**Characterisation of Voids in a Polymer Composite Wind Turbine Blade Manufactured via Resin Infusion Process**

by

Rifdi Zulfadhli Bin Ruslan

Dissertation submitted in partial fulfillment of
The requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

______________________________

( Muhamad Ridzuan bin Abd Latif)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
MAY 2011

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.

RIFDI ZULFADHLI BIN RUSLAN

## ABSTRACT

Resin infusion is an advanced laminating technique that greatly improves the quality and strength of a material. During the resin infusion process, void may be formed due to in proper degassing process, out gassing of dissolved gas in the resin, evaporation of volatile component in the resin, shrinkage of resin and leakage in connection and mould. Void is a formation of air bubbles trapped during a composite fabrication and it has a strong impact on the mechanical properties. Therefore, void must be reduced by controlling the parameters such as resin viscosity, vacuum pressure and cure temperature. It is important to know the void content and how it has been distributed. In this project, the void analysis was done to the wind turbine blade polymer composite that manufactured using resin infusion process. The objective of the project is to characterize the void in a polymer composite wind turbine blade manufactured via resin infusion process and a mapping of void content will then be produced. The processes involved are manufacturing the blade using the strategy design of line feed type from root to tip, the specimen was cut from various important locations, separation of wood from the fiber glass and lastly the void content testing. A total of 108 specimens have been tested using the loss on ignition method to measure the void content according to the ASTM Standard D2584-94. In this method, the specimen is burned in a furnace until only the reinforced material remains. Next, the void content calculated by referring to the ASTM Standard D2734-94. It was found that the lower side (23.71%) has lesser void content than the upper side (25.42%) and voids tend to accumulate at the outlet area (26.23%) than the inlet area (23.36%). There are also variation distributions of the void through the process for upper side and lower side due to the flow distribution. In the future, the test should be done to other strategies design such as line feed type from tip to root to find the best strategy design that can produce the lesser void content.

## ACKNOWLEDGEMENT

First of all, the author would like to express utmost gratitude and appreciation to Allah because with His blessings and help, the Final Year Project went very smoothly and been able to complete on time. Within one year of researching and doing experiments, the author had gained lots of experience and knowledge especially in the void analysis and resin infusion process.

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Once again, thanks to all that help whether direct or indirect in order for the author to complete his final year project. Thank you.

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## ABBREVIATIONS AND NOMENCLATURES

| | |
|---|---|
| $m_1$ | Weight of specimen, *g* |
| $m_2$ | Weight of crucible, *g* |
| $m_3$ | Weight of crucible + residue, *g* |
| $R_{wt}$ | Weight percent of resin, *%w* |
| $F_{wt}$ | Weight percent of fiber, *%w* |
| $T_d$ | Theoretical density, *g/cm3* |
| $M_d$ | Measured density, *g/cm3* |
| $V$ | Void content, *%* |
| $D$ | Density of resin, *g/cm3* |
| $d$ | Density of fiber, *g/cm3* |

# CHAPTER 1
# INTRODUCTION

## 1.1 BACKGROUND OF STUDY

As the world is running out of fossil fuels and the prices keep increasing time by time, there is a need to try other source of energy. As for now, the fastest growing technology would be the wind power. Recently, the number and size of the wind turbines has increased strongly. Over the years, the wind turbines have become larger and larger. The driving motivation is that larger wind turbines have larger energy output per unit rotor area due to increase mean wind velocity with height [1]. As the design of the blade is becoming larger, it is important to keep blade weight under control because as the blade becoming larger, the gravity loads also becoming larger. Therefore, it is important to make a blade that is strong enough but light in weight. Some of the characteristic that should be looked after are high strength to weight ratio, corrosion resistant, fatigue, high resistant and void contents. One of the methods that have been widely used to manufacture wind blade turbine is by using the resin infusion technique where a glass fiber reinforce plastic was used.

Resin infusion process is an advanced laminating technique that greatly improves the quality and strength of a material. There are several methods in operating the resin infusion, some of them are Resin Transfer Moulding (RTM), SCRIMP, RIFT and VARTM. 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 tools. 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. As for this project, a core of wooden wind turbine blade will be used. By applying the resin infusion technology, it allows for optimization of a part in terms of strength and weight. Some of the advantages by using this technique are high quality laminate, user friendly, large objects can be infused with a minimum workforce, weight reduction of the part and environmentally friendly.

One of the most important aspects that strongly influence the performance and mechanical properties is void content. Voids also known as air bubbles, trapped during a composite fabrication. Voids may form due to leakage in the connection, evaporation of volatile components in the resin, gas dissolved in the resin coming out of solution, shrinkage of the resin and not properly degassing of the polymer matrix. The formation of void can be controlled by using manufacturing parameters such as vacuum pressure, cure temperature and degassing pressure. In this project, void analysis such as its contents and its location has been done to the polymer composite wind turbine blade manufactured via resin infusion process.

## 1.2 PROBLEM STATEMENT

To manufacture a strong in strength of a wind blade turbine, it is important to consider the suitable process because of its curved shape and closed profile. In this project, resin infusion process was used to manufacture a polymer composite wind blade turbine. Unfortunately, during the mixing of the matrix, degassing process and the flow front effect during infusion, the air bubbles formed. Due to this reason, there will be formation of void in the final product. The distribution of voids is also not widely known especially in a wind turbine blade manufactured using resin infusion process. Therefore, it is important to understand the formation of the void during the manufacturing process as it can effects the mechanical properties of the composites. It is also important to know the void content for the resin infusion process of wind turbine blade and to see which location have the most voids. This information is needed to know the quality of the current manufactured blade.

## 1.3 OBJECTIVE AND SCOPE OF STUDY

The main objectives of this research are:

- To characterize the void in a wind turbine blade polymer composite manufactured via resin infusion process.
- To produce a mapping of void content in a single blade.

The scope of study for this project covered the effect of flow front of manufactured wind turbine blade using resin infusion process with the void contents. In this project, the wind turbine blade polymer composite was fabricated using resin infusion process with strategies used was from root to tip. The specimen was prepared by cutting the wind turbine blade to the desired specimen dimension from various important locations and the separation of wood from the fiber glass need to be done. Next, void testing will be done and the analysis of the void such as its contents and distribution were mapped.

# CHAPTER 2
# LITERATURE REVIEW

## 2.1 VACUUM INFUSION PROCESS

There are several methods in operating the resin infusion, some of them are Resin Transfer Moulding (RTM), SCRIMP, RIFT and VARTM. All of the methods using the same principle but the laminate set up used may be different. In this project, resin infusion process or vacuum infusion process is chosen. 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 core.

Figure 1 below show the arrangement done during the vacuum infusion process [2].

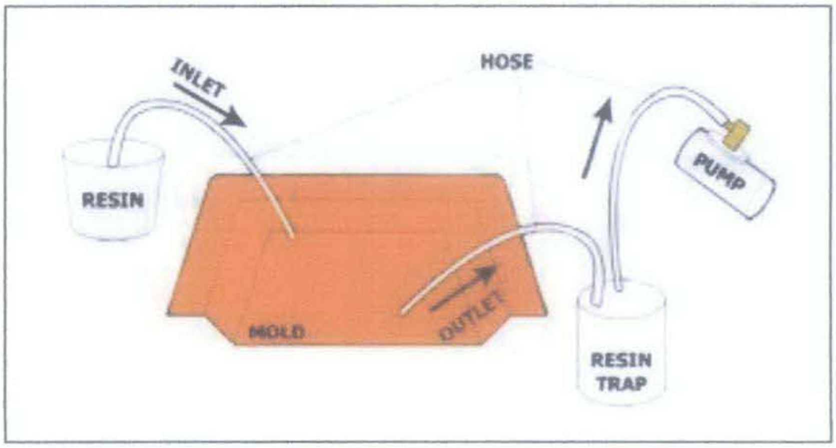



**Figure 1: Arrangement of vacuum infusion process**

## 2.2 VOID CONTENT

Voids are generally seen as air bubbles trapped during a composite fabrication. It is one of the common types of defects that must be look after. Void content measures the voids in reinforced polymers and composites. Information on void content is useful as the high void contents can reduce the composites' strength [3].

By using the ASTM standard, there are two ways to measure the void content which are acid digestion method and loss on ignition method.

For the acid digestion method, it used the standard ASTM D3171. Based on the standard, the specimen need to be dried and cooled. The density then is determined by using standard ASTM D792. The specimen then placed in the dissolution medium and heated until all the organic material is dissolved. The remaining solution is then filtered and the amount of remaining fiber is determined. After gather all the data, void content can then be calculated [4].

As for the loss on ignition, it used standard ASTM D2734. In this method, the densities of the resin, the composites and reinforcement are measured. Then, the resin content is measured and theoretical composite density is calculated. The different in densities indicates the void content. As for this project, we will be using loss on ignition method as our method to calculate the void content. A good composite may have 1% void or less, while a poorly made composite can have a much higher void content [5].

## 2.3 LITERATURE REVIEW

The effect of void on mechanical properties has been widely research. One of the examples is a research done by Zhu Hong-yan et al [6] some research on influence of voids on interlaminar shear strength of carbon/epoxy fabric laminates. In this research, they have found that, the void shape, size and location are important because they can influence whether or not a crack emanates from a void. The stacking sequences affect the void shape and size and in turn influence the effect of voids on the mechanical behavior of the composite laminar.

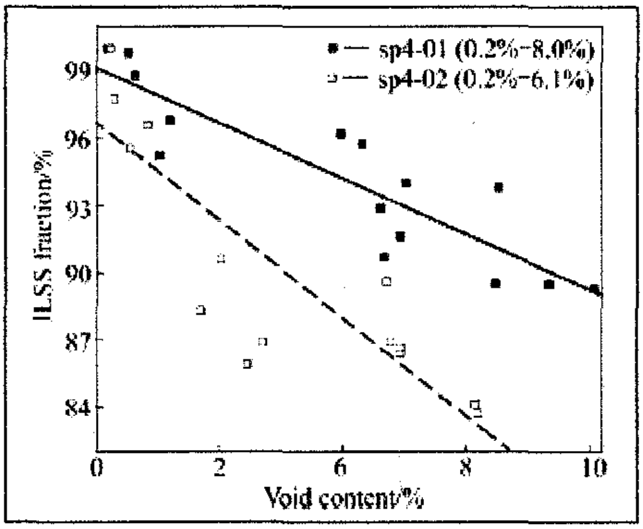



**Figure 2: ILSS fraction vs Void content**

From the research done Zhu Hong–yan et al [6], it is proven that as the void content increases, the strength of the material becoming weaker. This can be seen when ILSS fraction percentage has been greatly decrease as void content percentage increases. Although the two laminates have similar void content, there is different scatter in the strength data. This is because of the shape and size of voids in the composite that influence it.

Besides that, Benjamin J [7] also had done some research on the Characterization of the void content of fiber reinforced polymer composite materials fabricated by the composites pressure resin infusion system (COMPRIS). In the research, he has observed voids in the composite specimen fabricated by the vacuum-assisted process, where as no significant voids were observed in the composite specimens fabricated by the CompPRIS process. The difference in the void content is due to the difference in the resin infusion driving force such as vacuum pressure. To characterize the polymer matrix composite materials, they have used electron microprobe analysis (EMPA).

Based on the optical data some of the parameters can be obtained such as fiber volume ratio, density of matrix cracks, fiber shape, and uniformity of the fiber/matrix distribution.

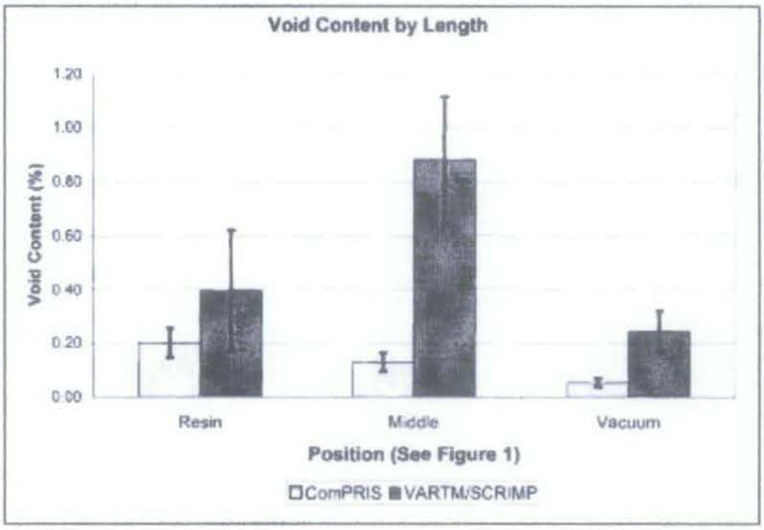



**Figure 3: Comparison of void content by fabrication process and position along the panel length. Error bars represent standard error [7].**

The pattern of void content distribution along panel length, in almost void free region close to the resin inlet (because bubbles which are formed will migrate to other parts of the laminate); a middle region with a high void content (because bubbles which are formed remain trapped there); and a region close to the resin outlet with a low void content (because no bubbles are formed nor can bubbles migrate into this region) [8].

Another researched done by C. Santulli et al [9] where they have measured the void content through the optical micrograph. From the analysis, they have found that there are four types of voids which are microvoids, coplanar voids, intratow voidage and extensive voids.

Figure 4 to 7 shows the types of voids.

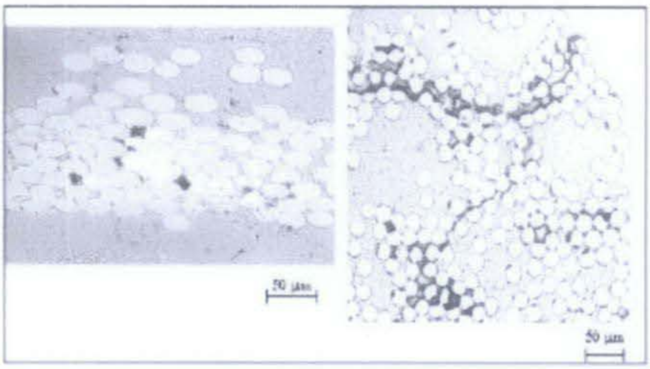



**Figure 4: Intratow voidage**

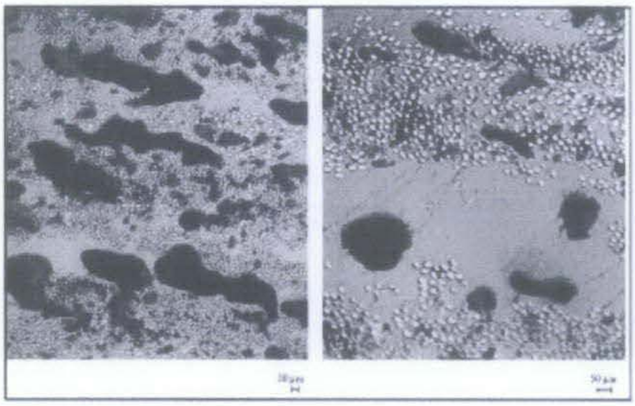


**Figure 5: Extensive voidage**

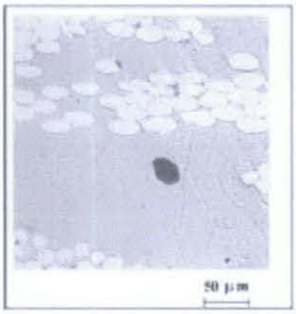
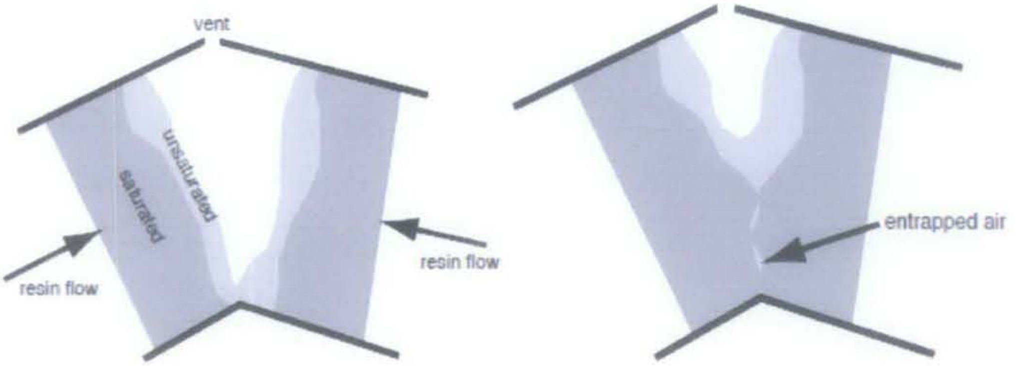



**Figure 6: Coplanar void**


**Figure 7: Microvoids**

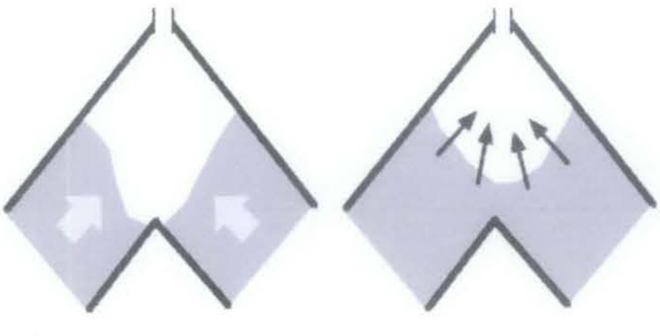
The effect of flow front also can influence the formation of voids. In a research done by Gion Andrea[10], the laminate void content strongly depends in effects occurring directly at the flow front.



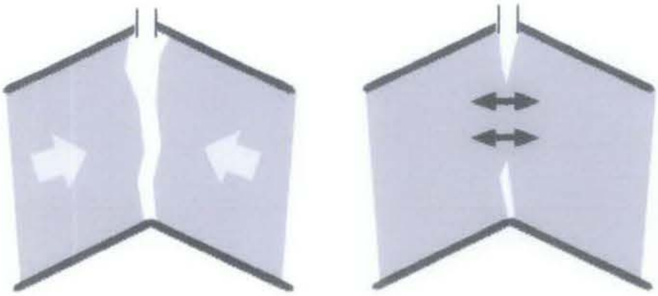

(a) Flow fronts before contact (b) Flow fronts joining

**Figure 8: Converging flow fronts entrapping air from unsaturated region**

Two flow front contact and joining at an angle, the entrapped air is enclosed and cannot move to the vent. Due to these conditions the void was formed.



(a) Fronts meeting at small angle act as one flow front after merging — the pressure gradient pushes towards the vent.



(b) Fronts meeting at big angle entrap air and eliminate the pressure gradient.

**Figure 9: Pressure gradient with different meeting angles**

The study also has shown that the porosity due to confluence zone can rise up to 4%. The angles between the converging flow fronts also give a significant effect on the void volume fraction. Flow front that meet at a small angles between the flows directions will act as one flow front shortly after the first collision. Due to the pressure gradient, the entrapped air might still be pushed towards the newly formed flow front. Which mean less void formation. For the big angles between the flow directions, the entrapments are caught between the saturated flow regions and not pushed towards the vent, as the pressure gradient decreasing in the moment the flow front collide [10].

Most of the works of the void contents were done on a flat panel, but for our work two surfaces like a sandwich laminate was used. The flow of resin during infusion process will be different especially the flow front meeting dynamic. By doing the void content analysis we can understand more about the distribution and the content of the void for polymer composite wind turbine blade manufactured using resin infusion process for both upper side and lower side. Besides that, we can also see the pattern of void content for both upper side and lower side and whether it produces the same pattern or not. That is what distinguishes our work from others.

# CHAPTER 3
# METHODOLOGY

In this project, eight layers of glass fibers were used to laminate the wooden wind turbine blade. The blade then manufactured using line feed type from root to tip strategy. In the preparation of the specimen, it involved the cutting process and separation of wood from fiber glass. Void content analysis then conducted for each sample.

## 3.1 MATERIALS AND EQUIPMENTS

The equipments used for conducting the experiment were listed as follows:

**Table 1: Materials and equipments with their details**

| MATERIALS/EQUIPMENTS | DETAILS |
|---|---|
| Wind turbine blade polymer composite | To test the property of void content at different locations. |
| Sketch tool | - Pencil<br>- Ruler<br>- Marker pen |
| Vernier caliper | To measure the thickness of the wind turbine blade polymer composite and dimension of specimens. |
| Electrical balance | To measure the weight of the specimens |
| Linear abrasive cutter machine | To cut the wind turbine blade polymer composite to specimen |
| Rotating Abrasive cutter machine | To cut the polymer composite into required dimension |
| Sand paper | To smoothen the edge of specimens and to eliminate the wood from the fiber glass |

| | |
|---|---|
| Muffle Furnace | To burn the specimen for loss ignition test |
| Polymer resin | The resin used was epoxy |
| Reinforcement | E-glass fiber |
| Acetone | To vary the viscosity of the resin |
| Resin infusion kit | - Vacuum pump<br>- Resin storage and resin trap<br>- Plastic bag<br>- Sealant tape<br>- Peel ply<br>- Net<br>- Aluminum plate<br>- Degassing chamber |
| Bunsen | To heat the specimen and crucible before heating in the muffle furnace |
| Crucible | To withstand high temperature during the heating of the specimen |

Figures 10 to 13 below shows some of the equipments used in this project.

**Figure 10: Bunsen**

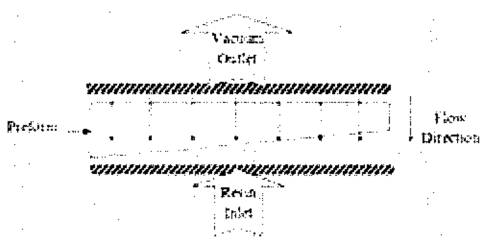
**Figure 11: Crucible**

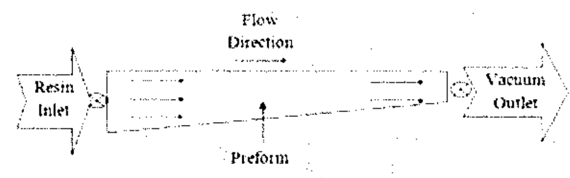
**Figure 12: Muffle Furnace**

**Figure 13: Electrical balance**

## 3.2 STRATEGIES DESIGN

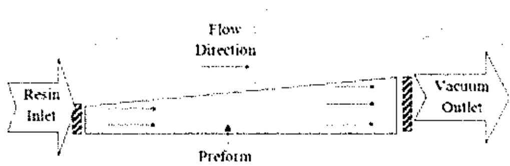
There were five strategies design use for the manufacturing of wind turbine blade using the resin infusion process. But in this project, strategy design line feed type, from root to tip was used. Specimens from various important locations will be taken and void testing was conducted. Void content was measured and the mapping produced. The mapping is important to see which parts reflect the highest void contents.



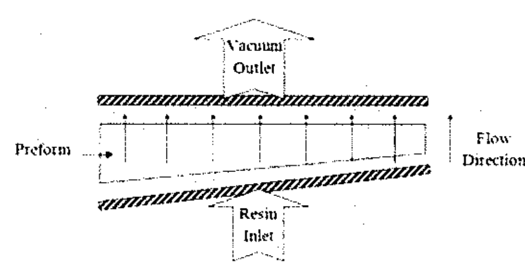



**b)Point feed type: root to tip**

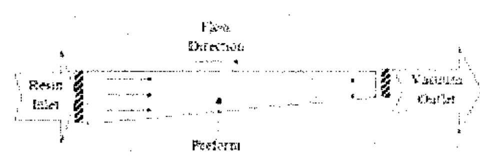
**a)Line feed type: leading edge to trailing edge**




**c)Line feed type: tip to root**




**d)Line feed type: trailing edge to leading edge**



**e)Line feed type: root to tip**

**Figure 14: Strategies used to manufacture wind turbine blade polymer composite**

### 3.3 PROJECT PLANNING (WORKFLOW)

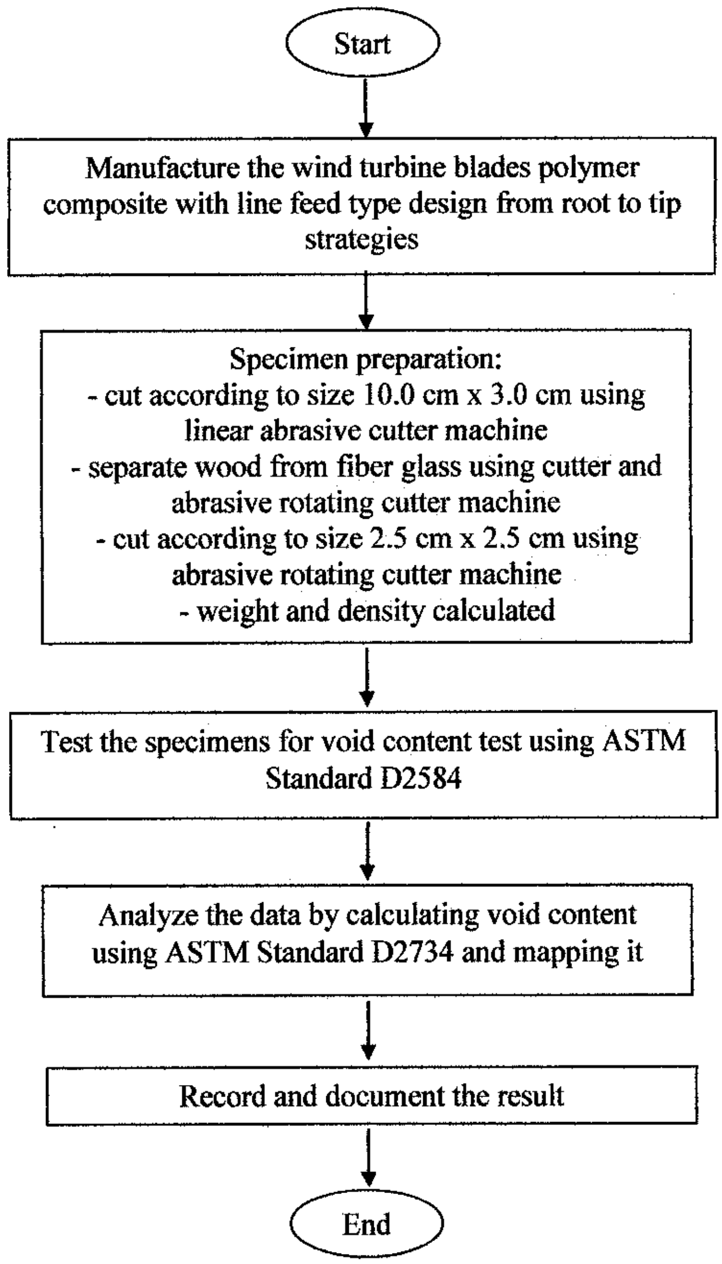



**Figure 15: Work flow for the project**

### 3.4 POLYMER COMPOSITE BLADE CONSTRUCTION

Strategy used, line feeding type from root to tip. Figure below shows the arrangement of resin infusion process.

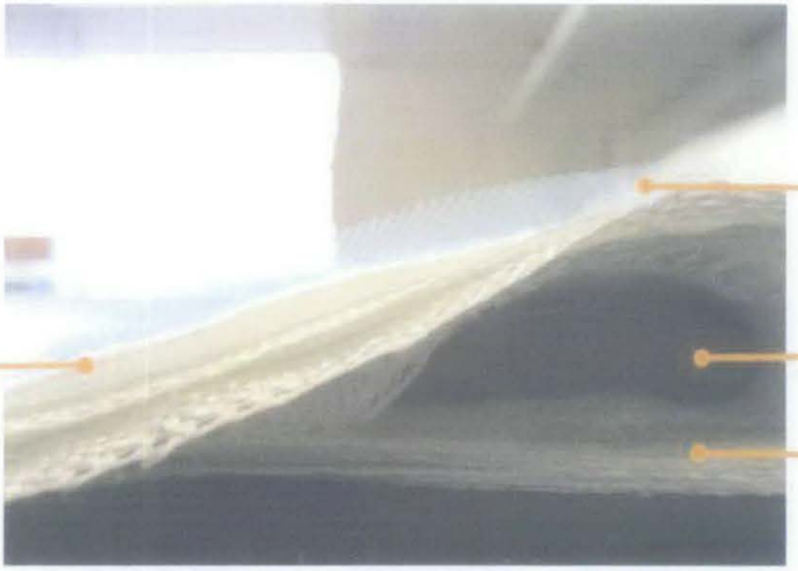



**Figure 16: Arrangement of blade, fibre, net and breather.**

Procedure:

1. Blade, fibre, net and breather are arranged as shown in the Figure 16.
2. Spiral tubing was cut similar to the length of the root length and placed there. The root area will be the resin inlet line.
3. Another spiral tubing was cut similar to the tip length and placed there. The tip area will be the resin outlet line.
4. A vacuum bag was used to wrap the whole surfaces of the arrangement above and a sealant tape was used to seal it.
5. The air trapped inside the vacuum bag was evacuated by using a vacuum pump.
6. Make sure the blade was sealed properly and no leakage occurs before resin infusion process started.
7. 80 g epoxy, 48 g hardener and 192 g acetone are then mixed slowly.

8. Bubbles eliminated from the mixture by using degassing chamber for 30 minutes.
9. Placed inlet tube inside the mixture and vacuum pump started.
10. Turned off the vacuum pump after the resins accumulate the entire blade.
11. The blade was left for curing process for about three days.
12. Removed the breather and net from the blade. Figure 17 show the final product.

**Figure 17: Final product**

### 3.5 NUMBER AND LOCATION OF SPECIMENS

Specimen is a portion of a material that was used in the testing. A wind turbine blade consists of 4 main parts which are leading, trailing, root and tip. Figure 18 show the wind turbine blade polymer composite has been divided into 9 columns (1-9) and 5 lines (A, a, B, b and C). The column start from column 1 which is the root area and towards the column 9 which is the tip area while the line start with line A which is the leading area and towards the line C which is the trailing area. A total of 108 specimens have been taken. 54 are from the upper side and another 54 are from the lower side. For each column and line four specimens were taken, 2 from the upper side and another 2 from the lower side.

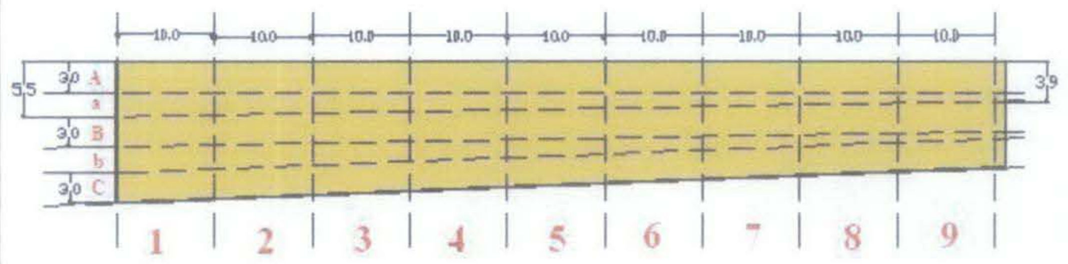



**Figure 18: Division of blade**

## 3.6 PREPARATION OF SAMPLE

1. The lines are sketched according to Figure 19 on the wind turbine blade polymer composite.
2. The blade is then cut according to the lines that have been sketched in vertical direction using Linear Abrasive Cutter machine into 9 pieces.
3. Each piece of the blade will be labels starting from number 1 until 9 from the largest part until the smallest part.
4. All of the part label 1until 9 will then be cut in horizontal direction using Linear Abrasive Cutter machine.
5. Each piece will then be labels with A, a, B, b and C with label A start from the leading side until C, the trailing side.
6. Next, the polymer composite will be split from the wood blade by using the Rotating Abrasive Cutter machine for each block. Note that the polymer composite must be free from the wood residue. If required, grind the polymer composite by using grinder.
7. The dimension of the required specimen will be sketched according to the ASTM D2584.

8. The polymer composite then is cut into specific dimension by using Rotating Abrasive Cutter Machine. Note that the wood should be eliminating from the glass fiber and if required, sand paper should be used.
9. The entire specimen will be label according to its line and column both for upper side and lower side. Figure 20 show the wind turbine blade after being cut.

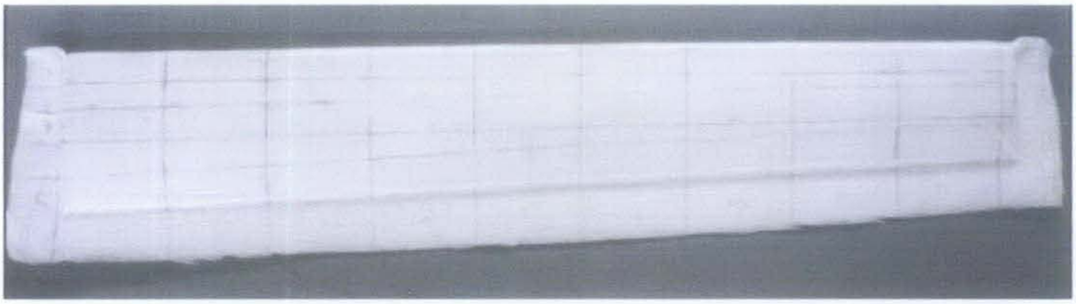


**Figure 19: Wind turbine blade polymer composite with specimen division's line.**

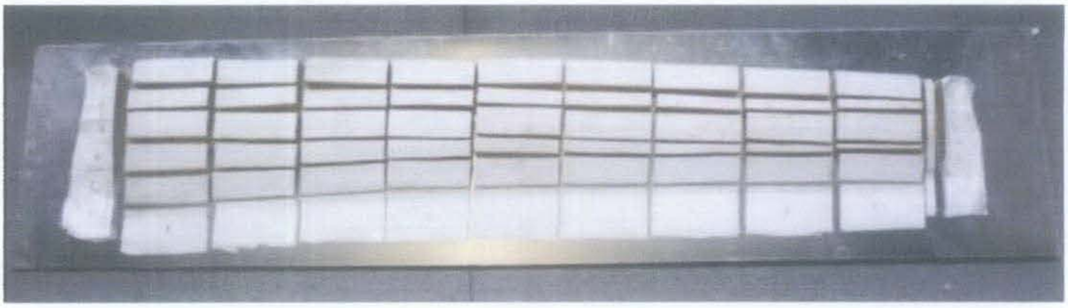


**Figure 20: Wind turbine blade polymer composite after cut into division.**

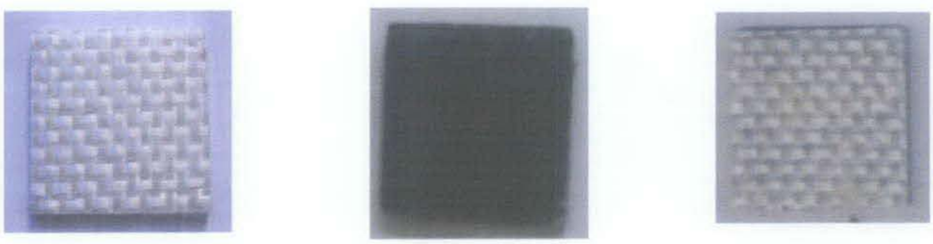
## 3.7 LOSS IGNITION TEST

The test was done by following previous Final Year Project Report, Ahmad Syazwan Bin Samsudin [3].

This test was carried out according to the standard ASTM D2584

1. The sample from the fabrication part was cut into specimens with the dimension of 25 mm x 25 mm. the weight ($m_1$) and density of every specimen is measured.
2. A crucible is heated at 500-600°C for 10 minutes.
3. The crucible is cooled and weighted ($m_2$).
4. The specimen is placed inside the crucible and is heated using a Bunsen until only carbon material remains.
5. Then, the crucible is heated inside a furnace at 565°C for 40 minutes.
6. The crucible is cooled and weighted ($m_3$).

Figure 21 below shows the specimen tested using loss ignition test.



(a) (b) (c)

**Figure 21: Sequence of the specimen tested in loss ignition process. (a) Before burning; (b) After burning using Bunsen; (c) Complete burning process in a furnace**

## 3.8 DATA ANALYSIS

After the loss ignition test have been done, the data analysis need to be done. This step is important to measure the void content and analysis of each sample. The Void content analysis will be performed using the standard test method ASTM D 2734. The step involved is:

1. The densities of the composite, resin and glass fiber are measured.
2. The resin content of composite is measured using the value gained from the loss ignition test and the theoretical composite density is calculated.
3. The difference between the theoretical and measured density of composite will show the result of the void content.

Microsoft Excel software was used to calculate the void content data and plotted the graph. Here are the calculations involved [3,5]:

i. Calculation for resin and fiber content:

$$R_{wt} = \frac{(m_1 + m_2) - m_3}{m_1} \times 100$$

$$F_{wt} = 100 - R_{wt}$$

Where; $R_{wt}$ = weight percent of resin, *%w*

$F_{wt}$ = weight percent of fiber, *%w*

$m_1$ = weight of specimen, *g*

$m_2$ = weight of crucible, *g*

$m_3$ = weight of crucible + residue, *g*

ii. Calculation for void content:

$$T_d = \frac{100}{\frac{R_{wt}}{D} + \frac{F_{wt}}{d}}$$

$$V = \frac{T_d - M_d}{T_d} \times 100$$

Where;

$T_d$ = theoretical composite density

$M_d$ = measured composite density

$F_{wt}$ = fiber weight %

$d$ = density of fiber

$V$ = void content (volume %)

$R_{wt}$ = Resin weight %

$D$ = density of resin

# CHAPTER 4
# RESULT AND DISCUSSION

## 4.1 POLYMER COMPOSITE BLADE VOID ANALYSIS

From the specimens' weight and density, void content for each sample calculated. Appendix 2-1, Appendix 2-2 and Appendix 2-3 show the void content value for each specimen. The location data for Appendix 2-1, A1.A1 refers to the specimen at A1 section and upper side location while A1.B1 refers to the specimen at A1 section but at lower side location. It applies to all specimens A2 until A9. Four specimens were taken from each column. Two from upper side and another two are from the lower side. The average of 2 specimens calculated to represent void content value of that section. The reading also applies for other locations, Section B and Section C.

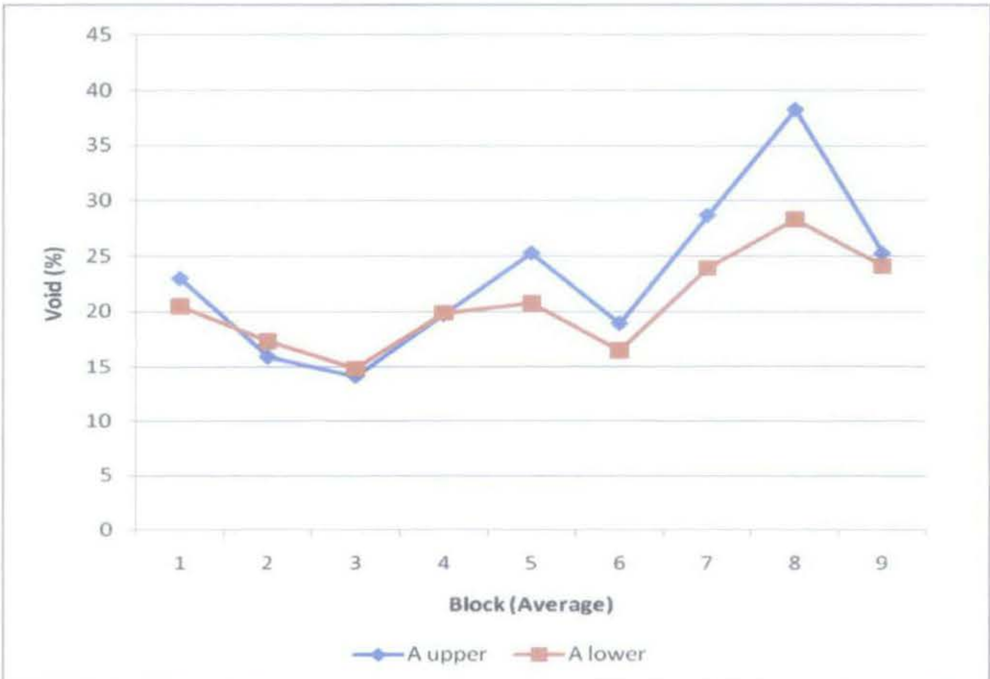



**Figure 22: Comparison of Void value for upper side and lower side from A1 to A9**

Figure 22 shows that both upper and lower side void content pattern is almost the same. The pattern of void content is increasing and decreasing along the block. The value for void content at A4 block fot both upper and lower side has approximately the same value where for upper side (19.72%) and for lower side (19.86%).

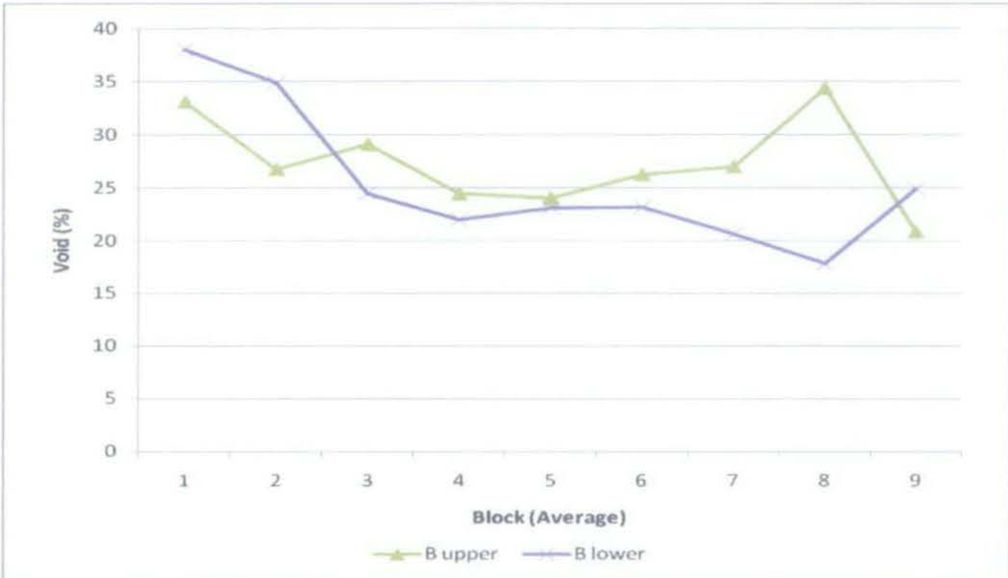



**Figure 23: Comparison of Void value for upper side and lower side from B1 to B9**

Figure 23 shows that upper side void content is higher compared to the lower side void content. But near the inlet and outlet, the lower side have the highest void content compared to the upper side.

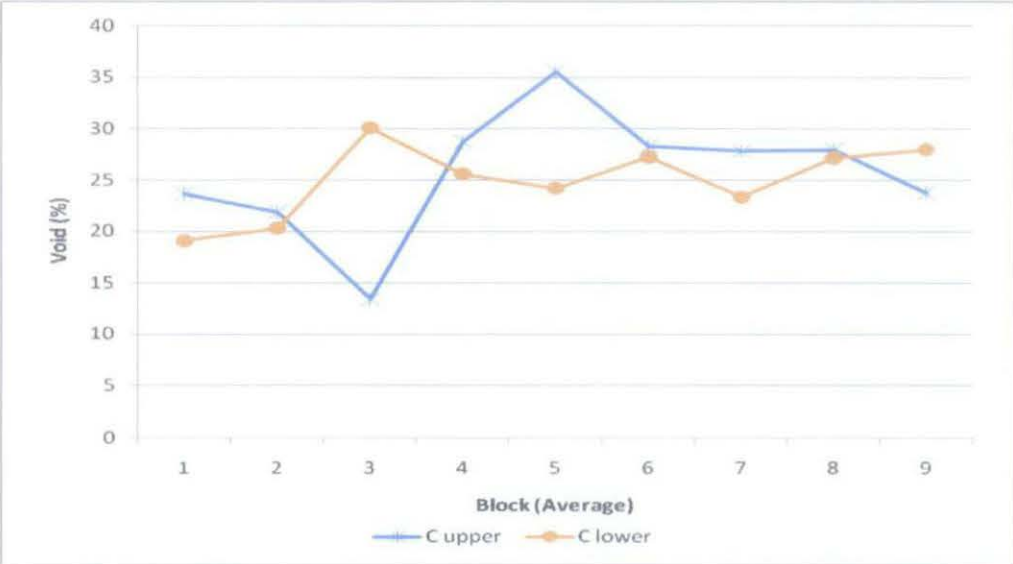



**Figure 24: Comparison of Void value for upper side and lower side from C1 to C9**

Figure 24 shows that along the trailing edge, the pattern of void content for lower side is much more constant but for the upper side, the void have significant low value at block C3 and highest value at block C5.

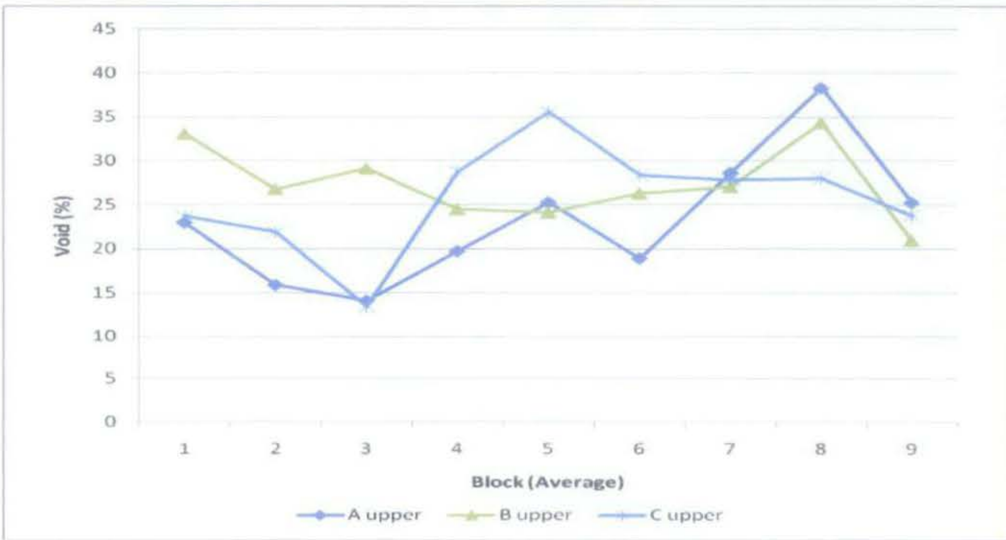



**Figure 25: Comparison of Void value for upper side from root to tip**

For the upper side, from Figure 25 the highest value of void are at A8 (38.30%), B8 (34.37%) and C5 (35.55%). While for the lowest value of void content are at A3(14.10%), B9 (20.89%) and C3 (13.44%). The value of void content for A and C for the upper side is approximately the same near the inlet and outlet.

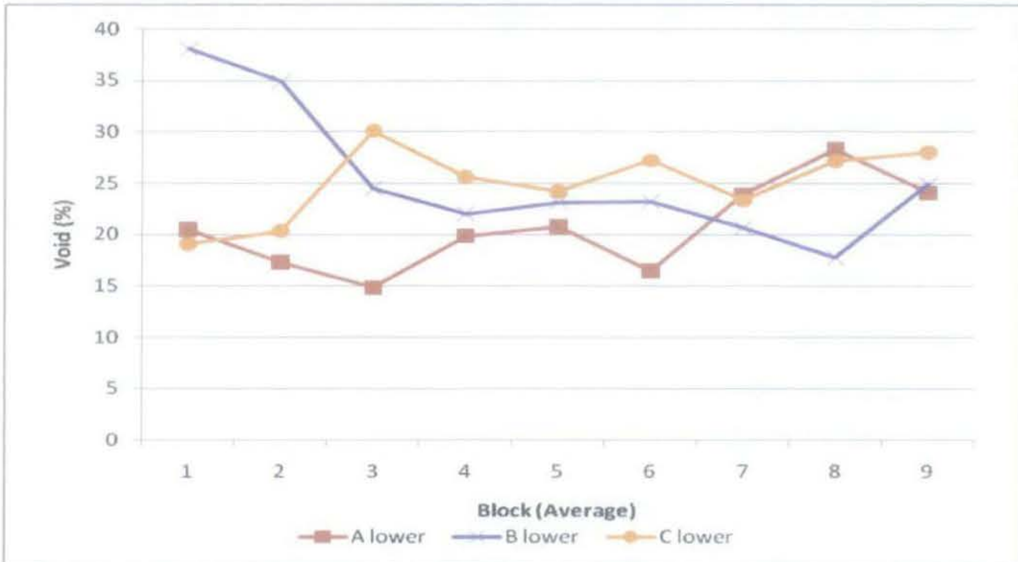



**Figure 26: Comparison of Void value for lower side from root to tip**

From the lower side graph, the highest value of void content are at A8 (28.29%), B1 (38.03%), and C3 (30.11%). While for the lowest value of void content are at A3 (14.85%), B8 (17.79%) and C1 (19.09%). The value of void content for A and C near the inlet and for A and B near the outlet are approximately the same.

## 4.2 VOID ANALYSIS FROM ROOT TO TIP

Figure 27 shows the overall distribution of void for both upper and lower side. The value of void content for each division are the average value of section A, B and C in the same division. Division 1 is near to the inlet while Division 9 is near to the outlet.

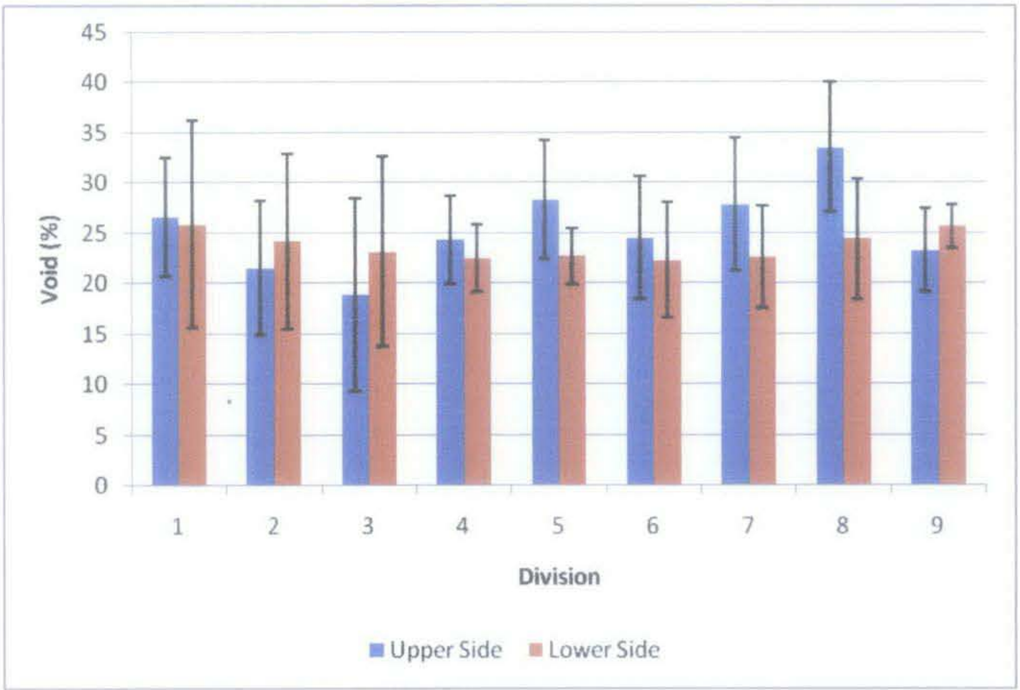



**Figure 27: Comparison of Void value from root to tip**

The void content for the upper side seem really high compared to the lower side. The distribtution of void in the lower side decreasing in the middle and increase back through the end (outlet). The higher value of void was due to the chemical reaction during the mixing of epoxy, acetone and the hardener process. Although the degassing process has been done after the mixing process, there still lots of bubbles that cannot be sucked out from the resin. The used of acetone is also one of the reason of higher bubbles formation. The mixture of resin with high bubbles that was used through out the experiment making the bubbles distribute. The entrapped air remains there through the process of curing. The location where void content is high is mainly the location where the most of air trapped.

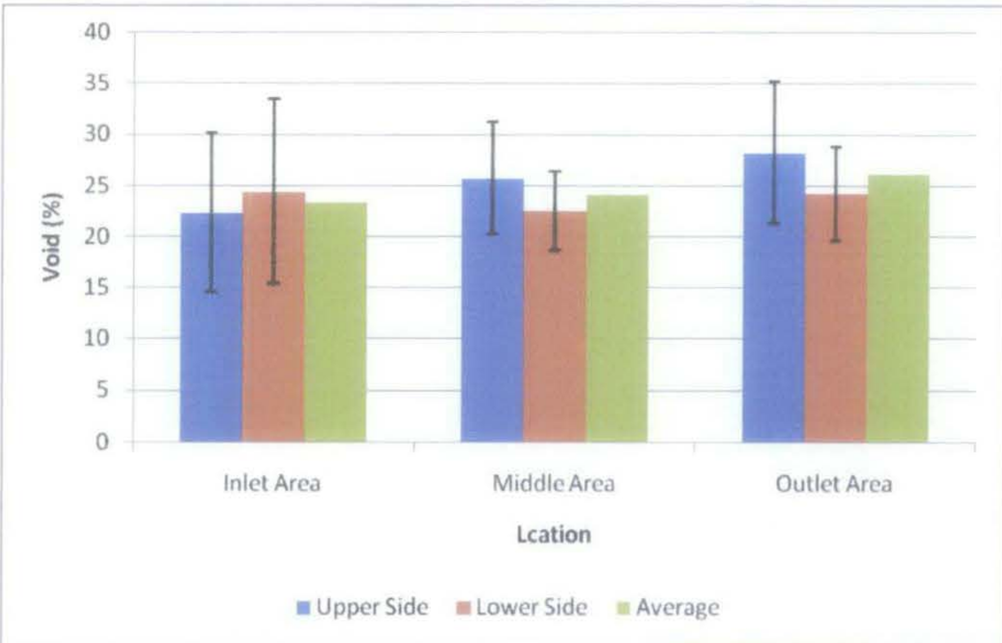



**Figure 28: Comparison of Void value for inlet, middle and outlet area**

In this analysis, three major part has been used to describe the void distribution. The locations are inlet area, middle area and outlet area. The inlet area consists of the average value of Division 1 until Division 3, middle area consists of average value of Division 4 until Division 6 while for outlet area Division 7 until Division 9.

The trend distibution of void by location for the upper side is increasing from inlet area to the outler area. While for the lower side, the trends are higher at inlet area and outlet area but low in the middle area. The flow of resin from inlet to outlet make the void travel and been distributed. During the travelling and distribution of the voids, voids tend to gather at the outlet area. Due to the curing process and the resin started to gel, air that should be sucked out cannot move and remains there. For the upper side, the inlet area has low void content compared to the middle area and outlet area. The reason is because the void has been travelled and moved towards the outlet area.

Voids distribution at lower side seem cannot really move. This may due to the low permeability at the lower side area of the blade that resists the movement of void. The pressure exerted by the weight and gravity effect are also one of the reason of the low permeability. As the result of low permeability, there are low void content for the lower side compared to the upper side and higher value of void content at inlet of the lower side. During the infusion process, the resin with bubbles enters the blade at the inlet area, but due to the difficulity to travel at the lower side, the voids remains there until the end of the process.

Generally, comparing the void content for the upper side and the lower side, the lower side seem to have lower void content than the upper side. And by looking at the trend pattern averagely, the void distribution is increasing from inlet area to the outlet area.

## 4.3 VOID ANALYSIS FROM LEADING EDGE TO TRAILING EDGE

In this section, void analysis have been done to the leading edge until the trailing edge. The leading edge compromise the void content value for Section A area while for the intersection area is referring to Section B and trailing edge is referring to Section C.

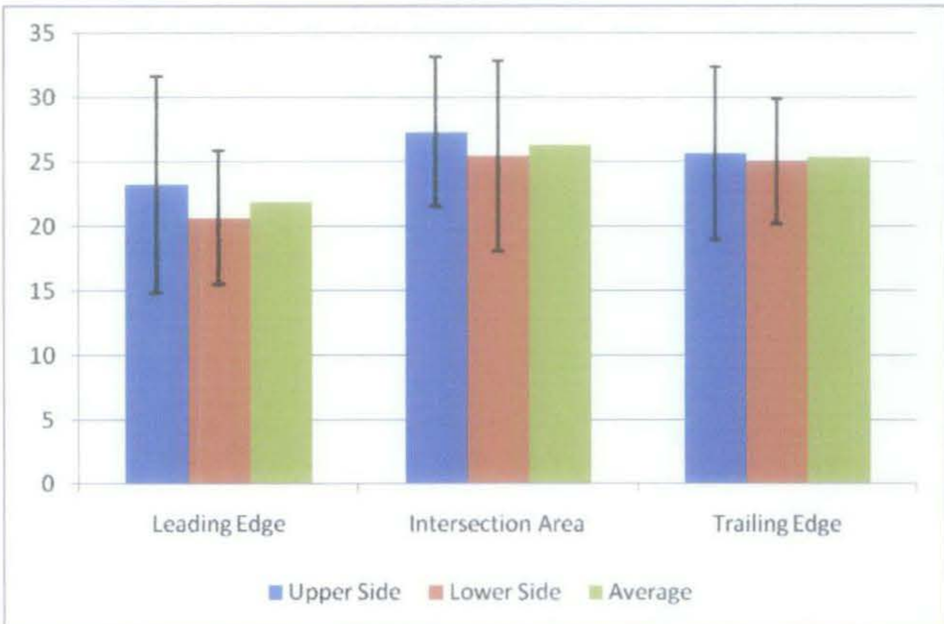



**Figure 29: Comparison of Void value from leading edge to trailing edge**

The pattern for the void content distribution for both upper side and lower side is the same. The void content is higher at the intersection area and lowest at the leading edge.

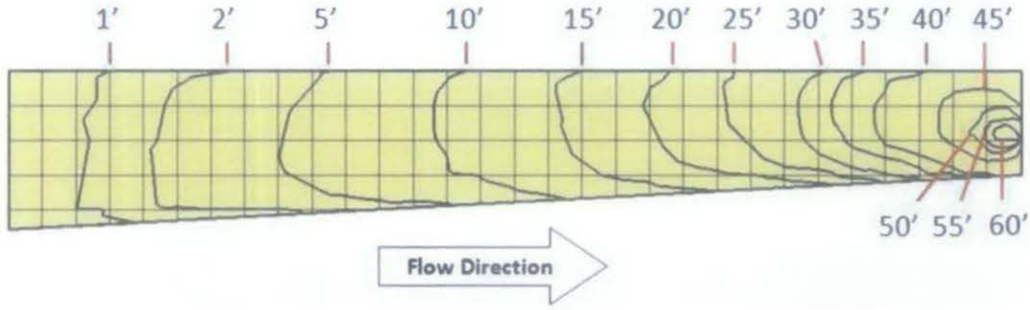



**Figure 30: Flow front pattern during infusion for root to tip strategy**

By comparing the flow front and the distribution of void from root to tip, nearly the outlet area the resin start to gather and merging. This is the location where the void tends to gather and accumulate. From previous discussion, the outlet area is the area which has the highest void content value compared to the inlet area and middle area. The flow front also shows that the resin start to gather and merging at the intersection area and near the trailing edge. This is also one of the reason the distribution of voids are higher at the intersection area and followed by trailing edge. The flow front effect the distibution of void content.

## 4.4 MAPPING OF VOID DISTRIBUTION ON A SINGLE BLADE

Figure 31 and Figure 32 show the mapping of void content distribution for upper side and lower side of a resin infused wind turbine blade polymer composite over distance for a single blade. Generally, these figures show that for the upper side the void content value is higher at the outlet area and void content value is higher at the inlet area for lower side. Figure 33 and Figure 34 show the mapping of void content distribution for upper side and lower side of a resin infused wind turbine blade polymer composite over block for a single blade. These figures generally show that more green area at the lower side compared to the upper side. Lower side has low void content compared to the upper side.

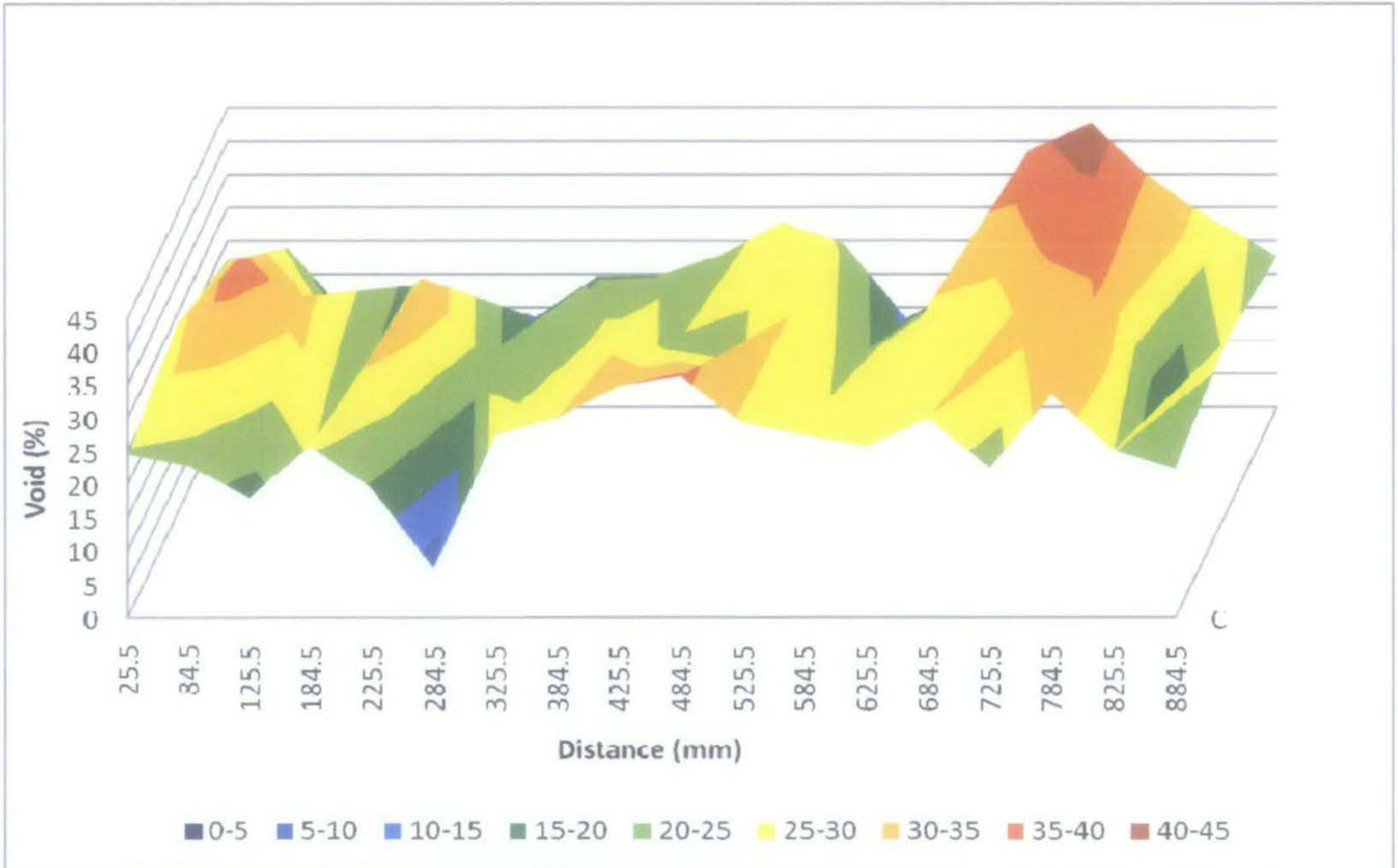



**Figure 31: Void distribution for the upper side of blade by distance**

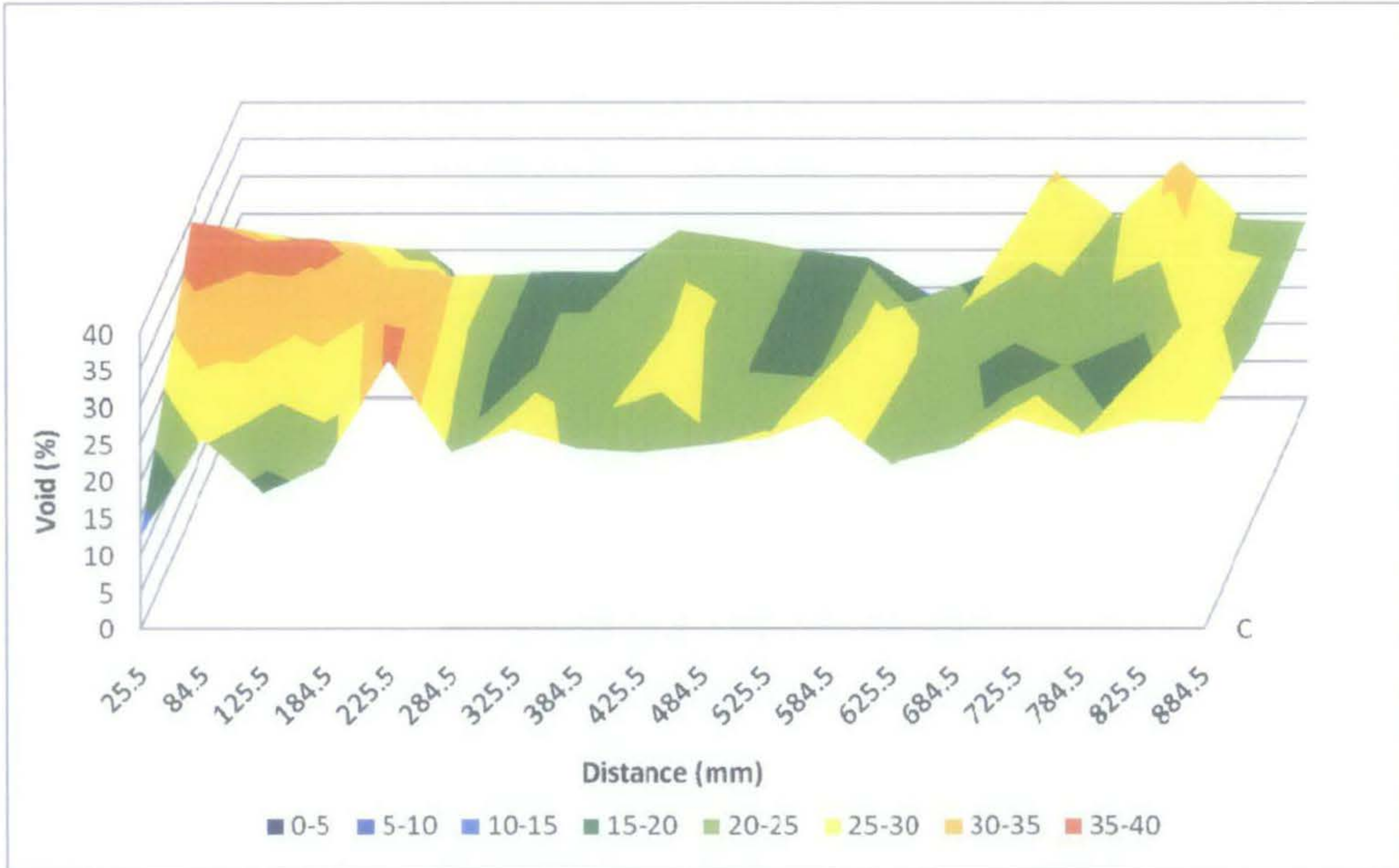



**Figure 32: Void distribution for the lower side of blade by distance**

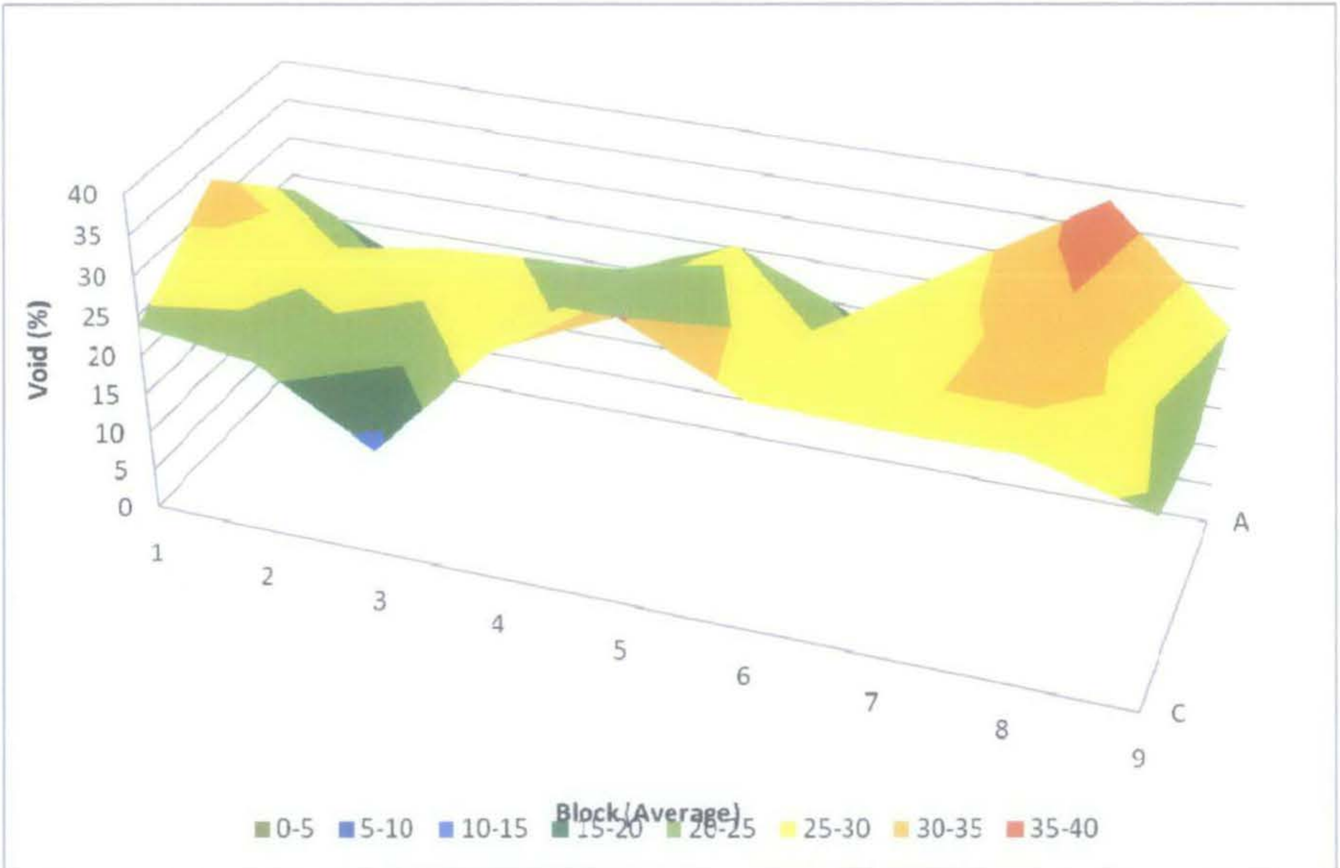



**Figure 33: Void distribution for the upper side of blade by division**

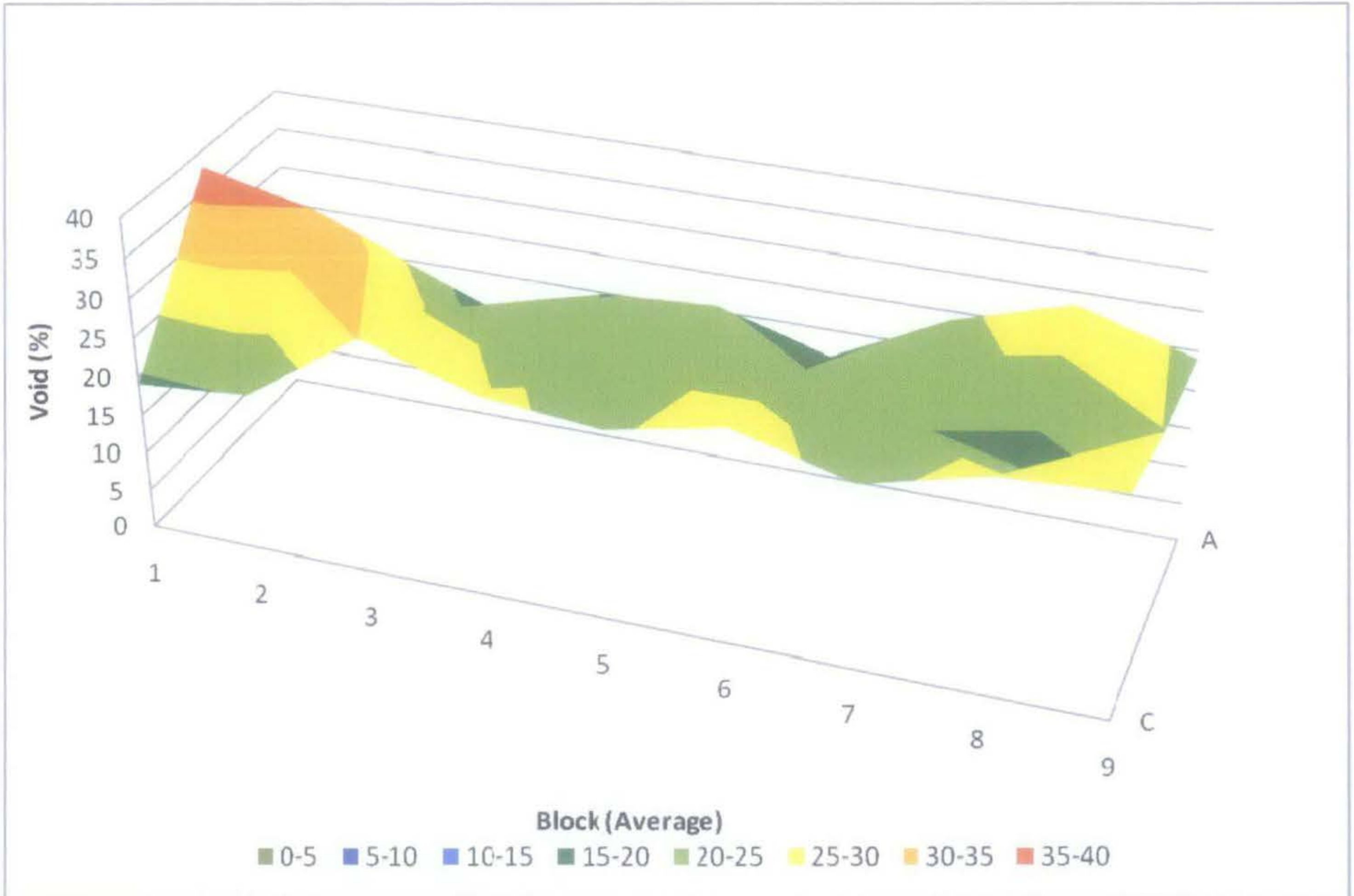



**Figure 34: Void distribution for the lower side of blade by division**

# CHAPTER 5
# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 CONCLUSIONS

Void information such as void content and its distribution is useful as the high void contents can reduce the composites' strength. Void is strongly influence the performance, consistency and mechanical properties of a polymer composite. To study the characterization of void content in a wind turbine blade polymer composite, it involves lots of process such as the manufacturing of the wind turbine blade, preparation of the specimen, loss ignition test and the analysis of the data obtained. The void distribution influenced by the effect of flow front process. Low void content at lower side compared to the upper side and void tends to accumulate at the outlet area than the inlet area. The mapping for voids distribution for a single wind blade successfully created.

## 5.2 RECOMMENDATIONS

Some of the recommendations that can be made to improve the results such as:

1. Using other solvent to replace acetone as acetone is easy to volatile and produces bubbles inside the mixture during the infusion process.
2. Degassing process should be done properly as it can affect the formation of the bubbles during infusion process.
3. Make sure that the dimension of the specimen is following the desired standard and measurement. And during the separation of the wood from the fiber glass, avoid the elimination of fiber glass as it can affect the weight and density of the specimen and thus affect the void content.
4. An optical micrograph can be used to describe which type of voids appear most.

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**APPENDIX 1-1**

## PROJECT PLANNING (GANTT CHART)

GANTT CHART FOR FINAL YEAR PROJECT 1

| No. | Details\Week | 1 | 2 | 3 | 4 | 5 | 6 | m | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Selection of project topic | | | | | | | i | | | | | | | | |
| 2 | Meeting with supervisor and team members | | | | | | | d | | | | | | | | |
| 3 | Preliminary Research | | | | | | | | | | | | | | | |
| 4 | Submission of preliminary report | | | | | | | s | | | | | | | | |
| 5 | Lab work on Resin Infusion | | | | | | | e | | | | | | | | |
| 6 | Submission of progress report | | | | | | | m | | | | | | | | |
| 7 | Seminar | | | | | | | b | | | | | | | | |
| 8 | Lab on Void Test | | | | | | | r | | | | | | | | |
| 9 | Submission of progress report | | | | | | | e | | | | | | | | |
| 10 | Submission of Interim Report Final Draft | | | | | | | a | | | | | | | | |
| 11 | Oral Presentation | | | | | | | k | | | | | | | | |

GANTT CHART FOR FINAL YEAR PROJECT 2

| No. | Details\Week | 1 | 2 | 3 | 4 | 5 | 6 | m | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Continuation of Lab Void Testing | | | | | | | i | | | | | | | | | | | |
| 2 | Progress Report 1 | | | | | | | d | | | | | | | | | | | |
| 3 | Progress Report 2 | | | | | | | s | | | | | | | | | | | |
| 4 | Seminar | | | | | | | e | | | | | | | | | | | |
| 5 | Data Analysis and compilation | | | | | | | m | | | | | | | | | | | |
| 6 | Poster presentation | | | | | | | b | | | | | | | | | | | |
| 7 | Submission of final dissertation report | | | | | | | r | | | | | | | | | | | |
| 8 | Final oral presentation | | | | | | | e | | | | | | | | | | | |
| 9 | Submission of final dissertation report | | | | | | | a k | | | | | | | | | | | |

**APPENDIX 2-1**

## SECTION A LOSS IGNITON TEST RESULT

| sample tag | m1(g) | m2(g) | m3(g) | Rwt(%w) | Fwt(%w) | Td (g/cm3) | Md(g/cm3) | void (%) |
|---|---|---|---|---|---|---|---|---|
| A1.A1 | 1.574 | 123.854 | 124.838 | 37.533 | 62.467 | 1.823 | 1.420 | 22.076 |
| A1.A2 | 1.541 | 133.991 | 134.976 | 36.069 | 63.931 | 1.843 | 1.403 | 23.870 |
| A2.A1 | 1.666 | 123.824 | 124.857 | 37.969 | 62.0305517 | 1.816794452 | 1.571 | 13.547 |
| A2.A2 | 1.630 | 123.824 | 124.846 | 37.328 | 62.67212 | 1.82557733 | 1.492 | 18.264 |
| A3.A1 | 1.584 | 122.128 | 123.096 | 38.876 | 61.1239739 | 1.80452678 | 1.539 | 14.702 |
| A3.A2 | 1.450 | 122.128 | 122.950 | 43.310 | 56.6896552 | 1.746832925 | 1.511 | 13.498 |
| A4.A1 | 1.633 | 133.953 | 134.961 | 38.286 | 61.7142857 | 1.81249589 | 1.457 | 19.627 |
| A4.A2 | 1.586 | 133.953 | 134.925 | 38.735 | 61.2652375 | 1.80642743 | 1.449 | 19.814 |
| A5.A1 | 1.583 | 122.155 | 123.195 | 34.340 | 65.660 | 1.868 | 1.441 | 22.820 |
| A5.A2 | 1.508 | 123.760 | 124.806 | 30.635 | 69.365 | 1.923 | 1.389 | 27.726 |
| A6.A1 | 1.532 | 123.824 | 124.835 | 34.008 | 65.9921671 | 1.872419344 | 1.414 | 24.504 |
| A6.A2 | 1.620 | 122.128 | 123.126 | 38.395 | 61.6049383 | 1.81101441 | 1.570 | 13.300 |
| A7.A1 | 1.622 | 133.953 | 134.963 | 37.698 | 62.3021583 | 1.820502329 | 1.481 | 18.671 |
| A7.A2 | 1.548 | 123.824 | 125.203 | 10.939 | 89.0611542 | 2.278677917 | 1.397 | 38.681 |
| A8.A1 | 1.591 | 123.824 | 125.274 | 8.883 | 91.1166981 | 2.323599908 | 1.334 | 42.581 |
| A8.A2 | 1.639 | 123.824 | 125.188 | 16.758 | 83.2418141 | 2.160432238 | 1.425 | 34.023 |
| A9.A1 | 1.542 | 133.927 | 134.977 | 31.941 | 68.059 | 1.903 | 1.374 | 27.812 |
| A9.A2 | 1.535 | 122.104 | 123.109 | 34.513 | 65.487 | 1.865 | 1.442 | 22.661 |
| A1.B1 | 1.683 | 123.760 | 124.846 | 35.472 | 64.528 | 1.851 | 1.491 | 19.464 |
| A1.B2 | 1.595 | 133.927 | 134.990 | 33.390 | 66.610 | 1.881 | 1.476 | 21.534 |
| A2.B1 | 1.596 | 133.953 | 134.922 | 39.305 | 60.6946475 | 1.798774822 | 1.532 | 14.858 |
| A2.B2 | 1.600 | 133.953 | 134.896 | 41.049 | 58.9513889 | 1.775791201 | 1.424 | 19.799 |
| A3.B1 | 1.646 | 123.824 | 124.837 | 38.457 | 61.5431349 | 1.810178146 | 1.580 | 12.697 |
| A3.B2 | 1.524 | 122.128 | 123.031 | 40.748 | 59.2519685 | 1.779712131 | 1.477 | 17.012 |
| A4.B1 | 1.592 | 122.128 | 123.093 | 39.372 | 60.6282723 | 1.797888822 | 1.492 | 17.003 |
| A4.B2 | 1.504 | 123.824 | 124.737 | 39.287 | 60.7134943 | 1.799026556 | 1.390 | 22.709 |
| A5.B1 | 1.635 | 122.104 | 123.178 | 34.278 | 65.722 | 1.869 | 1.466 | 21.552 |
| A5.B2 | 1.628 | 123.858 | 124.869 | 37.885 | 62.115 | 1.818 | 1.455 | 19.948 |
| A6.B1 | 1.531 | 133.953 | 134.906 | 37.731 | 62.2686697 | 1.820044337 | 1.476 | 18.883 |
| A6.B2 | 1.533 | 133.953 | 134.944 | 35.363 | 64.6367986 | 1.85300932 | 1.593 | 14.035 |
| A7.B1 | 1.620 | 122.128 | 123.125 | 38.469 | 61.5305493 | 1.810007945 | 1.501 | 17.071 |
| A7.B2 | 1.605 | 123.824 | 125.187 | 15.057 | 84.9428868 | 2.193708177 | 1.521 | 30.687 |
| A8.B1 | 1.795 | 123.824 | 125.267 | 19.591 | 80.4085422 | 2.107194275 | 1.591 | 24.514 |
| A8.B2 | 1.596 | 123.824 | 125.182 | 14.915 | 85.0846041 | 2.19652673 | 1.492 | 32.072 |
| A9.B1 | 1.561 | 133.941 | 134.977 | 33.614 | 66.386 | 1.878 | 1.423 | 24.224 |
| A9.B2 | 1.540 | 123.858 | 124.807 | 38.340 | 61.660 | 1.812 | 1.378 | 23.921 |

**APPENDIX 2-2**

## SECTION B LOSS IGNITON TEST RESULT

| sample tag | m1(g) | m2(g) | m3(g) | Rwt(%w) | Fwt(%w) | Td (g/cm3) | Md(g/cm3) | void (%) |
|---|---|---|---|---|---|---|---|---|
| B1.A1 | 1.695 | 123.824 | 125.211 | 18.191 | 81.809 | 2.133 | 1.528043969 | 28.368 |
| B1.A2 | 1.7 | 123.824 | 125.199 | 19.118 | 80.882 | 2.116 | 1.314594626 | 37.871 |
| B2.A1 | 1.632 | 123.824 | 125.233 | 13.664 | 86.336 | 2.222 | 1.501775629 | 32.405 |
| B2.A2 | 1.797 | 123.824 | 125.278 | 19.087 | 80.913 | 2.116 | 1.669117106 | 21.137 |
| B3.A1 | 1.74367 | 123.824 | 125.288 | 16.058 | 83.942 | 2.174 | 1.410765271 | 35.108 |
| B3.A2 | 1.689 | 122.128 | 123.151 | 39.412 | 60.588 | 1.797 | 1.382176664 | 23.099 |
| B4.A1 | 1.606 | 133.953 | 135.01 | 34.184 | 65.816 | 1.870 | 1.456650586 | 22.099 |
| B4.A2 | 1.682 | 133.953 | 135.067 | 33.789 | 66.211 | 1.876 | 1.372849687 | 26.804 |
| B5.A1 | 1.648 | 133.953 | 135.051 | 33.354 | 66.646 | 1.882 | 1.419135946 | 24.592 |
| B5.A2 | 1.61533 | 133.953 | 135.048 | 32.233 | 67.767 | 1.898 | 1.451779413 | 23.529 |
| B6.A1 | 1.61 | 133.953 | 135.001 | 34.928 | 65.072 | 1.859 | 1.30656507 | 29.725 |
| B6.A2 | 1.77867 | 133.953 | 135.105 | 35.214 | 64.786 | 1.855 | 1.432166415 | 22.800 |
| B7.A1 | 1.595 | 133.953 | 134.998 | 34.462 | 65.538 | 1.866 | 1.333129022 | 28.552 |
| B7.A2 | 1.71467 | 133.953 | 135.067 | 35.031 | 64.969 | 1.858 | 1.384241338 | 25.487 |
| B8.A1 | 1.472 | 133.953 | 134.976 | 30.503 | 69.497 | 1.925 | 1.281405212 | 33.418 |
| B8.A2 | 1.54 | 133.953 | 135 | 32.013 | 67.987 | 1.902 | 1.229884904 | 35.328 |
| B9.A1 | 1.622 | 122.128 | 123.146 | 37.217 | 62.783 | 1.827 | 1.536833794 | 15.887 |
| B9.A2 | 1.48667 | 122.128 | 123.041 | 38.565 | 61.435 | 1.809 | 1.340454641 | 25.889 |
| | | | | | | | | |
| B1.B1 | 1.65 | 123.824 | 125.236 | 14.424 | 85.576 | 2.206 | 1.336964354 | 39.404 |
| B1.B2 | 1.642 | 123.824 | 125.208 | 15.713 | 84.287 | 2.181 | 1.381166674 | 36.666 |
| B2.B1 | 1.67667 | 123.824 | 125.243 | 15.388 | 84.612 | 2.187 | 1.375670911 | 37.102 |
| B2.B2 | 1.758 | 123.824 | 125.272 | 17.653 | 82.347 | 2.143 | 1.443723526 | 32.641 |
| B3.B1 | 1.789 | 123.824 | 125.29 | 18.036 | 81.964 | 2.136 | 1.449333163 | 32.150 |
| B3.B2 | 1.70333 | 133.953 | 135.043 | 35.988 | 64.012 | 1.844 | 1.533876938 | 16.827 |
| B4.B1 | 1.618 | 133.953 | 135.037 | 33.024 | 66.976 | 1.887 | 1.461784602 | 22.524 |
| B4.B2 | 1.63 | 133.953 | 135.035 | 33.620 | 66.380 | 1.878 | 1.474568666 | 21.484 |
| B5.B1 | 1.64233 | 133.953 | 135.003 | 36.067 | 63.933 | 1.843 | 1.3528272 | 26.600 |
| B5.B2 | 1.67 | 133.953 | 135.061 | 33.653 | 66.347 | 1.878 | 1.508764082 | 19.643 |
| B6.B1 | 1.622 | 133.953 | 135.021 | 34.135 | 65.865 | 1.871 | 1.508438701 | 19.360 |
| B6.B2 | 1.686 | 133.953 | 135.05 | 34.935 | 65.065 | 1.859 | 1.357552048 | 26.978 |
| B7.B1 | 1.627 | 133.953 | 135.017 | 34.624 | 65.376 | 1.864 | 1.417864924 | 23.916 |
| B7.B2 | 1.68333 | 133.953 | 134.996 | 38.059 | 61.941 | 1.816 | 1.50113105 | 17.319 |
| B8.B1 | 1.654 | 133.953 | 134.985 | 37.606 | 62.394 | 1.822 | 1.452921479 | 20.246 |
| B8.B2 | 1.706 | 133.953 | 135.004 | 38.394 | 61.606 | 1.811 | 1.533266 | 15.337 |
| B9.B1 | 1.429 | 122.128 | 123.088 | 32.843 | 67.157 | 1.889 | 1.384957132 | 26.699 |
| B9.B2 | 1.66 | 122.128 | 123.237 | 33.213 | 66.787 | 1.884 | 1.448196443 | 23.132 |

**APPENDIX 2-3**

## SECTION C LOSS IGNITON TEST RESULT

| sample tag | m1(g) | m2(g) | m3(g) | Rwt(%w) | Fwt(%w) | Td (g/cm3) | Md(g/cm3) | void (%) |
|---|---|---|---|---|---|---|---|---|
| C1.A1 | 1.692 | 122.128 | 123.162 | 38.869 | 61.131 | 1.805 | 1.362661152 | 24.490 |
| C1.A2 | 1.619 | 133.953 | 134.971 | 37.122 | 62.878 | 1.828 | 1.410829313 | 22.839 |
| C2.A1 | 1.73433 | 133.953 | 135.093 | 34.288 | 65.712 | 1.868 | 1.53068189 | 18.074 |
| C2.A2 | 1.644 | 133.953 | 135.004 | 36.071 | 63.929 | 1.843 | 1.369809749 | 25.677 |
| C3.A1 | 1.715 | 133.953 | 135.107 | 32.692 | 67.308 | 1.892 | 1.523434689 | 19.466 |
| C3.A2 | 1.838 | 133.953 | 134.981 | 44.088 | 55.912 | 1.737 | 1.608048994 | 7.429 |
| C4.A1 | 1.616 | 133.953 | 135.017 | 34.138 | 65.862 | 1.871 | 1.357499513 | 27.427 |
| C4.A2 | 1.509 | 133.953 | 134.977 | 32.163 | 67.837 | 1.900 | 1.328948713 | 30.037 |
| C5.A1 | 1.56333 | 133.953 | 135.047 | 30.021 | 69.979 | 1.932 | 1.25877981 | 34.844 |
| C5.A2 | 1.44 | 133.953 | 134.948 | 30.903 | 69.097 | 1.918 | 1.222911011 | 36.255 |
| C6.A1 | 1.49267 | 133.953 | 134.975 | 31.554 | 68.446 | 1.909 | 1.350310213 | 29.252 |
| C6.A2 | 1.54667 | 133.953 | 134.987 | 33.168 | 66.832 | 1.885 | 1.367753559 | 27.427 |
| C7.A1 | 1.46533 | 133.953 | 134.923 | 33.781 | 66.219 | 1.876 | 1.392430323 | 25.765 |
| C7.A2 | 1.574 | 133.953 | 134.982 | 34.625 | 65.375 | 1.864 | 1.306314406 | 29.901 |
| C8.A1 | 1.542 | 133.953 | 134.979 | 33.485 | 66.515 | 1.880 | 1.457263067 | 22.487 |
| C8.A2 | 1.483 | 133.953 | 134.925 | 34.457 | 65.543 | 1.866 | 1.240847737 | 33.500 |
| C9.A1 | 1.491 | 133.953 | 134.933 | 34.272 | 65.728 | 1.869 | 1.399561952 | 25.101 |
| C9.A2 | 1.59 | 133.953 | 135.017 | 33.103 | 66.897 | 1.886 | 1.4633024 | 22.396 |
| | | | | | | | | |
| C1.B1 | 1.72467 | 133.953 | 135.061 | 35.756 | 64.244 | 1.847 | 1.615195197 | 12.572 |
| C1.B2 | 1.642 | 133.953 | 134.986 | 37.069 | 62.931 | 1.829 | 1.360897164 | 25.600 |
| C2.B1 | 1.866 | 133.953 | 135.096 | 38.746 | 61.254 | 1.806 | 1.475430057 | 18.316 |
| C2.B2 | 1.664 | 133.953 | 134.987 | 37.841 | 62.159 | 1.819 | 1.412745957 | 22.315 |
| C3.B1 | 1.591 | 133.953 | 135.119 | 26.734 | 73.266 | 1.984 | 1.259617349 | 36.510 |
| C3.B2 | 1.635 | 133.953 | 134.983 | 37.023 | 62.977 | 1.830 | 1.395978671 | 23.708 |
| C4.B1 | 1.646 | 133.953 | 134.992 | 36.898 | 63.102 | 1.832 | 1.337728253 | 26.961 |
| C4.B2 | 1.565 | 133.953 | 134.975 | 34.718 | 65.282 | 1.862 | 1.410275819 | 24.268 |
| C5.B1 | 1.7 | 133.953 | 134.991 | 38.922 | 61.078 | 1.804 | 1.375988992 | 23.722 |
| C5.B2 | 1.563 | 122.128 | 123.104 | 37.556 | 62.444 | 1.822 | 1.372945852 | 24.665 |
| C6.B1 | 1.67 | 133.953 | 135.014 | 36.467 | 63.533 | 1.837 | 1.365991714 | 25.660 |
| C6.B2 | 1.59 | 133.953 | 134.995 | 34.444 | 65.556 | 1.866 | 1.328637144 | 28.802 |
| C7.B1 | 1.68 | 133.953 | 134.977 | 39.048 | 60.952 | 1.802 | 1.400978817 | 22.264 |
| C7.B2 | 1.61667 | 133.953 | 134.966 | 37.320 | 62.680 | 1.826 | 1.380457504 | 24.387 |
| C8.B1 | 1.576 | 133.953 | 134.982 | 34.687 | 65.313 | 1.863 | 1.332487846 | 28.463 |
| C8.B2 | 1.53233 | 133.953 | 134.947 | 35.153 | 64.847 | 1.856 | 1.375815104 | 25.872 |
| C9.B1 | 1.48267 | 133.953 | 134.941 | 33.386 | 66.614 | 1.881 | 1.352181183 | 28.131 |
| C9.B2 | 1.60767 | 133.953 | 135.028 | 33.133 | 66.867 | 1.885 | 1.359839282 | 27.866 |

## APPENDIX 3-1

### SAMPLES PREPARATION