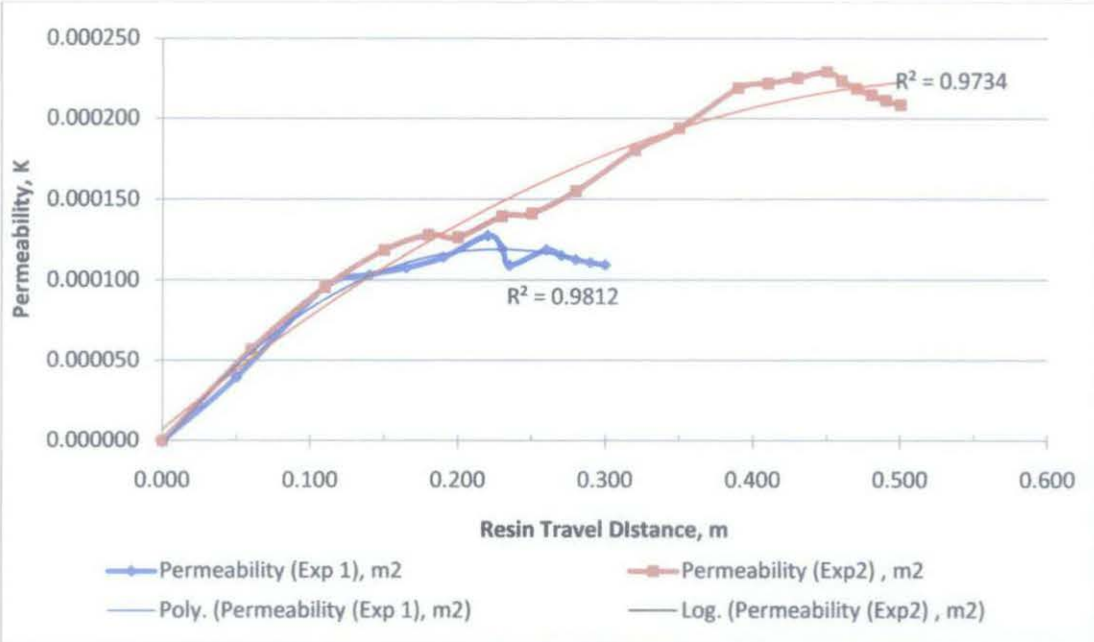

Figure 27: Graph of Permeability versus resin travel distance for trial experiment 1 and 2

The graph above is the combination of two that shows the permeability of the glass fiber which allows the resin to flow through and establish strong adhesive between the reinforcement and the matrix. Permeability of the distribution medium varies with the number of fibrous layers and so does the porosity. In both experiments, the glass fiber layers are fixed to be 8 layers and same thickness for each layer. Average permeability from experiment 1 and 2 are calculated as control value for the resin infusion strategy analysis

4.1.1 Wind turbine blade with infusion strategies experiment

Based on the previous experiment 1 and 2 data, we able to come out with a average permeability which can be used as control value (theoretical value) to compare with the infusion strategies (strategy A and B).

Table 2 : Permeability from trial experiment 1 and 2

Permeability, Trial Experiment 1	Permeability Trial Experiment 2
$K_1 = 0.000112\ m^2$	$K_2 = 0.000129\ m^2$

Average Permeability = (0.000112 + 0.000129)/2 = **0.000120 m²**

Value above is used in the Darcy equation to get the experimental time which can be used in determine the ideal time for a particular area filled in percentage.

Darcy Equation :

$$\text{Fill time, (t)} : \frac{\text{Viscosity, Pa.s } (\mu) \times \text{Flow length,m } (d)^2}{\text{Permeability,m2 } (K) \times \text{Pressure gradient}(-\Delta p)}$$

Strategy A : Line feeding strategy from trailing edge to leading edge

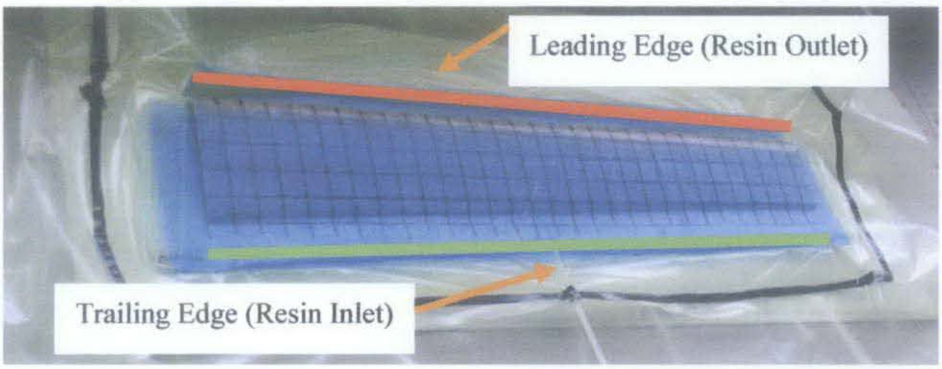

Figure 28: Resin flow from Inlet to Outlet

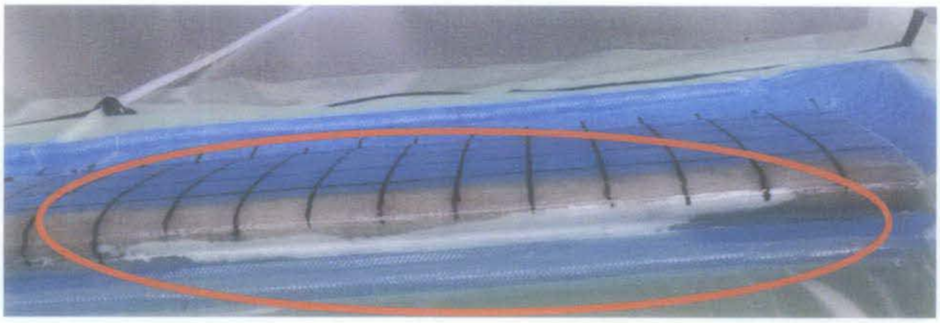

Figure 29: Slow moving of resin filling the remaining area (in red circle)

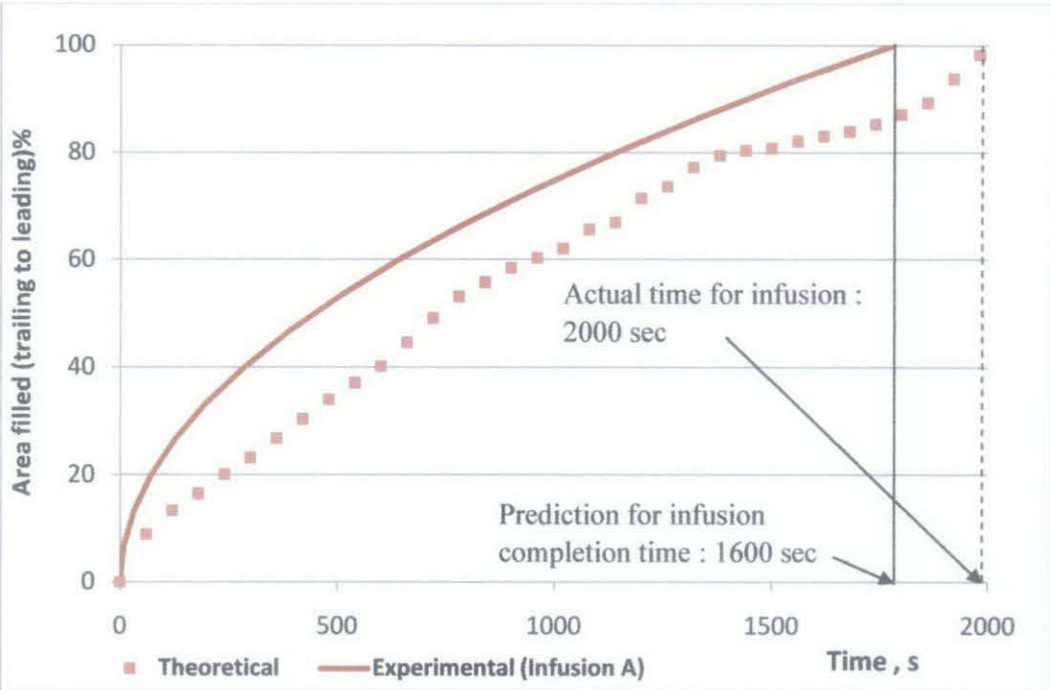

Figure 30: Experimental and theoretical graph for Strategy A

This graph shows the infusion time for 15c m (0.15m) length of blade. The time filling for strategy A is about 34 minutes. This is the infusion time recorded and this time taken at the shortest distance which resin needs to travel from the resin inlet to the resin 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, prediction line predict the infusion will complete within 1600 sec (26 minutes) but the actual infusion takes about 2000 sec (33 minutes) this gap is about 25% from the time completion of theoretical value. This is because 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.

Strategy B : Line feeding strategy from tip to root

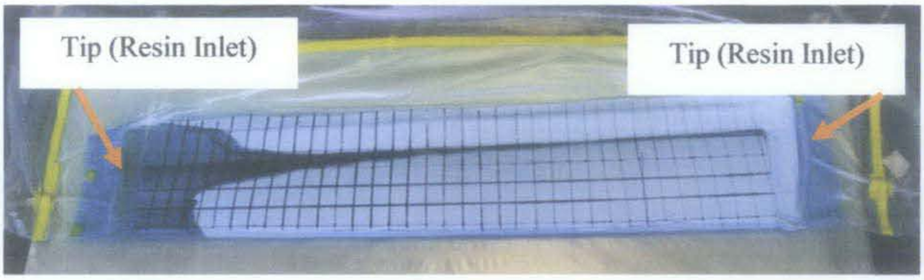

Figure 31: Infusion strategy B from tip to root

Figure 32: View from the back of the blade

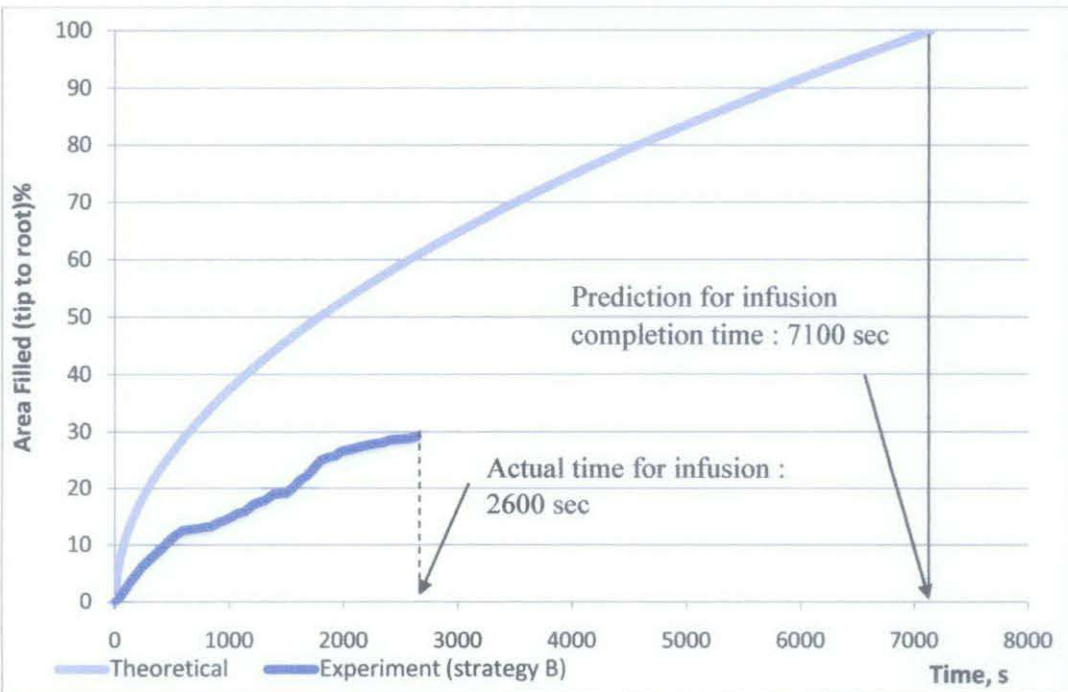

Figure 33: Experimental and theoretical graph for Strategy B

The above graph is for the tip to root strategy which need the resin to travel about 97 cm to complete the infusion from inlet to outlet. Based on the graph, the infusion is able to infuse up to 28% of the blade length. The time filling for strategy B is however cannot be recorded because the flow progression is too slow due to the leak at seal tape and the infusion is disturbed and cannot be completed. The leak cause the pressure inside the vacuum bag increased and full vacuum is not achieved. Due to the slow flow progression of the resin, the resin started to gel on the 28% of the overall infusion process.

Figure 34: Finish product of strategy A

4.2 DISCUSSIONS

4.2.1 Resin Infusion Trial Experiment

i. From the experiment, it is found out that epoxy and hardener mix well with acetone. The flow getting slower as more epoxy and hardener start to gel. But the experiment can be finished before the mixture become gel and stops the flow.

ii. For this experiment, we are expecting the time will be not much different (3-4 minutes different) because the area of fiberglass is the same for both experiment. Based on the result show the first experiment gives us the faster time to fill the fiberglass compared to the second experiment. After make several researches, we manage to get several reasons for the result that we get:

- Fiberglass Dimension
  → Shorter dimension will able to initiate less infusion time
- Fiberglass Permeability
  → Higher permeability increases time to fill the layers
- Fiberglass Thickness
  → Increase thickness more time to fill the layers
- Gravity force
  → May differ at every point of infusions

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

4.2.2 Wind turbine blade with infusion strategies experiment

i. 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.

ii. 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.

iii. 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.

iv. 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 s and errors experiments later. The experiment conducted is just to help in determine the mixture usage, the time needed for a particular mixture starts to gel and find the right amount of resin flow at determine direction.

After conducted two 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.

Besides, in determine the effective strategies of infusions, the author need to examine several factors such as permeability of fiberglass, distribution layer, distance of inlet and outlet from the preform before conducted an experiment. Based on the experiments, the author need to set parameters to be maintained such as permeability, distribution layer and pressure applied during the experiment. There are some variable factors should be considered as the main attributes to the results of the experiments. There are the distance of spiral tubing as inlet and outlet and also the length of the fiberglass.

5.2 RECOMMENDATION

i. Repeat experiment to observe the effect of line feeding. Another strategy such as multiple feeding should be tested as it is assume to give better time filling with better resin to fiberglass ratio.

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

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

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APPENDIX A

Gantt Chart

GANTT CHART (FYP _MAB 4012)

COMPARATIVE STUDY BETWEEN TWO RESIN INFUSION STRATEGIES FOR WIND TURBINE BLADE

PROJECT GANTT CHART FOR FYP 1

No.	Activities \ Weeks	1	2	3	4	5	6		7	8	9	10	11	12	13	14
1	*Propose project title*	■	■					Mid-Semester Break								
2	*Meeting with supervisor and team members*		■													
3	*Preliminary Research Work*		■	■	■											
4	*Collecting information from journals, research papers, etc*		■	■	■											
5	*Practice on how to do vacuum infusion*				■	■	■									
6	*Submission of Progress Report 1*									■						
7	*Purchase the necessary materials*						■		■	■						
8	*Set up and conduct trial experiments*						■		■	■	■	■				
9	*Submission of Progress Report 2*											■	■			
10	*Seminar (compulsory)*									■						
11	*Submission of interim report final draft*															■
12	*Oral presentation*											study weeks				

PROJECT GANTT CHART FOR FYP 2

No.	Activities\Weeks	1	2	3	4	5	6		7	8	9	10	11	12	13	14	15	16	17
1	*Mechanical testing preparation*	■	■	■				Mid-semester break											
3	*Improve infusion preparation and set-up*			■	■	■													
4	*Progress Report 1*				■	■													
5	*Run testing for all samples*					■	■												
6	*Progress Report 2*									■									
7	*Seminar*									■									
8	*Run testingfor all samples (cont.)*								■	■	■	■	■	■					
9	*Poster Presentation*												■	■	■				
10	*Submission of final dissertation report (draft)*															■	■	■	
11	*Final oral presentation*																	■	■
12	*Submission of final dissertation report (final)*															exam weeks			

Filling Time, s	Flow Distance, cm	Flow Distance, m	Flow Distance, m2	Viscosity, Pa.s	Pressure Gradient, Pa	% Flow Distance, cm	Permeability (Exp 1), m2
0	0	0.000	0.0000	0.57	0.60	0%	0.000000
60	5	0.050	0.0025	0.57	0.60	17%	0.000040
120	11	0.110	0.0121	0.57	0.60	37%	0.000096
180	14	0.140	0.0196	0.57	0.60	47%	0.000103
240	17	0.165	0.0272	0.57	0.60	55%	0.000108
300	19	0.190	0.0361	0.57	0.60	63%	0.000114
360	22	0.220	0.0484	0.57	0.60	73%	0.000128
420	23	0.230	0.0529	0.57	0.60	77%	0.000120
480	24	0.235	0.0552	0.57	0.60	78%	0.000109
540	26	0.260	0.0676	0.57	0.60	87%	0.000119
600	27	0.270	0.0729	0.57	0.60	90%	0.000115
660	28	0.280	0.0784	0.57	0.60	93%	0.000113
720	29	0.290	0.0841	0.57	0.60	97%	0.000111
780	30	0.300	0.0900	0.57	0.60	100%	0.000110

Data Collection from experiment 2

Filling TIme, s	Flow Distance, cm	Flow Distance, m	Flow Distance, m2	Viscosity, Pa.s	Pressure Gradient, Pa	% Flow Distance, cm	Permeability (Exp2), m2
0	0	0.000	0.0000	0.57	0.60	0%	0.000000
60	6	0.060	0.0036	0.57	0.60	12%	0.000057
120	11	0.110	0.0121	0.57	0.60	22%	0.000096
180	15	0.150	0.0225	0.57	0.60	30%	0.000119
240	18	0.180	0.0324	0.57	0.60	36%	0.000128
300	20	0.200	0.0400	0.57	0.60	40%	0.000127
360	23	0.230	0.0529	0.57	0.60	46%	0.000140
420	25	0.250	0.0625	0.57	0.60	50%	0.000141
480	28	0.280	0.0784	0.57	0.60	56%	0.000155
540	32	0.320	0.1024	0.57	0.60	64%	0.000180
600	35	0.350	0.1225	0.57	0.60	70%	0.000194
660	39	0.390	0.1521	0.57	0.60	78%	0.000219
720	41	0.410	0.1681	0.57	0.60	82%	0.000222
780	43	0.430	0.1849	0.57	0.60	86%	0.000225
840	45	0.450	0.2025	0.57	0.60	90%	0.000229
900	46	0.460	0.2116	0.57	0.60	92%	0.000223
960	47	0.470	0.2209	0.57	0.60	94%	0.000219
1020	48	0.480	0.2304	0.57	0.60	96%	0.000215
1080	49	0.490	0.2401	0.57	0.60	98%	0.000211
1140	50	0.500	0.2500	0.57	0.60	100%	0.000208

Data Collection from experiment 1