CERTIFICATION OF APPROVAL

Investigation into Resin Infusion Strategies in the Fabrication of GRE Composite Wind Turbine Blade

by

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Approved:

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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.

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MOHAMMAD EL HAFIZ BIN MUSHADAD

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ABSTRACT

Common manufacturing material of wind turbine blade is using glass-fiber reinforced polymer composite by vacuum-assisted resin transfer mold. Selecting the right infusion strategy is important to determine the effectiveness of Resin infusion process. Resin infusion strategy is important to achieve good fiber-to-resin ratio and with uniform distribution with the shortest time for mass production and better quality of product. 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 [1]. These project objectives are to investigate the effect of infusion strategy on the filling time and flow behavior of resin during mold filling. To achieve the objectives, steps in methodology will be carried out. Firstly by set up the camera video used to capture image of resin flow front progression. The vacuum bag will be mesh with square grid to observe the resin flow front. Then, performing the resin infusion process and record the fill time and flow progression. The result shows that the filling time for strategy A trial 1 takes 90 seconds while the seconds trial takes 95 seconds. Meanwhile filling time for strategy B is 1140 seconds for first trial and 1110 seconds for second trial. The flow lines are traced using AUTOCAD to obtain filled area. The result is compared with theoretical calculation using Darcy's equation and the graph of theoretical and experimental is plotted. The flow progression of resin is influenced by the distance of resin inlet and vacuum outlet, the pressure drop along the flow and the viscosity of resin used in the infusion process. Based on this project, strategy A from trailing edge of the blade to the leading edge is the best infusion strategy to manufacture GRE composite wind turbine blade.

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CHAPTER 1

INTRODUCTION

1.1PROJECT BACKGROUND

Resin Infusion is a relatively new technique in composite construction. A vacuum bag is constructed over the laminate, and a vacuum is pulled. Resin enters the laminate through feeder pipes and a runner system, and impregnates the glass, aramide or carbon fibers. Results are a high quality composite laminate, with high fiber/resin ratio, and perfect adhesion to core materials.

VIP = Vacuum Infusion Process, VARTM = Vacuum Assisted Resin Transfer Molding, RI = Resin Infusion, SCRIMP = Seeman Composites Resin Infusion Molding Process, CVI - Controlled Vacuum Infusion, all these terms are covering basically the same technique. The basic idea is simple: lay the reinforcements materials up dry, compact them under vacuum, and then use the vacuum to pull the resin in from outside the bag (or mold) which subsequently progresses through the dry layup. [2]

Advantages of resin infusion are high quality laminate (low void content which result in higher strength, high fiber to resin ratio), user friendly, large objects can be infused with a minimum of workforce, environmentally friendly (reduction of VOC, when using polyester), repeatable results and weight reduction of the part (especially sailing boat hulls, multihulls and fast powerboats can benefit).

The vacuum infusion process eliminates the inconsistencies of hand lay-up that's heavily dependent on laminator's skill and it completely does away with air entrapment and void problems that can compromise durability. The process creates the highest resin-to-glass ratio in wind turbine blade construction. [3]

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. [4]

1.2 PROBLEM STATEMENT

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. [1] Moreover, the process is sensitive to leakage in the flexible membrane and a good surface finish is only available on one side of the part. Complex geometries such as sharp edges and thickness variations can disturb the flow [15]

Currently, few research and experiment is done on close profile infusion process due to its complexity such as non-uniform thickness due to pressure difference, location of resin inlet and vacuum outlet and the shape of mold. Furthermore, little is done involving different infusion strategy and its effect on resin flow. It is important to study the flow characteristic to understand the resin fluid dynamic of how it travels within the wind turbine blade preform. This project is relevant to find out the best infusion strategy to conduct Vacuum Infusion that produce more uniform resin distribution thus eliminate voids and bubbles to improve strength and quality, achieving complete wetting of all areas within the fiber containing preform, improving the curing process and reduce resin fill time which is important for mass production

1.3 OBJECTIVE AND SCOPE OF STUDY

This project objective is to investigate the effect of infusion strategy on the filling time and flow behavior of resin during mold filling. There are two infusion strategies that will be tested are strategy 1: line feeding from trailing edge to leading edge and strategy 2: line feeding from root to tip. This project will use glass fiber with latex with vinyl ester and wood core.

The scope include preparation of image capture tools using camera to record the resin flow front progression, conducting the infusion process and finally analyzing resin flow behavior using CAD and Darcy's law based on the images obtained.

CHAPTER 2
LITERATURE REVIEW

2.1 RESIN INFUSION PROCESS

Composites industry has create many products from many different manufacturing processes. Each of the fabrication processes has characteristics that define the type of products to be produced. Resin Infusion is a process by which vacuum draws resin into a dry fibre laminate in a one sided mould. A rigid or flexible film membrane is placed over the top and sealed around the mould periphery. Resin infusion is considered a “Closed Mold Process”. Resin Transfer Molding (RTM) is basic infusion process and there are variation of this technique such as vacuum assisted transfer moulding (VARTM), Seeman Composite Resin Infusion Molding Process (SCRIMP™) and resin infusion by flexible tooling (RIFT) which use the same basic principle.

2.2 WIND TURBINE BLADE

New generation wind turbine designs are pushing power generation from the single megawatt range to upwards of 10 megawatts. The common trend of these larger capacity designs are larger and larger wind turbine blades. Covering a larger area effectively increases the tip-speed ratio of a turbine at a given wind speed, thus increasing the energy extraction capability of a turbine system [12]. New materials such as fiberglass laminate and manufacturing methods such as VARTM provide the opportunity to improve wind turbine efficiency by allowing for larger and stronger blades.

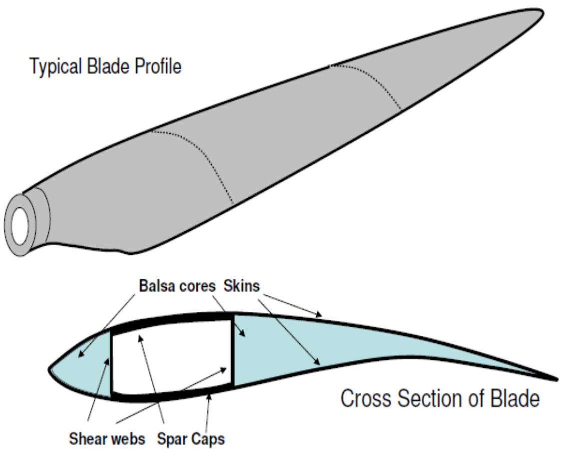

Figure 1: Blade design profile

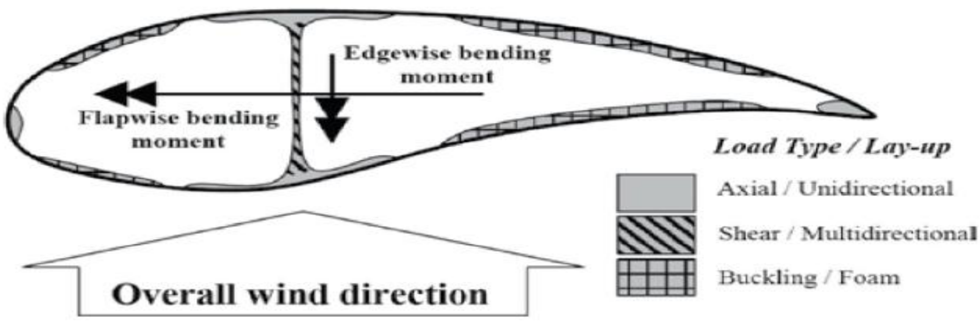

Figure 2: Blade cross section

2.3 RESIN TRANSFER MOLDING (RTM) [6]

Resin Transfer Molding or RTM as it is commonly referred to is a "Closed Mold Process" in which reinforcement material is placed between two matching mold surfaces – one being male and one being female. The matching mold set is then closed and clamped and a low-viscosity thermoset resin is injected under moderate pressures (50 – 100 psi typical) into the mold cavity through a port or series of ports within the mold. The resin is injected to fill all voids within the mold set and thus penetrates and wets out all surfaces of the reinforcing materials. The reinforcements may include a variety of fiber types, in various forms such as continuous fibers, mat or woven type construction as well as a hybrid of more that one fiber type. Vacuum is sometimes used to enhance the resin flow and reduce void formation. The part is typically cured with heat. In some applications, the exothermic reaction of the resin may be sufficient for proper cure. [6]

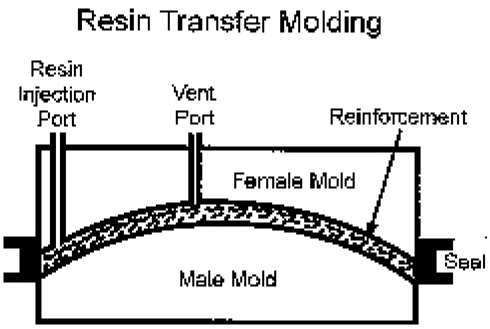

Figure 3: RTM (Resin Transfer Molding)

RTM as a process, is multi-compatible with a variety of resin systems including polyester, vinyl ester, epoxy, phenolic, modified acrylic and hybrid resins such as polyester and urethane. Typically, it requires a resin viscosity of 200 to 600 centerpoise to penetrate all surfaces of the mold cavity.

2.4 VACUUM ASSISTED RESIN TRANSFER MOLDING (VARTM) [6]

In the traditional RTM process, a matched set of molds or “closed mold” is used. The fiber reinforcements are usually preformed off line to enhance the production cycle time of the molds to perform at a respectable production rate. Resin is injected at high pressures and the process is sometimes assisted with vacuum.

However, Vacuum Assisted Resin Transfer Molding (VARTM) is different for many reasons. First, the fabrication of parts can be accomplished on a single open mold. Second, the process uses the injection of resin in combination with a vacuum and captured under a bag to thoroughly impregnate the fiber reinforcement. In the late 1980’s, Bill Seemann invented and patented a variation to the VARTM process called SCRIMP^{TM}, which is Seemann Composite Resin Infusion Molding Process. This process has been used in many new and large applications ranging from turbine blades and boats to rail cars and bridge decks. Unique to this process is the manufacturing method that allows the efficient processing of VARTM to produce large structural shapes that are virtually void-free. This process has been used to make both thin and very thick laminates. In addition, complex shapes with unique fiber architectures allow the fabrication of large parts that have a high structural performance.

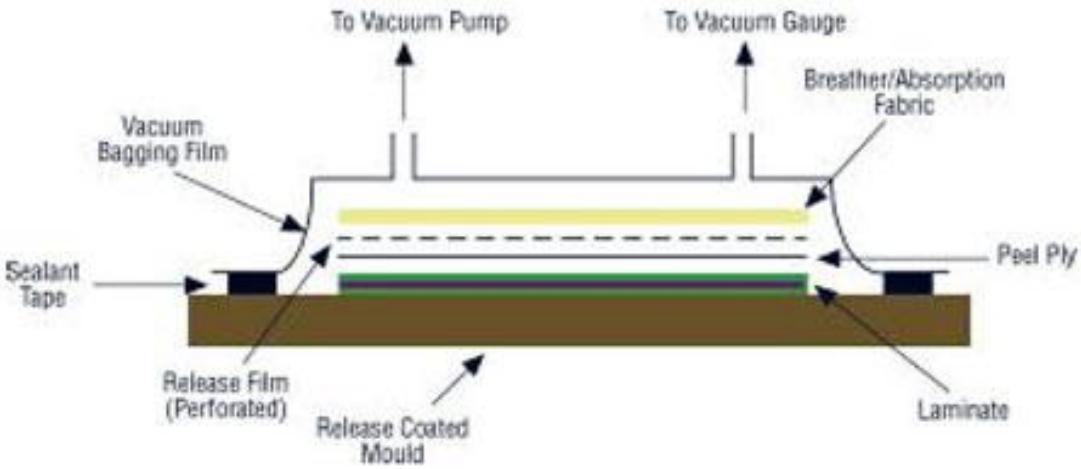

Figure 4: Vacuum Assisted Resin Transfer Molding (VARTM)

Parts using VARTM are made by placing dry fiber reinforcing fabrics into a mold, applying a vacuum bag to the open surface and pulling a vacuum using a compressor while at the same time infusing a resin to saturate the fibers until the part is fully cured. This process allows for easy visual monitoring of the resin to ensure complete coverage to produce good parts without defects.

2.5 HAND LAYUP –OPEN MOLDING PROCESS [7]

Fiberglass (typically E-glass) continuous strand mat and/or other fabrics such as woven roving is manually placed in the mold. Each ply is sprayed with catalyzed resin (1000-1500 cps). Brushes and rollers are used to work the resin into the fiber, wetting out and compacting the laminate.

Hand lay-up and spray-up methods are often used together to reduce labor. For example, fabric might first be placed in an area exposed to high stress. A spray gun then applies chopped glass, completing the part. Balsa or foam cores may be inserted between the laminate layers in either process. Typical glass fiber volume ranges from 15-35%, with spray-up at the lower end and hand lay-up at the higher end.

Spray-on surface materials, are available to finish parts made through Open or Closed Mold processes. This spray-on surfacing material bonds to fiberglass and other materials. Available in granite-look color blends, solid, accent and custom colors, it provides an attractive finish that is more durable then premium solid surface materials, but as economical as plastic laminate.

Figure 5: Hand layup process

2.6 SCRIMP™

SCRIMP™ process is characterized 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. [1]

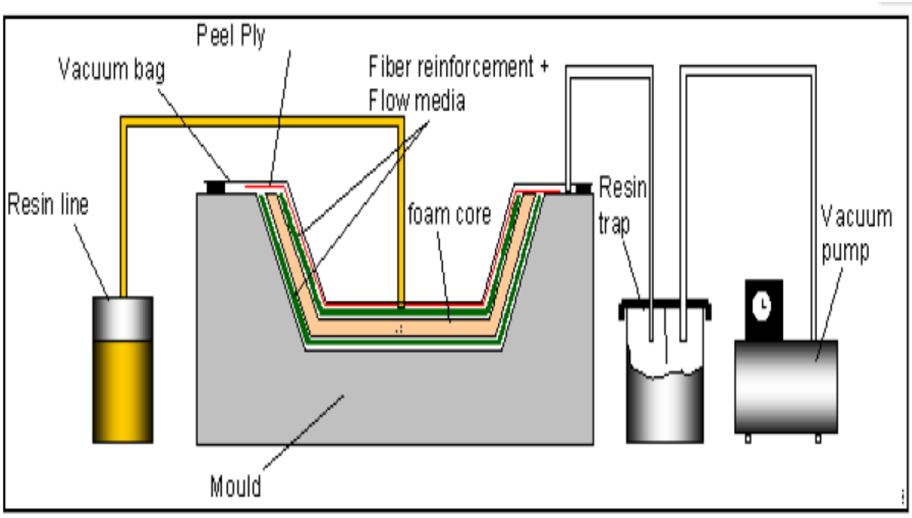

Figure 6: SCRIMP™ process

2.7 INFUSION CHARACTERISTICS:

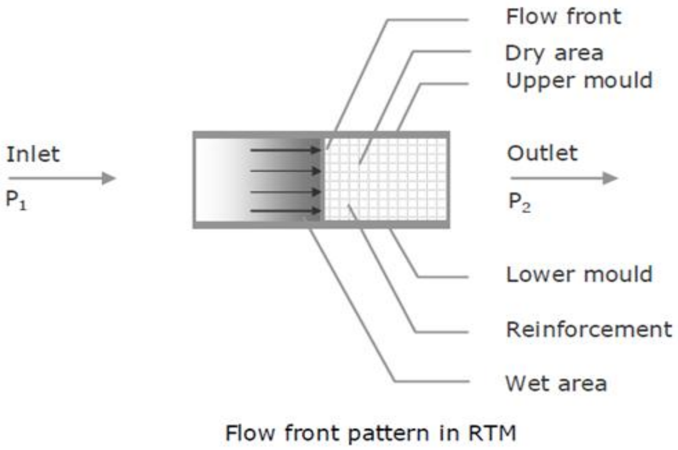

Figure 7: Flow behavior in Resin transfer moulding

During infusion process, inlet tube is connected to an atmospheric supply of liquid resin while the outlet is normally connected to a vacuum pump, via resin trap. The cavity is vacuumed by vacuum pump and resin is introduced. Flow is driven by the pressure difference and when the cavity is fully impregnated, the resin supply is disconnected. The finishing blade is debagged only after resin is cured. The distribution medium improves the impregnation dynamics and the fluid flows mainly through the thickness of the preform.

Darcy's law is a phenomenological derived constitutive equation that describes the flow of a fluid through a porous medium. The law was formulated by Henry Darcy based on the results of experiments. [8]

Darcy's law is a simple proportional relationship between the instantaneous discharge rate (Q) through a porous medium, the viscosity of the fluid and the pressure drop over a given distance.

$$Q = \frac{-kA}{\mu}\frac{(P_b - P_a)}{L} \qquad (1.0)$$

In Vacuum infusion, mold cavity thickness is constant and permeability of the preform remains constant. Velocity can be found by:

$$v = \frac{K}{\varepsilon \cdot \mu} \cdot \frac{dP}{dx} \qquad (1.1)$$

Where v is the insterstital velocity, K the preform permeability, ε the porosity, μ the fluid viscosity and dP/dx the pressure gradient over the flow distance.

An integration form of Darcy's law shows time as a function of flow front distance squared as described in Equation 1.2.

$$t = \frac{\mu \cdot \varepsilon}{2 \cdot K} \cdot \frac{x^2}{\Delta P} \qquad (1.2)$$

During the infusion, the compaction of the preform evolves locally with the pressure gradient and the latter evolves with flow front position as shown in Figure 8. The impregnated part of the preform is submitted to a non-uniform pressure distribution with atmospheric pressure at the inlet and vacuum at the flow front. The compaction and the permeability of the wet area vary with position and flow front progression. The thickness of the impregnated part is not uniform; the preform is typically thicker at the inlet where the pressure level is higher. The dry part of the preform is under uniform pressure equivalent to the vacuum set at the outlet. Flow in the cavity is in-plane only and rectilinear (at this stage of Vacuum Infusion description it is assumed that the lay-up has homogeneous permeability i.e no layers of different permeability) [5]

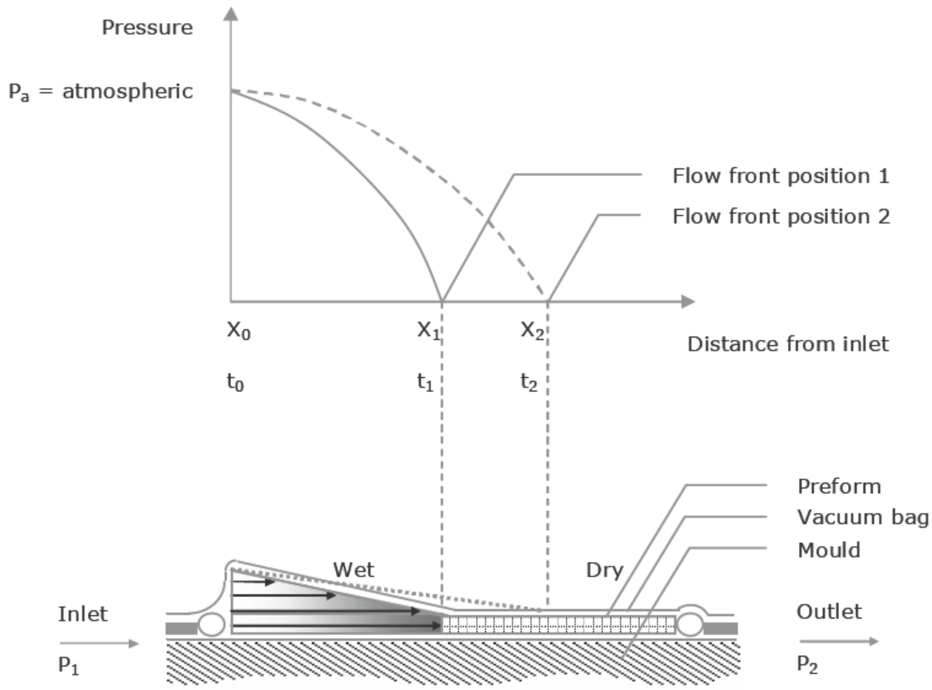

Figure 8: Progression of flowfront with pressure in vacuum infusion

In Vacuum infusion time is a critical factor as lay-up, infusion and part release are generally slow processes especially when producing large structures. A solution to reduce overall manufacturing time is to decrease infusion time by adding a distribution medium to the preform. The latter, usually a polymer mesh of polyamide or polyethylene, can also be a layer of reinforcement of high permeability made of the same fiber as the preform [9].

Infusion time in VI (Vacuum infusion) is directly dependent on preform thickness, pressure gradient and permeability variations in the preform. [5].

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. [5]

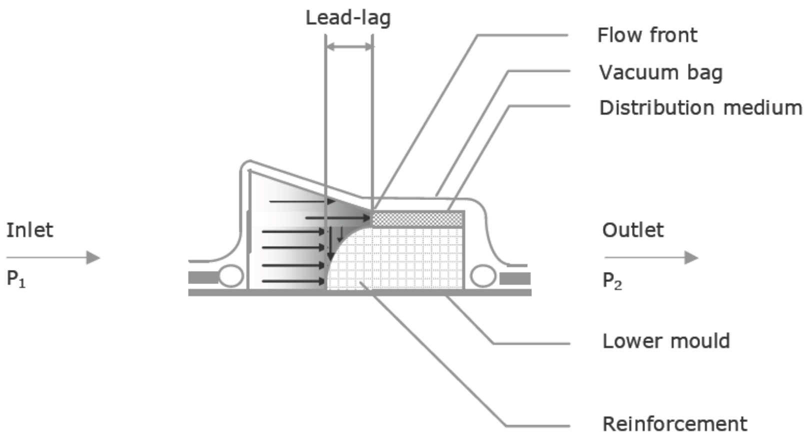

Figure 9: Lead-lag in vacuum infusion

Due to its high permeability the distribution medium increases resin flow at the upper surface of the preform, thus reducing impregnation time, up to 86 %. However, its higher permeability distorts the shape of the flow front .The resin flows through the distribution medium first and then impregnates the reinforcement. Therefore a delay occurs between the upper and lower faces of the preform where the side in contact with the distribution medium is impregnated ahead of the other side [10].

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. [1]. This project is significant in determining the best location of resin outlet and inlet port by using different strategy to get the best product for resin infusion.

2.8 INFUSION STRATEGIES

Implementing infusion strategies are by using different type of inlet/outlet port (line-feed or point-feed) and changing the way there are located on the blade (input at trailing, output at leading edge and input at root and output at tip of blade).

Point feed is simply an end of a hose connected to the flexible mold. Flow via point feed has tendency to develop angular progressions which is usually led to macro void formation [11].

For line feed, the point where the resin entered the mold is extended by a line of spiral tubing which is positioned perpendicular to the flow direction. As the process started when the resin is sucked into the mold, it will first fill in the cavity made by the spiral tubing. In this case, the spiral tubing acts as resin supplier. Once the whole cavity is filled up, the resin initially infused out to the reinforcement and a consistent flow front would likely to be observed. [12]

CHAPTER 3

METHODOLOGY

This chapter will explain in detail the methodology used in this project. The step and procedure is executed mainly to achieve the objective of this project and expected to produce the result needed to investigate the effect of infusion strategy on the filling time and flow behavior of resin during mold filling. The flow of methodology is as shown below:

3.1 PROCESS FLOW

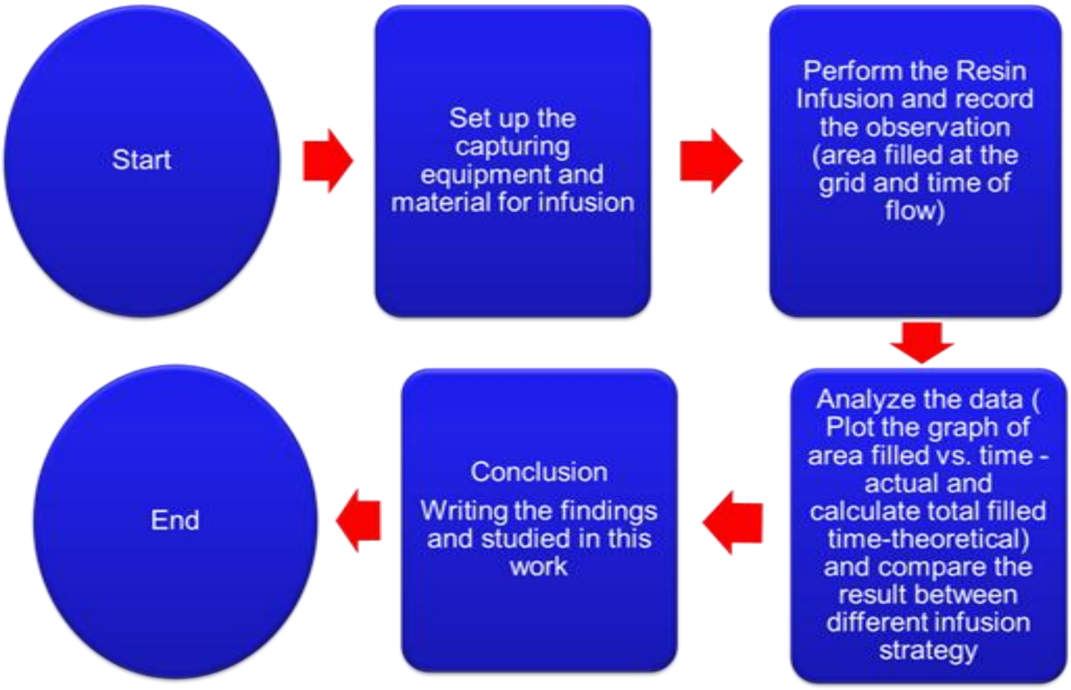

Figure 10: Process flow of the project

3.2 SET UP THE CAPTURING EQUIPMENT AND MATERIAL FOR INFUSION EXPERIMENT

3.2.1 Blade profile and construction

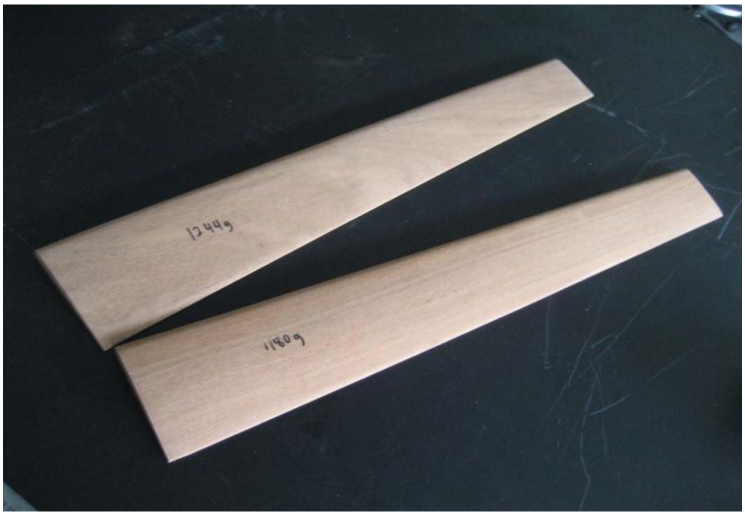

Figure 11: Wooden core blade

Wooden core

- laminating with 8 layers fibre glass reinforced epoxy
- Shape of wind turbine blade. 1” thick × 8” width, tapered in their width (narrower at the tips than they are near the root), tapered in their thickness (they are thinner at the trailing edge than they are at the leading edge), rounded trailing edge
- Advantage : Cheap, easy to cut,

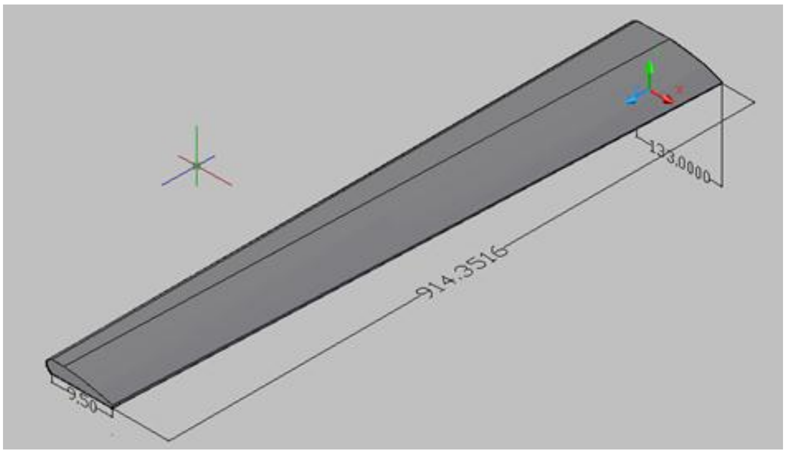

Figure 12: CAD Drawing of Blade

3.2.2 Set up the equipment and material

The equipment for conducting the resin infusion experiment is set up and listed as follow:

Equipment:

I. Fiberglass

II. Peel Ply

III. Net Cloth

IV. Resin trap

V. Vacuum pump

VI. Vacuum bag

VII. Spiral tube

VIII. Resin Storage

IX. Sealant tape

X. Image capturing (video camera with a tripod)

XI. resin: mix of vinyl ester and hardener (MEKP) with addition of cobalt

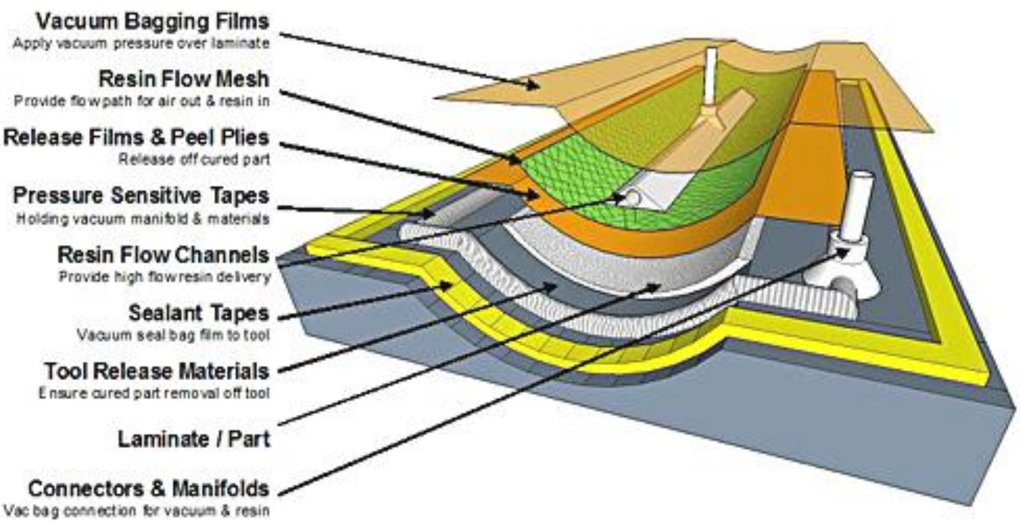

Figure 13: Arrangement of equipment (Source: http://www.tygavac.co.uk/process/resin-infusion.html)

To obtain an image which is in parallel position with the blade, the tripod is adjusted above it while tied with ropes. The camera need to be hold still and no movement at the camera is allowed during data recording.

Figure 14: Set-up of capturing equipment

The dry lay-up consist of glass fibers, peel plies and net. The peel ply protects the glass fibers from sticking to the mold and the net and helps in permeation of resin into fiber. The net is used as flow medium for the resin to travel along the fibers

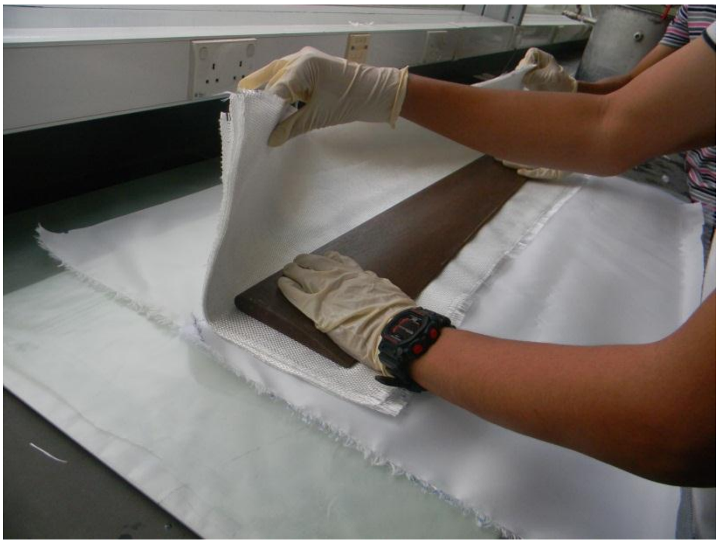

Figure 15: Blade is covered with fiberglass layer first then peel ply and net

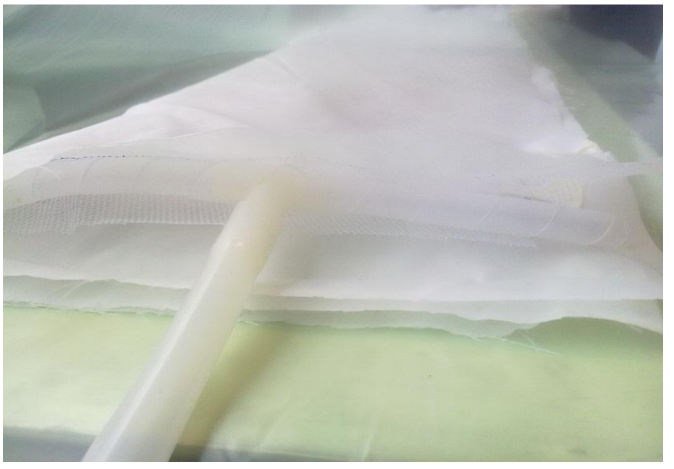

Figure 16: Spiral tube is placed on blade root and connect with inlet with T-joint

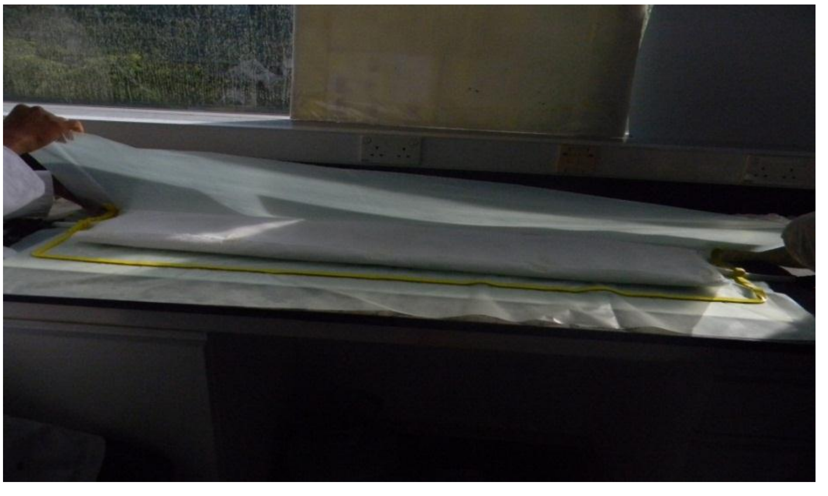

Figure 17: Tacky tape is placed around the blade to seal the vacuum bag

Figure 18: After the blade is set, Vacuum pump is started to begin infusion

Material:

Figure 19: Glassfiber woven mat

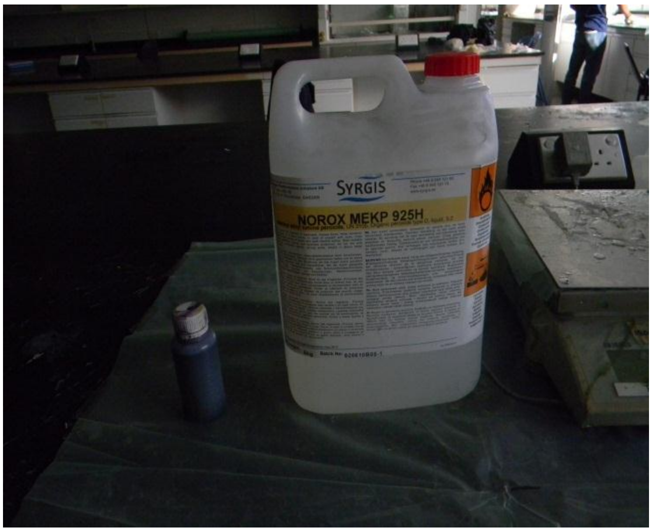

Figure 20: Hardener (MEKP) and Cobalt

Figure 21: Vinyl Ester

-glass fibre: woven mat $0^{o}/90^{0}$ of warp direction

-resin: mix of vinyl ester and hardener (MEKP) (peroxide/catalyst) with addition of cobalt(accelerator)

3.3 PERFORM THE RESIN INFUSION AND RECORD THE OBSERVATION (AREA FILLED AT HE GRID AND TIME OF FLOW)

In this project, Vacuum Infusion Resin was used to manufacture polymer composite wind turbine blade. For this method, pressure is applied to the laminate once laid-up. A plastic film or vacuum bag is sealing over the wet laid up laminate and the tool. The air under the bag is extracted by a vacuum pump and resin will be sucked into the laminate and impregnates the glass fibers and wooden core.

3.3.1 Infusion Strategies:

Two infusion strategies will be tested in investigating the resin filling time and flowfront behavior namely strategy A and strategy B, and four experiments will be conducted with two trials for each strategy they are line feeding from:

I. Trailing edge to leading edge
II. Tip to the root of the blade

For the first experiment, resin inlet is placed at the trailing edge of the blade while the vacuum line is placed at the leading edge of the blade. Then the experiment is repeated for second trial.

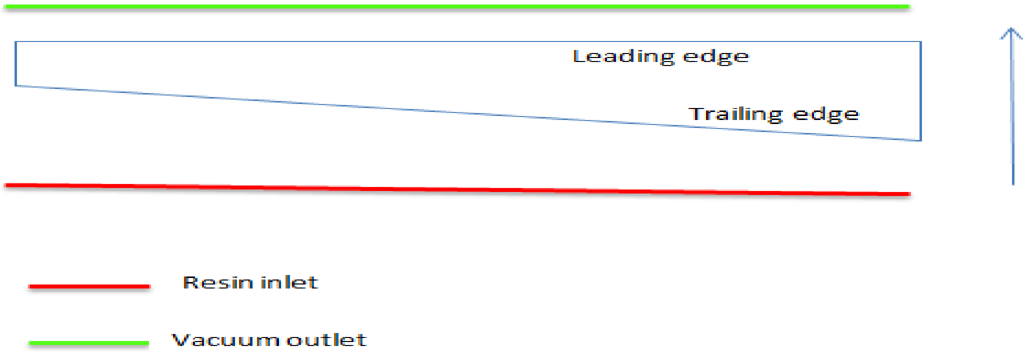

Figure 22: Strategy 1- Line feeding from trailing edge to leading edge

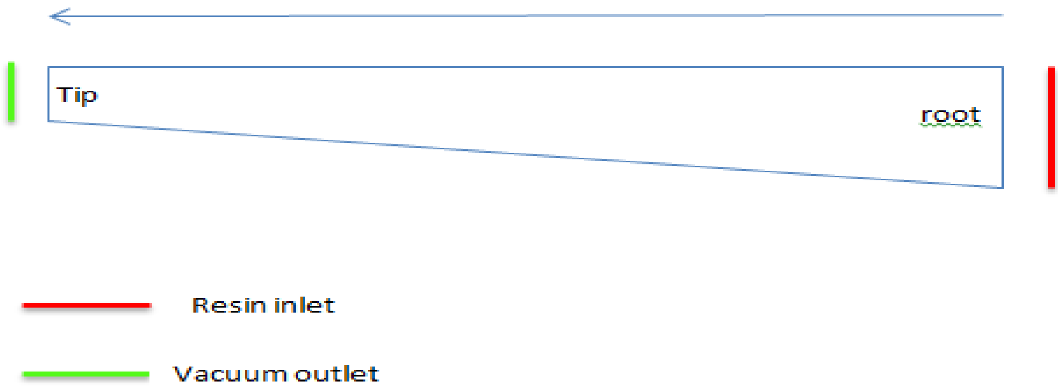

Figure 23: Strategy 2- Line feeding from root to tip

For second strategy, the resin inlet is placed at the tip of the blade while the vacuum line is at the root of the blade. The third experiment is repeated for second trial.

The flow is calculated theoretically using Darcy's law to compared with experimental result.

$$\text{Fill time} = \frac{\text{Viscosity x Flow length}^2}{\text{Permeability x Pressure difference}} \quad \text{(Eq. 1)}$$

3.3.2 Different infusion strategies experimental procedure

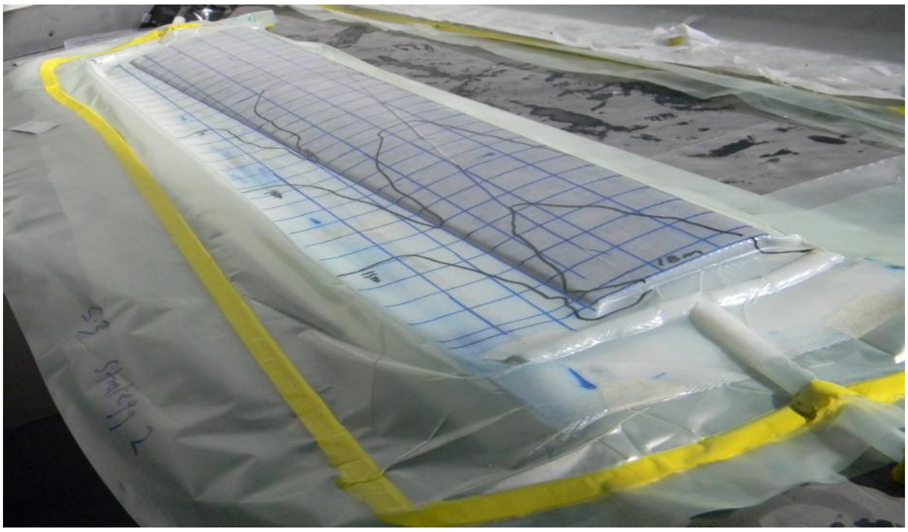

Figure 24: Complete set up of blade infusion experiment and meshing grid (strategy B)

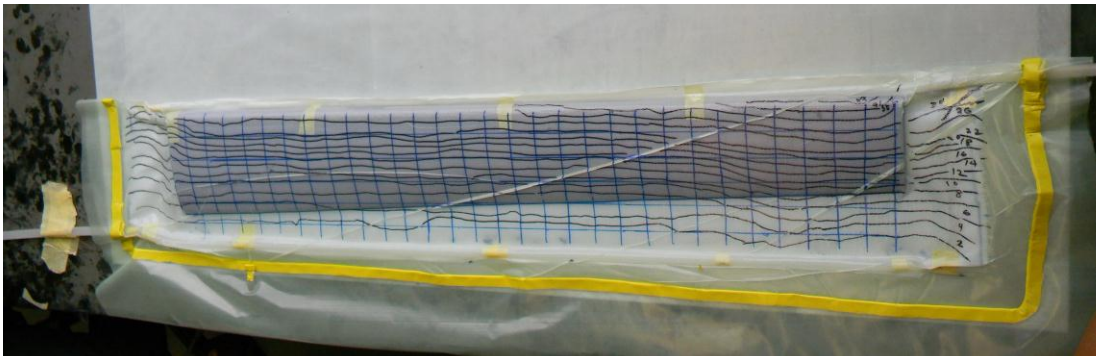

Figure 25: Complete set up of blade infusion experiment and meshing grid (strategy A)

Procedure:

1. The blade, fiber, breather, and net are set up.

2. First spiral tubing is cut similar length of the trailing edge length and is placed at the trailing edge of the blade for strategy A. Spiral tubing is cut as the same size as blade root for strategy B. This is the resin inlet line. The resin supply line is connected with spiral tubing by T-joint for strategy B.

3. Second spiral tubing is cut similar length of the leading edge length and is placed at the leading edge of the blade for strategy A. Spiral tubing is cut as the same size as blade tip for strategy B. This is the vacuum outlet line. The vacuum outlet line is connected with spiral tubing by T-joint for strategy B.

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 displaced.

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. Square grid in 30mm x 30mm square is marked on upper side of vacuum bag for flow front measurement and full infusion video to be recorded by digital camera.

8. The Digital Video Camera and the tripod are adjusted so that the images captured are parallel with the blade during infusion.

9. Vinyl ester, hardener and cobalt are then mixed slowly and stir properly. The mixture is 1000g Vinyl Esther, 10g hardener and 1g Cobalt according to MSDS. The mixing is done in vacuum chamber and using PPE for safety.

10. The mixture is then degassed to eliminate bubbles for 5 minutes.

11. Resin tube is placed inside the mixture. Make sure resin supply line is closed before the timing start. Open the resin supply line and the recording is started.

12. Repeat the experiment for strategy A and strategy B second time for repeatability result.

3.3.3 Data recording method for wind turbine infusion

Meshing is one of the method mapping rectangular/square shapes onto the laminating vacuum bag to observe the resin flow front. A 30mm x 30mm square block is used for meshing. It help in tracking the line of flowfront and also to calculate filling area. Time start when resin starts entering the rectangular space after filling the spiral tubing . During certain time in resin filling (example every 5 minutes), resin flow front will be monitored and captured by video camera and line will be marked on the surface grid marked on the vacuum bag to record the resin flowfront at certain time . Using video recording, the process can be rewind to get time taken for data recording

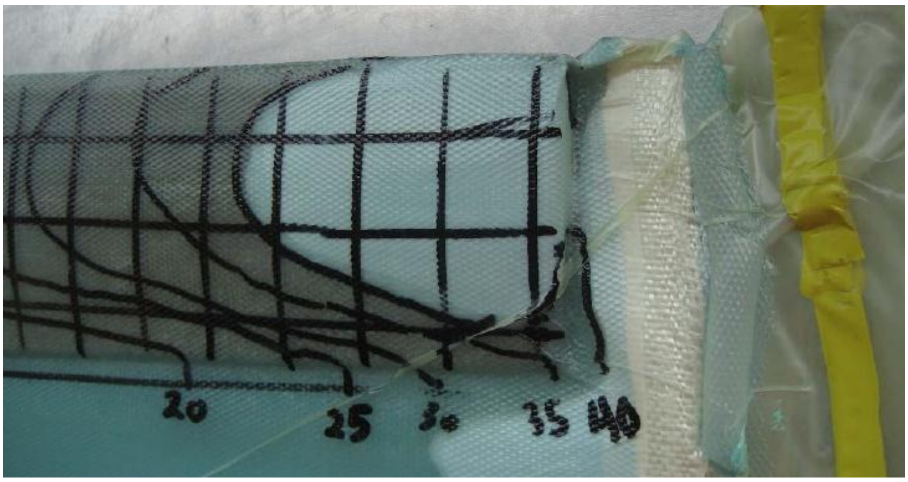

Figure 26: Resin flowfront data recording

3.4 ANALYZE THE DATA (PLOT THE GRAPH OF AREA FILLED VS. TIME –ACTUAL AND CALCULATE TOTAL FILLED AREA –THEORETICAL) AND COMPARE THE RESULT BETWEEN DIFFERENT INFUSION STRATEGIES.

Images captured will be transferred into CAD software and traced the flow front to determine the flow distance and volume filled at time interval. With Darcy equation, filling time can be calculated and actual result and theoretical will be compared.

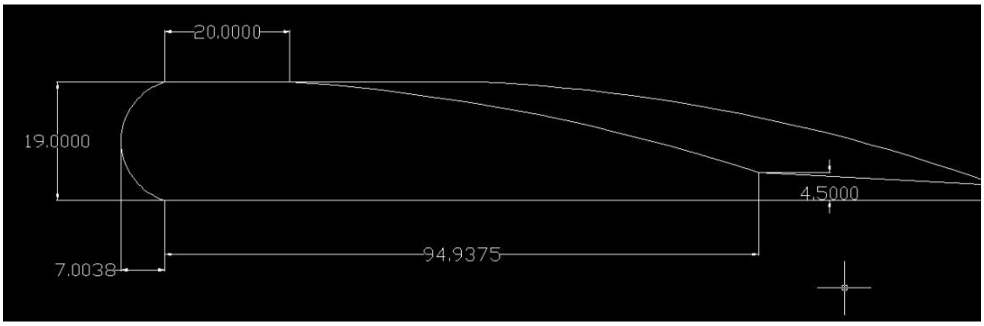

Figure 27: Wind turbine blade dimension in mm (tip view)

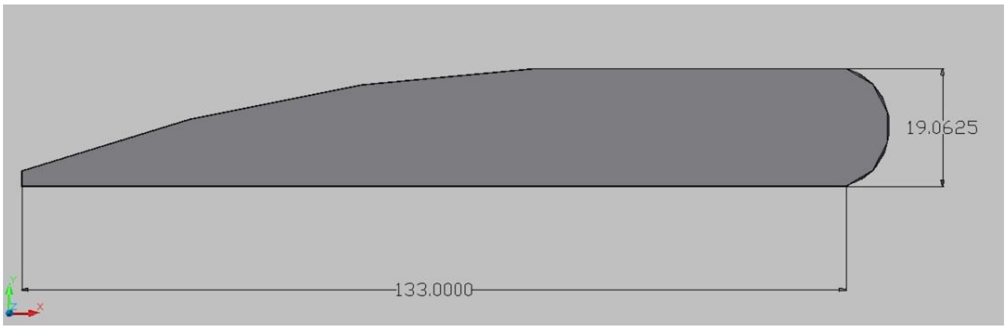

Figure 28: Wind turbine blade dimension in mm (root view)

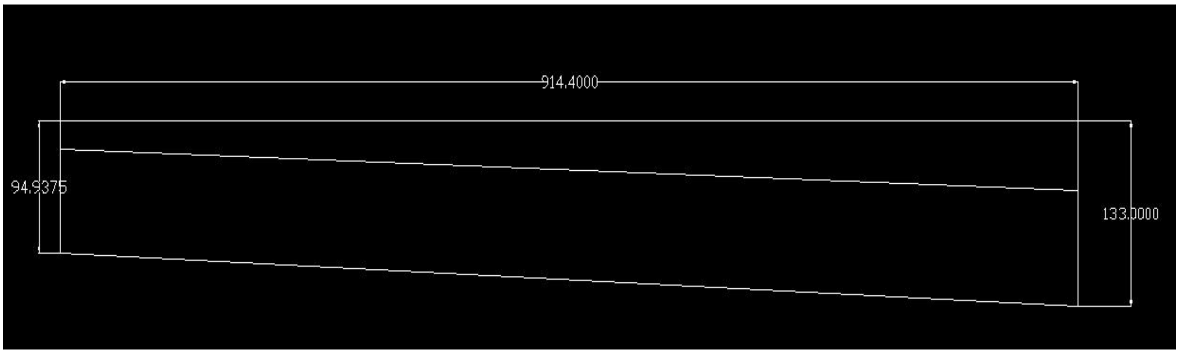

Figure 29: Wind turbine blade dimension in mm (top view)

CHAPTER 4

RESULT AND DISCUSSION

4.1 RESULT

This section discuss about the result obtained from experiment and the analysis of data. The first part of this chapter explains about how data is being collected from the experiment and second part of this chapter will explain about the finding from the experiment.

<u>Result for strategy A:</u>

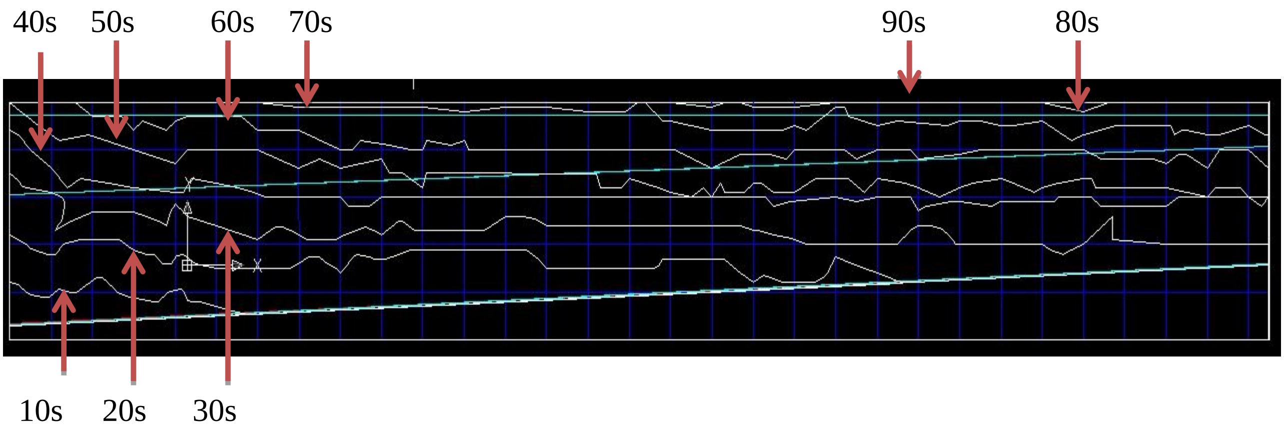

Figure 30: Resin flowfront progression with time for strategy A trial 1

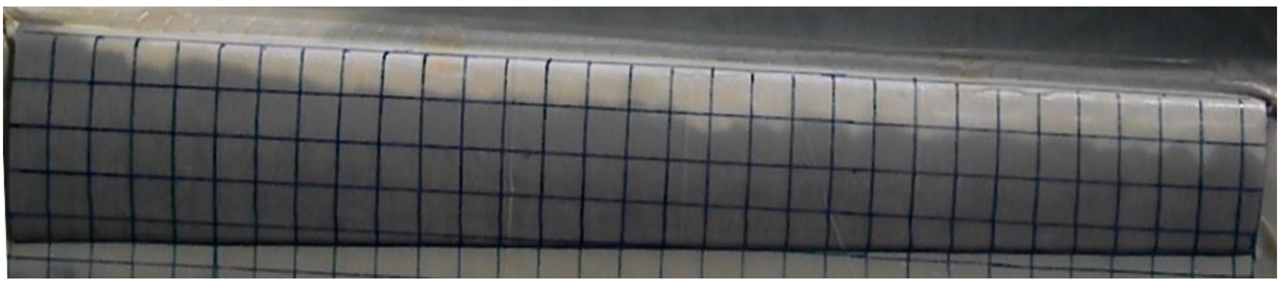

Figure 31: Resin flowfront image for strategy A trial 1

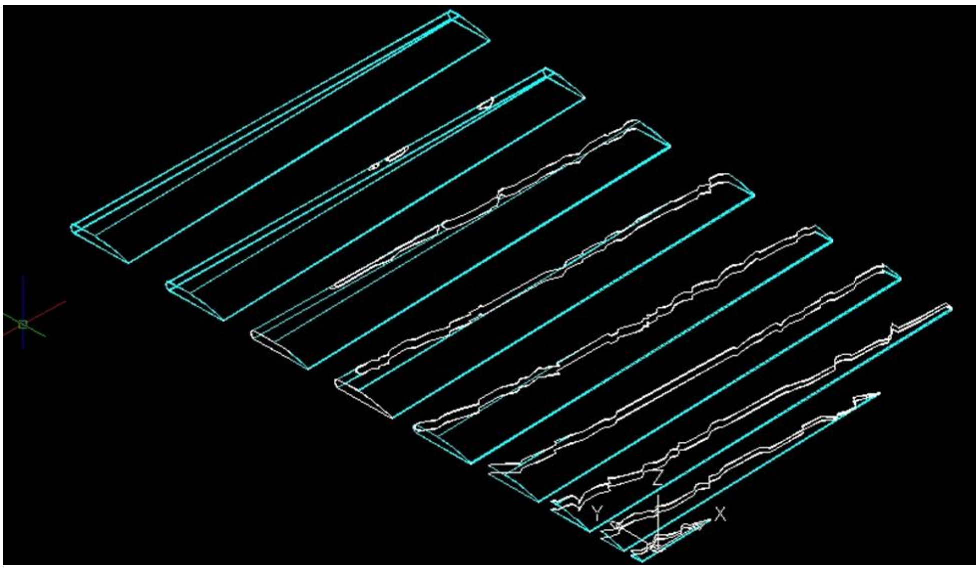

Figure 32: Resin flowfront 3D drawing in AutoCAD for Strategy A trial 1

<u>Strategy A trial 2:</u>

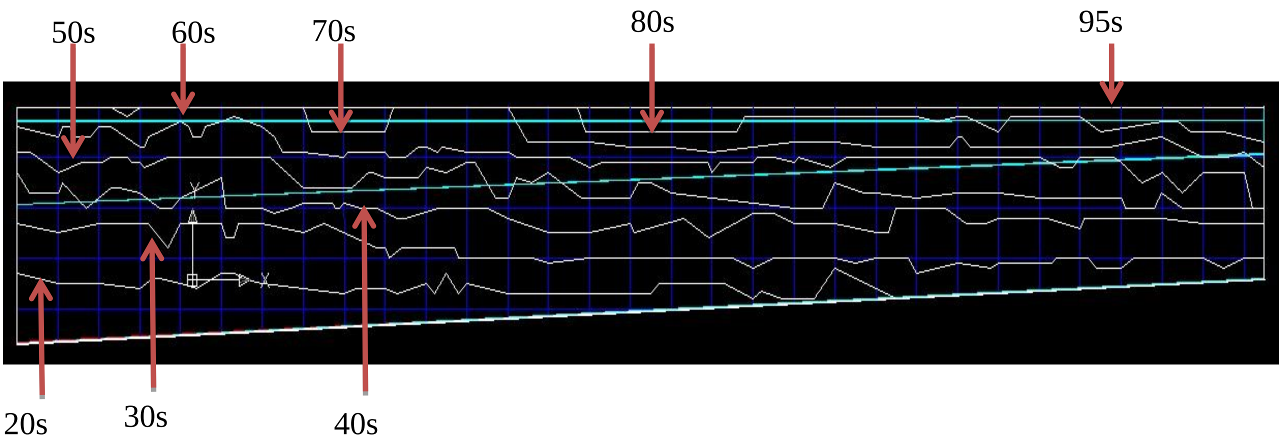

Figure 33: Resin flowfront progression with time for strategy B trial 1

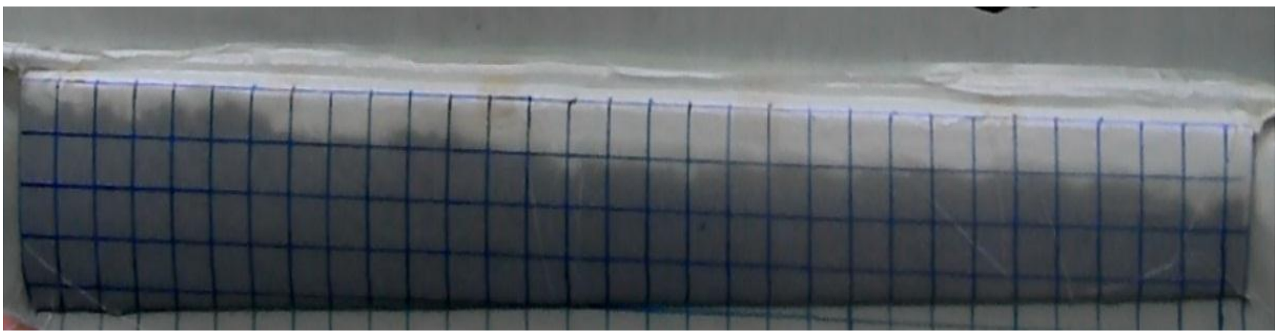

Figure 34: Resin flowfront image for strategy B trial 1

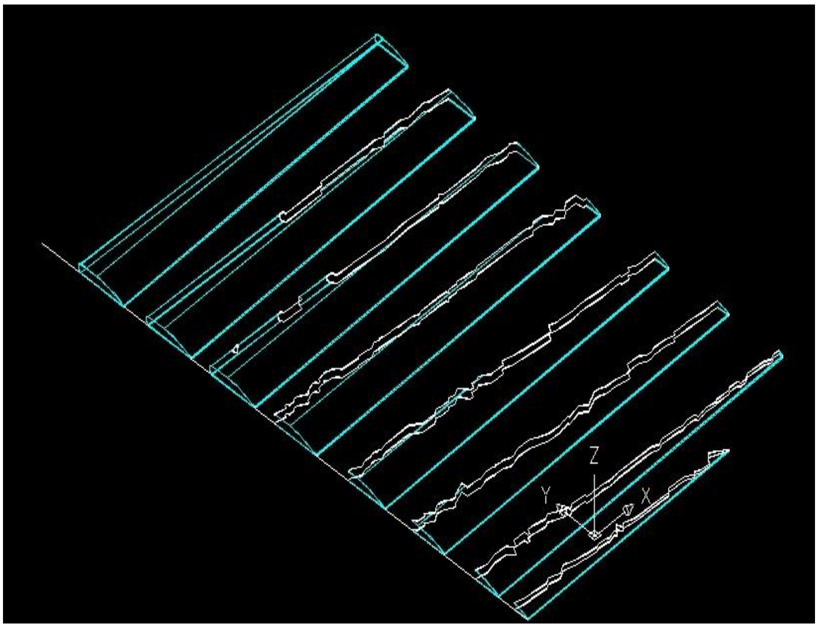

Figure 35: Resin flowfront 3D drawing in AutoCAD for Strategy B trial 1

<u>Result Strategy B Trial 1:</u>

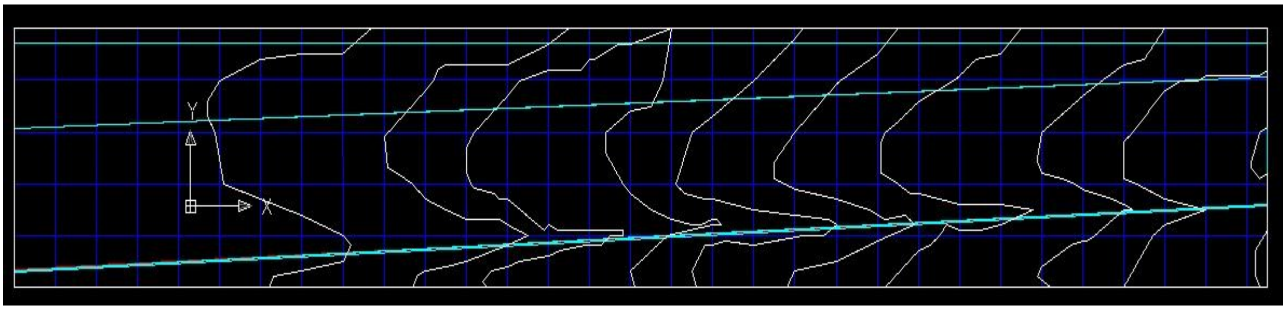

Figure 36: Resin flowfront progression with time for strategy B trial 1

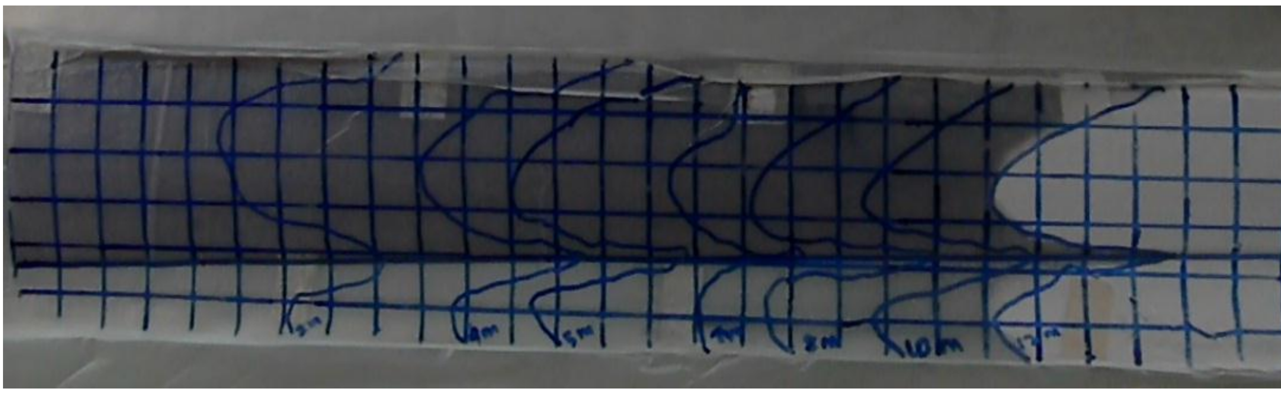

Figure 37: Resin flowfront image for strategy B trial 1

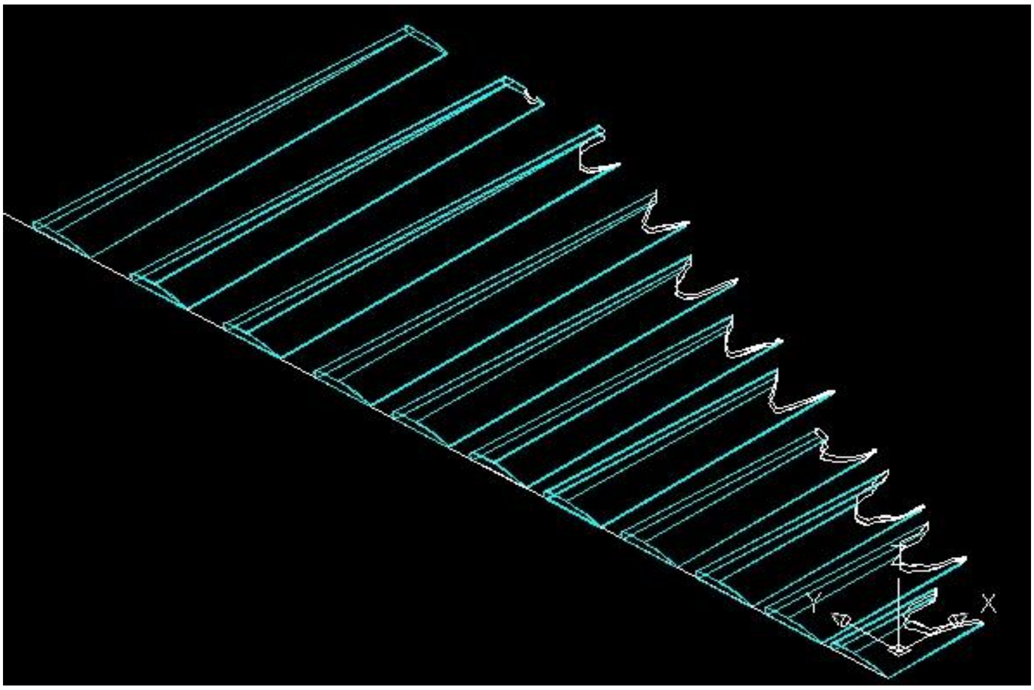

Figure 38: Resin flowfront 3D drawing in AutoCAD for Strategy B trial 1

<u>Strategy B Trial 2:</u>

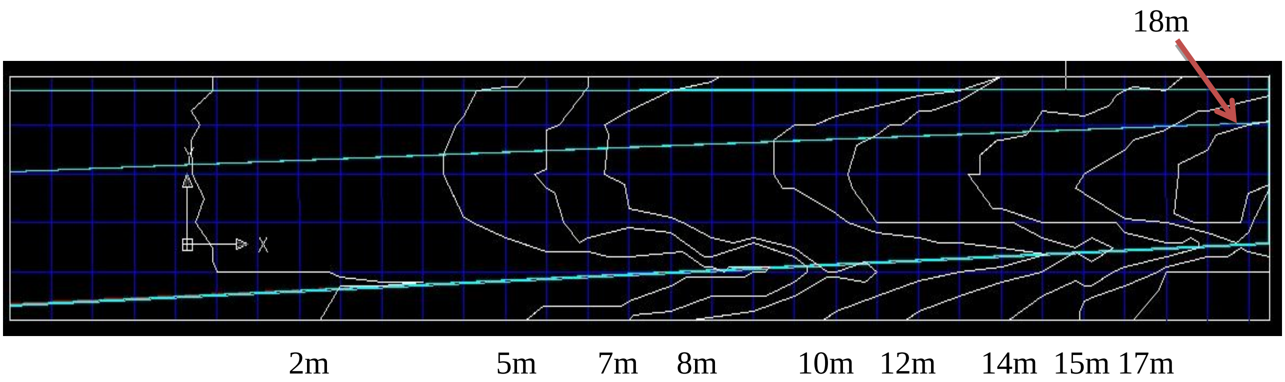

Figure 39: Resin flowfront progression with time for strategy B trial 2

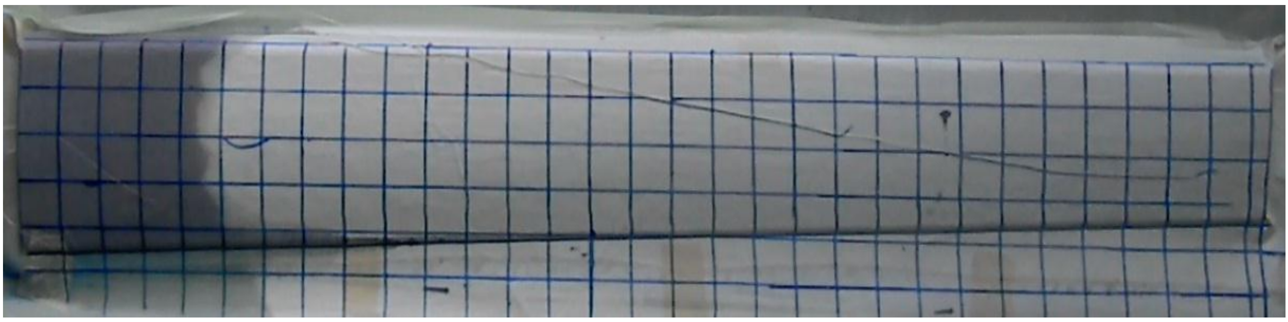

Figure 40: Resin flowfront image for strategy B trial 2

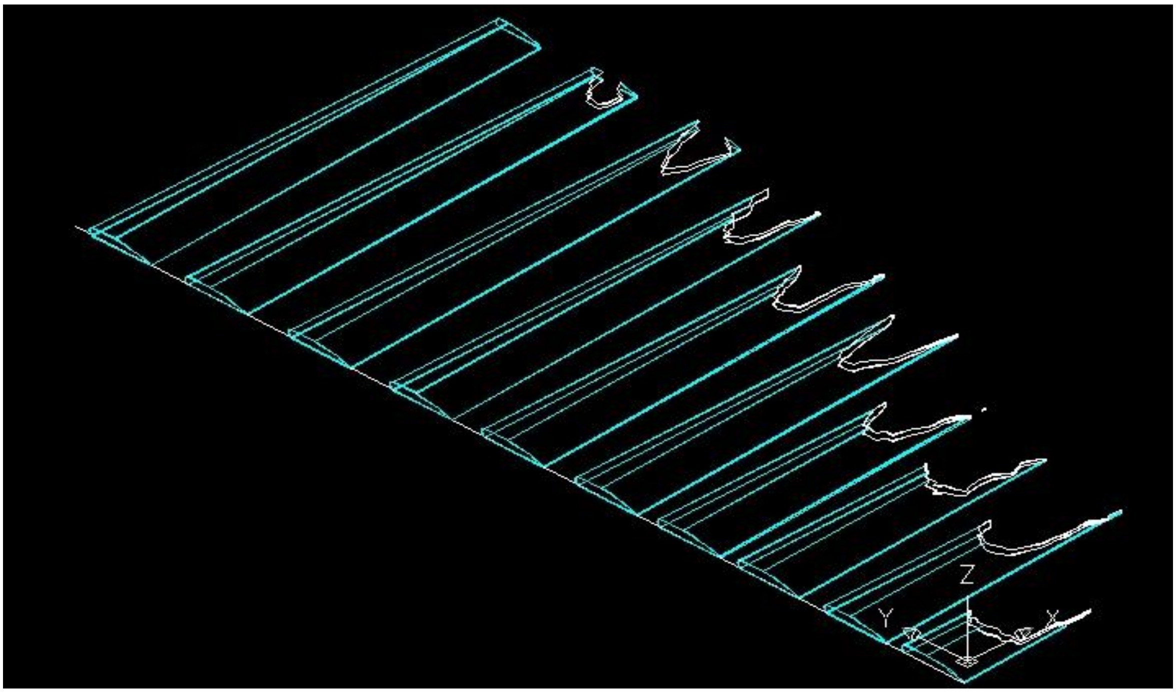

Figure 41: Resin flowfront 3D drawing in AutoCAD for Strategy B trial 2

Graph of Experimental and Theoretical result

Table 1: Experiment data for Strategy A trial 1

Time (s)	Area(mm3)	% fill
0	0	0
10	5680.9561	2.436068
20	37290.619	15.9907
30	77841.086	33.37927
40	118579.082	50.84826
50	143812.614	61.66872
60	178865.826	76.7
70	212939.915	91.31141
80	232209.655	99.57453
90	233201.863	100

Table 2: Experiment data for Strategy A trial 2

Time(s)	Area(m2)	%area filled
0	0	0
20	28027.0804	12.0183776
30	69604.0232	29.8471129
40	109488.036	46.9498976
50	140717.427	60.3414677
60	174490.663	74.8238721
70	200816.271	86.1126361
80	219060.68	93.9360762
95	233201.863	100

Table 3: Theoretical for strategy A

% Area	Time, s	Length, m	Distance, m	Viscosity, Pa.s	Permeability, k	Pressure Gradient, pa
0	0	0	0	0	0	0
1.0791725	0.3875969	0.2387	0.01	0.6	0.000129	0.6
3.9513898	1.5503876	0.437	0.02	0.6	0.000129	0.6
9.1646021	3.48837209	0.6757	0.03	0.6	0.000129	0.6
16.528926	6.20155039	0.914	0.04	0.6	0.000129	0.6
25.619835	9.68992248	0.914	0.05	0.6	0.000129	0.6
33.884298	13.9534884	0.914	0.06	0.6	0.000129	0.6
42.14876	18.9922481	0.914	0.07	0.6	0.000129	0.6
50.413223	24.8062016	0.914	0.08	0.6	0.000129	0.6
58.677686	31.3953488	0.914	0.09	0.6	0.000129	0.6
66.942149	38.7596899	0.914	0.1	0.6	0.000129	0.6
75.206612	46.8992248	0.914	0.11	0.6	0.000129	0.6
83.471074	55.8139535	0.914	0.12	0.6	0.000129	0.6
91.735537	65.503876	0.914	0.13	0.6	0.000129	0.6
100	75.9689922	0.914	0.14	0.6	0.000129	0.6

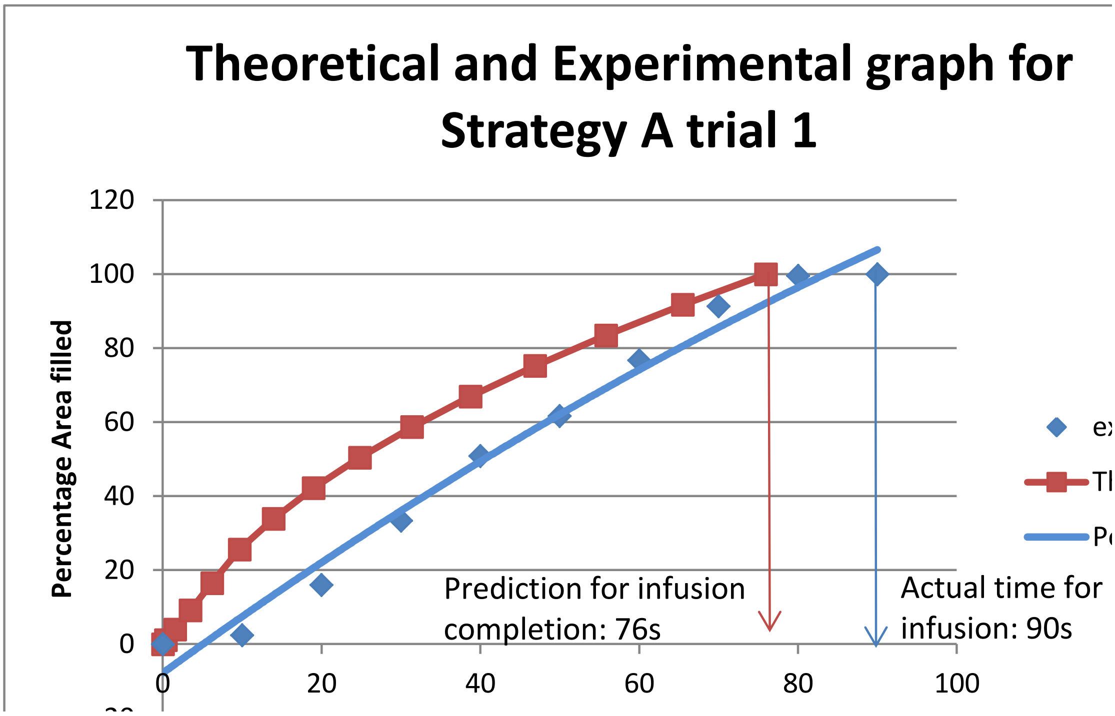

Figure 42: Experimental and theoretical graph for Strategy A Trial 2

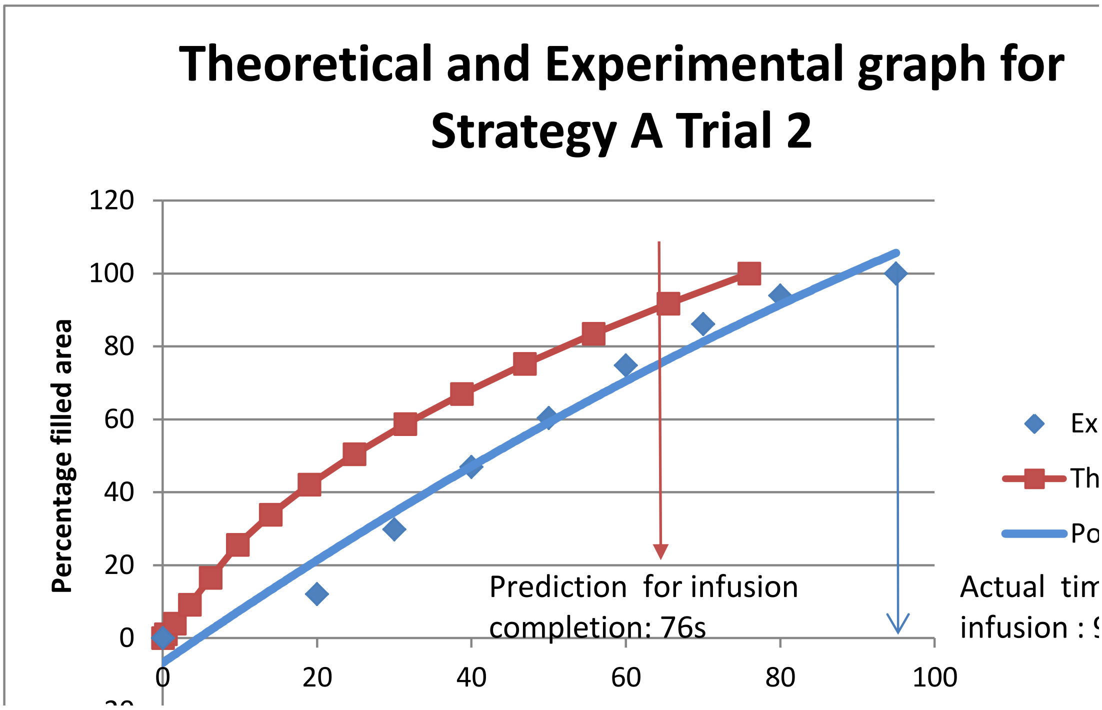

Figure 43: Experimental and theoretical graph for Strategy A Trial 2

Table 4: Experimental data for Strategy B Trial 1

Time(min)	time(sec)	Area(mm2)	%fill area
2	120	52511.1306	22.51746
4	240	88874.8549	38.1107
5	300	104222.0109	44.69176
7	420	125988.8048	54.02564
8	480	143031.0469	61.33358
10	600	160141.6963	68.67085
12	720	178956.6085	76.73893
15	900	204615.143	87.74164
17	1020	219321.7223	94.04801
18	1080	232721.7631	99.79413
19	1140	233201.8627	100

Table 5: Experimental data for Strategy B Trial 2

Time(min)	Time(s)	Vol(mm3)	Area(mm2)	%fill area
0	0	0	0	0
2	120	43039.73	43039.7297	18.455997
5	300	98823.997	98823.9967	42.377019
7	420	117555.6	117555.604	50.409376
8	480	130300.49	130300.488	55.874549
10	600	164988.08	164988.084	70.749042
12	720	176791.99	176791.987	75.81071
14	840	198942	198942.001	85.308925
15	900	217424.62	217424.618	93.234512
17	1020	227042.51	227042.511	97.35879
18.5	1110	233201.86	233201.863	100

Table 6: Theoretical for Strategy B

% Area	Time, s	Length, m	Distance, m	Viscosity, Pa.s	Permeability, k	Pressure Gradient, pa
	#DIV/0!	0	0	0	0	0
6.2819864	6.90407	0.0021	0.05	0.57	0.000129	0.8
12.469031	27.61628	0.0042	0.1	0.57	0.000129	0.8
18.561134	62.13663	0.0063	0.15	0.57	0.000129	0.8
24.558294	110.4651	0.0084	0.2	0.57	0.000129	0.8
30.463904	172.6017	0.01047	0.25	0.57	0.000129	0.8

36.271859	248.5465	0.01257	0.3	0.57	0.000129	0.8
41.986455	338.2994	0.01466	0.35	0.57	0.000129	0.8
47.604753	441.8605	0.01676	0.4	0.57	0.000129	0.8
53.130143	559.2297	0.01885	0.45	0.57	0.000129	0.8
58.558783	690.407	0.02095	0.5	0.57	0.000129	0.8
63.894967	835.3924	0.02304	0.55	0.57	0.000129	0.8
69.133949	994.186	0.02514	0.6	0.57	0.000129	0.8
74.280928	1166.788	0.02723	0.65	0.57	0.000129	0.8
79.333418	1353.198	0.02932	0.7	0.57	0.000129	0.8
84.288026	1553.416	0.03142	0.75	0.57	0.000129	0.8
89.15131	1767.442	0.03351	0.8	0.57	0.000129	0.8
93.916261	1995.276	0.03561	0.85	0.57	0.000129	0.8
98.590339	2236.919	0.0377	0.9	0.57	0.000129	0.8
100	2307.053	0.038	0.914	0.57	0.000129	0.8

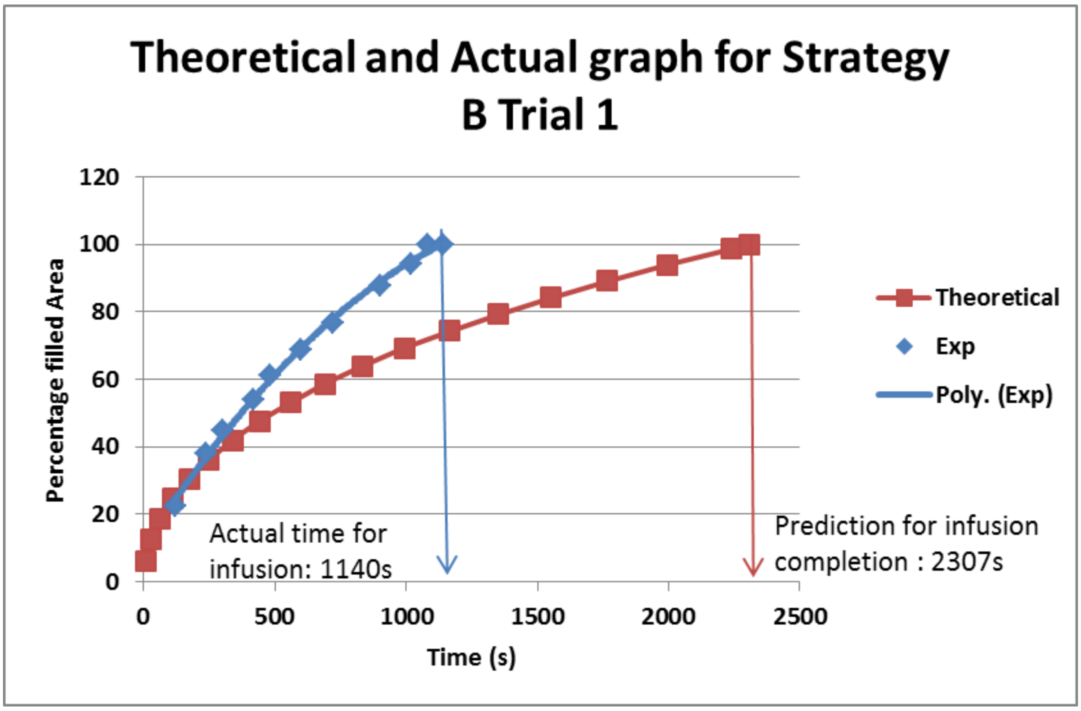

Figure 44: Experimental and theoretical graph for Strategy B Trial 1

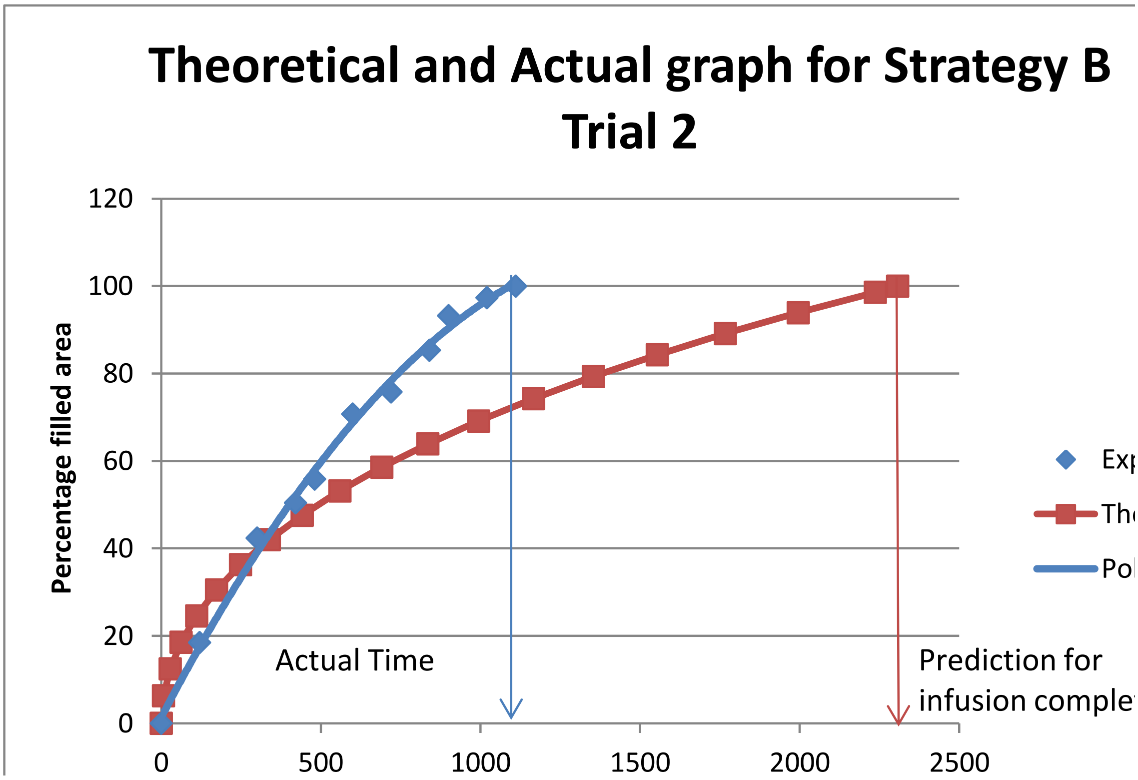

Figure 44: Experimental and theoretical graph for Strategy B Trial 2

Vinyl Ester, hardener (MEKP) accelerator (cobalt) is used for infusion. The amount of vinyl ester used is 1000g, hardener 10g and cobalt 1g according to MSDS. The blade is scrub with wax and silicon to avoid from sticking. Fiberglass is cut 99.5mm x 36.5mm for 8 layer, net 99.5mm x 42mm for 3 layer and peel ply 99.5 x 42mm for 2 layers in size to cover the blade. Spiral tube is cut according to the length of the blade and strategy used. Peel ply is important to remove the finishing blade from the vacuum bag afterward.

After the blade is set up, vacuum pump is started to evacuate the air from the vacuum bag and resin is pulled into the vacuum bag by vacuum pressure. Atmospheric pressure on the resin feed pushes resin into the bag through the inlet tube. Resin entering the bag encounters the net used to channel the resin to the basic fiber preform. Resin flows through the flow media over the preform and subsequently downward into the preform. The preform has the lowest permeability to flow and the highest resistance to the flow of resin.

There are 4 graphs of experimental result for resin flow. The filling time for Strategy A is 90s for first trial and 95 for second run. Meanwhile it takes 1140s for strategy B for first run and 1110s for second run to complete the filling. The filling area is calculated using AutoCAD software based on the video recorded using a digital camera. It may have some margin in error due to the precision of the equipment and human error.

4.2 DISCUSSION

The result show a very fast resin flow for strategy A where it takes 92.5 seconds average to complete the filling while longer time needed for strategy B which is 1125 seconds average. This is due to the distance of resin inlet line and vacuum outline give very important influence for the flow. For strategy A, resin has to travel short distance from inlet to vacuum outlet, the length of trailing edge to leading edge of blade 140mm while it take larger distance for resin to travel from blade root to tip for strategy B around 914mm causing longer filling time. The pressure difference is high when the distance is small and vice versa. The vacuum pressure is important draw more resin and pulls it to the outlet and help in the flow progression. If the distance is high, there is a significant pressure drop along the flow causing slow flow of resin and higher filling time as in strategy B. There is less difference in filling time for the second trial of both experiments where trial 1 for strategy A is 90 seconds and second trial is 95 seconds meanwhile first trial for strategy B is 1140 seconds and second trial for strategy B is 1110 seconds. We can say both experiments are repeatable.

It is also noticed that during the experiment, the flow is faster at first then it slows as it progress. This is because pressure level is higher at atmospheric inlet and the drop and uniform at vacuum outlet.

Distribution medium also contribute to faster flow of resin due to its low permeability. Resin flow preferentially in distribution medium.

Other factor contributing to this result is the material used for the resin. Vinyl ester has low viscosity (600cps) which cause the smooth flow of resin during infusion. Compared to epoxy which take much longer time (30minutes for strategy A and 1 hour and more for strategy B) due to its high viscosity (1000 cps), using vinyl ester is a good method to achieve less filling time for blade infusion.

Without the accelerator/cobalt the resin will never cured. We have already tried by mixing only vinyl ester and hardener only and it does not cured for several days. Using Cobalt it takes around two hours for the resin to be cured. Cobalt is very reactive material and using right quantity is important to mix with vinyl ester and hardener. Catalysts (peroxides/hardeners) for un-saturated polyesters are unstable, energy rich molecules which decompose into highly reactive molecule fractions - defined as radicals - under the influence of heat, metal salts and amines (accelerators), or ultra violet light. These radicals are capable of reacting with the polyester or styrene molecule, forming new radicals, and starting of a chain reaction. The chemical reaction provoked by the catalysts and accelerators creates an exothermic (heat generating) reaction that promotes optimum cure. Cobalt accelerator helps to speed up curing reaction of vinyl ester and allow them to cure at room temperature. Cobalt helps the catalyst to start the chemical reaction between the resin and styrene monomer and form a cured solid. The exact amount of promoter added to the resin will depend on the resin used, the temperature in the workshop and the gel time desired. Usually 0.1 to 1% (based on the mass of resin) of cobalt 6% type promoter is added.

The difference in theoretical and experimental graph is due to some error involved such as human error and equipment error. First is the blade dimension might be inconsistent. This might affect the calculation of resin filled area. The thickness of marker using to mark the grid of the blade might upset some length of the grid and cause the image data and CAD drawing to be different. Next, due to fast flow of resin, we have not enough time to mark the flow and some of the image of flow is blur causing it hard to estimate the flow in the drawing. Transferring the image to CAD drawing also have some precision error involved and we only manage to make the estimation. The flow or resin at top and below of the blade is assumed the same because we are unable to capture the below part of the blade. In theoretical calculation of area filled, the flow is assumed to be straight uniform line to simplify the calculation while in real experiment, the shape of flowfront is uneven. Viscosity is also to be assumed constant while it actually changes with time during the flow.

In the experiment, using spiral tubing instead of hole tubing has increase more the flow dispersion of resin because more resin can discharge from the inlet to the preform. After the resin if filled into the blade, it is crucial to seal the tube quickly after the vacuum pump is stopped. Otherwise bubble may form at the blade from the air entering the tube. Leaking is another problem need to be cautious about during infusion. It will form bubbles rapidly and time taken for resin to travel will be much longer due to partial vacuum achieved inside the vacuum bag. Any gas leakage sound need to be noted and seal immediately to avoid the bubble form during the infusion.

CHAPTER 5

CONCLUTION AND RECOMMENDATION

5.1 CONCLUTION

The study of flow behavior of Vacuum Resin Infusion is necessary to investigate the effect of different infusion strategies with filling time during mold filling. The infusion strategies are based on distance between resin line inlet and vacuum line outlet which can affect filling time. Several factors can affect filling time such as fiberglass dimension, permeability, preform thickness, pressure difference and distance of resin inlet and vacuum outlet and this project focused on the latter one. The capturing equipment will be set up to record the flowfront and time. Before the resin infusion can be done, equipment and material such as vinyl ester and vacuum bag need to be prepared and set up. Then the flowfront will be traced using CAD software to calculate filling area in certain time. A graph of area filled vs. time was plotted to compare experimental data and theoretical calculation. The best infusion strategies will be obvious from this graph. The result from experiments show strategy A: From trailing edge to leading edge of blade takes the less filling time about 92.5seconds average compared to strategy B: From blade root to tip which is 1125 seconds average.

5.2 RECOMMENDATION

For future studies of this project, some recommendation can be implement to improve the result and data such as using plastic seal as used in food product to seal the vacuum bag instead of tacky tap which is difficult to set up and probability of leak is high. Due to quick progression of the flow, a coloring material can be added to the resin to see the flow more clearly to record the flow. Finally, electrical sensor can be used to directly record the resin flow to computer and calculate the area, reduce the probability of error and save a lot of time

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APPENDIX

Gantt Chart

Gantt Chart (FYP 1 MBB 4012)

Investigation into Resin Infusion Strategies in the Fabrication of GRE Composite Wind Turbine Blade

No.	Activities /Weeks	1	2	3	4	5	6	7	Mid-Semester break	8	9	10	11	12	13	14
1	Selection of project topic															
2	Meeting with supervisor															
3.	Preliminary Research Work															
4	Practice and familiarize with vacuum infusion and specimen testing															
5	Submission of Extended Proposal Defence							▲								
6	Prepare and purchase equipment and material															
7	Proposal Defence															
8	Fabricate the first blade using the first infusion strategies															
9	Taking experimental data															
10	Submission of Interim														▲	

	Draft Report														
10	Submission of Interim Report														▲

▲ -Milestone

Gantt Chart (FYP 2 MBB 4024)

Investigation into Resin Infusion Strategies in the Fabrication of GRE Composite Wind Turbine Blade

No.	Activities /Weeks	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
1	Prepare for experimental testing								Mid-Semester break								
2	Fabricate the first blade using the second infusion strategies																
3.	Run testing and take experimental data																
4	Submission of Progress Report									▲							
5	Analyzing data and result documentation																
6	Pre-EDX												▲				

7	Submission of Draft Report													▲			
8	Submission of Dissertation (soft bound)														▲		
9	Submission of Technical Paper														▲		
10	Oral Presentation															▲	
10	Submission of Project Dissertation (hard bound)																▲