A Study on Repeatability of a Resin Infusion Strategy in the Manufacturing of Polymer Composite Wind Turbine Blade via Resin Infusion Process

by

Muhammad Faris Bin Che Salam

Dissertation submitted in partial fulfillment of

The requirement for the

Bachelor of Engineering (Hons)

(Mechanical Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

____

(Muhamad Ridzuan B Abdul Latif)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2012

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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(MUHAMMAD FARIS BIN CHE SALAM)

ABSTRACT

Resin Infusion Process is a common process that is used in industrial application nowadays. This technique is capable of producing high mechanical strength and high quality product cost effectively. Although the Resin Infusion Process is common, there is little evidence that the quality of the material that has been produced is reproducible. Hence, it is important to know whether the Resin Infusion Process is a repeatable process or not. The objective of the project is to investigate how repeatable is the Resin Infusion Process of wind turbine blade with regards to its properties. Two blades will be fabricated using resin infusion which is called *Sample 1* and *Sample 2*. The blades are then cut into 25 mm x 25 mm specimens. The specimens are burned in the muffle furnace until fibres is the only remaining materials. The property of interest in this project is the void content. Loss in ignition test will be used to measure the void content in reinforced fiber according to the ASTM standard D2584. The void content value for each specimen is calculated using ASTM Standard D2734. The final result that is obtained from the experiment show that the Resin Infusion Process is not repeatable process based on the setup that has been done when *Sample 2* has lower void content percentage compared to *Sample 1*.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

One of the most efficient ways of reducing carbon dioxide release is the application of wind turbine system. Energy from wind turbine is regarded as the most clean, renewable and highly potential for large scale installation to cater increasing energy demand [1]. This has lead to development of composite in blade part design as well as its manufacturing process i.e. Resin Infusion Process. This technique use material such as carbon fiber fabric and fiberglass, along with resin, epoxies and vinyl ester in order to laminate the material together with a vacuum bag operation. The advantages of this technique are high quality and high mechanical strength of composite products can be produced with less manufacturing cost.In typical vacuum infusion process (VIP), a dry reinforcement will be placed in an open mold. To avoid any leakage during sucking process, a laminate bag is laid onto reinforcement and sealed. Then, the vacuum will be use in order to pull the resin into the lamination section. Once the complete vacuum is achieved, the resin will be sucked into the laminate through the inlet pipe and distributed through the composite material. As the penetration process goes on, the remaining resin will be sucked by the pump and will send it to the outlet basin. The process will continue until the complete infusion is obtained. The result of this process is the reinforced composite material with higher mechanical strength

Basically, this is a manufacturing technique that is suitable for large load carrying composite and sandwich structure such as marine vessels, cooling trailers, hull of boats and etc [2]. However, producing a successful part using Resin Infusion Process can be very challenging due to complex geometry and predicting the flow front through mold is also a difficult problem [3]. Although the Resin Infusion Process is common, there is little evidence that the quality of the material that has been produced is reproducible. Hence, it is important to know whether the Resin Infusion Process is a repeatable process or not. The property of interest in this project is the void content. Voids are formed mostly 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 polymer matrix[4].

1.2 Problem Statement

Although the Resin Infusion Process is common, there is little evidence that the quality of the material that has been produced is reproducible. Hence, it is important to know whether the Resin Infusion Process is a repeatable process or not. So, this project will be done in order to investigate this.

1.3 Objective and Scope of the Study

1.3.1 Objective

The objectives of this project are:

1. To investigate the repeatability of Resin Infusion Process with respect to the property of composite product. The value of interest in this project is void content.
2. To map the void distribution in each blade manufactured

1.3.2 Scope of Study

The scope of this study is based on wind turbine blade polymer composite manufactured by using resin infusion technique. The base material of the wind turbine blade is made from wood and it is laminated with glass fibres reinforce plastic. In this process, the resin used were the mixture of vinyl-ester, methyl ethyl ketone peroxides (mekp) and cobalt. In this project, the blade will be fabricated by using the trailing to leading edge method, this process will be repeated so that the properties of infusion such as void content can be calculated and compared. Then, the result was analyzed covers from root to tip view, trailing edge to leading edge view and the mapping of void content in order to see the distribution of void content.

CHAPTER 2

LITERATURE REVIEW

2.1 Resin Infusion Process

There are several methods that are popular in operating the resin infusion, some of them are Resin Transfer Moulding (RTM), SCRIMPT, resin infusion by flexible tooling (RIFT), and vacuum assisted transfer moulding (VARTM) and resin film infusion (RFI). All of the method that is highlighted apply the same basic principle but not limited to tooling and size of application.In this project, Resin Infusion Process is used to fabricate polymer composite wind turbine blade [5].

Pressure is applied to the laminate once laid up. A plastic film or also called the vacuum bag is sealed over the wet laid up laminate and the tool. The air under the bag is sucked by the vacuum pump and this will make the resin flow through the mould and impregnates the glass fiber and core. Once the reinforcement is completely infused, it is left to specific temperature to be cured. The bag is then removed and the end product is taken out for further processing .This improvement provides a significant clean and healthy working environment over the conventional hand lay-up method, the high quality laminate also can be produced and large object can be infused with a minimum workforce.

Figure 2.1 below show the arrangement done during the Resin Infusion Process [6].

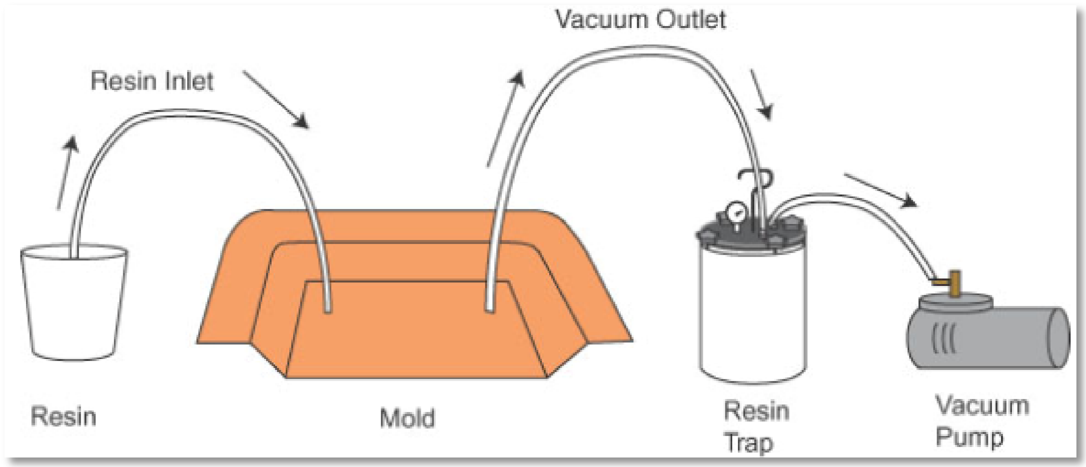

***Figure 2.1**: Sequence of vacuum infusion*

Resin Infusion Process is governed by Darcy's Law. The time needed to fill a cavity is described in this law. Darcy Law can be simplified to this equation as shown below [7].

$$\text{Fill time} = \frac{\mu\, x^2}{K\, \Delta P} \qquad \text{(eq. 1)}$$

Where:

μ = viscosity

x^2 = flow length

K = permeability

ΔP =Pressure difference

2.2 Resin Infusion Strategies

The resin infusion technique operates by flowing resin from inlet to outlet across the interest area which is the wind turbine blade and glass fiber. This process can be conducted in various strategies and each strategy has different influence to the quality of the wind turbine blade [5]. The term infusion strategy refers to the type of the inlet and outlet ports and their arrangement combination to achieve the best quality laminate and to reduce infusion time. There are two type of infusion strategies which is point feed type and line feed type.

Point feed type is a simple feed type. The end of a hose will connected straight to material. Because of it only has one exit for resin flow out, it has tendency to develop angular progression which is led to macro void formation. Figure 2.2 below show the example of point feed flow on perform [7].

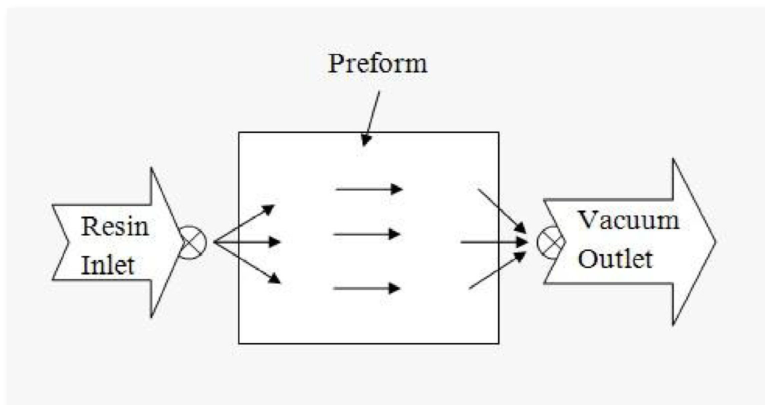

***Figure 2.2**: Point feed type flow on perform* [7]

For line feed, spiral tubing is the main factor in order to extend the point where the resin entered the mold. Line of spiral tubing 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. Figure 2.3 below show the example of line feed flow on perform [7].

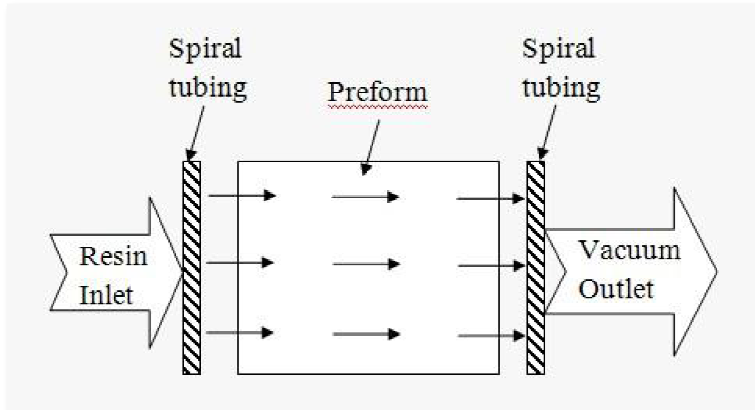

***Figure 2.3**: Line feed type flow on perform* [7]

Each strategy that is used may bring the different in the result that is obtained. For this project, only line feed type was used. By using Resin Infusion Process, the formation of void is unavoidable fact and each strategy produce different inclusion of the void. Void formation can happened when air is trapped during the formulation of the resin system, in resin rich areas, and due to moisture absorbed during the material storing and processing [2].

2.3 Void Content

Voids are generally seen as air bubbles trapped during a composite fabrication. It is one of the common types of defect that must be look after. Void content measure the void in the reinforced polymers and composite. Theoretically, if the value of the void content in the composite is high, the strength of that composite will be reduced. This statement can be proof on some research on influence of voids on inter laminar shear strength of carbon/epoxy fabric laminates by Zhu Hong- yan et al [8]. In this research, they have found that, the void shape, size and location are important in influencing whether or not a crack emanates from a void. The stacking sequence affect the void shape and size and in turn influence the effect of voids on the mechanical behavior of composite laminar.

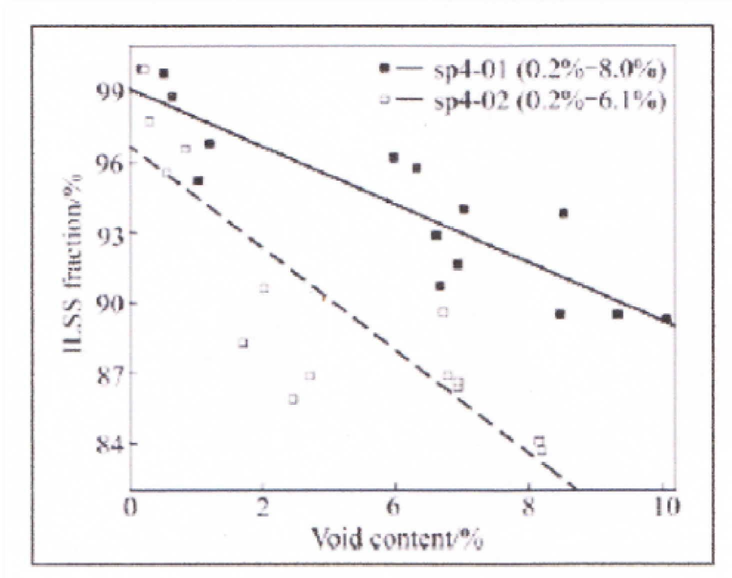

Figure 2.4: ILSS fraction vs Void Content

So, it is very important to get the information on the void content. According to the ASTM standard, there are two ways to measure the void content which are acid digestion method and loss on ignition method. For this project, only one method will be used to measure the void which is loss on ignition method.

2.4 Repeatability Test

One important aspect of experimental studies is their repeatability. Repeatability is a property that allows experimental studies to be repeated and the results reproduced .Repeatability has two functions which are [9]:

(i) To make makes experimental results available for comparison with other research

(ii) Guarantees the consistency of experimental results

In this project, repeatability test is done in order to investigate how repeatable is the Resin Infusion Process of wind turbine blade. Although Resin Infusion Process always has been performed with the same methodology and concept, but until now, there is little research that has been established to prove that the resin infusion is a repeatable process.

CHAPTER 3

METHODOLOGY

3.1 Materials and Equipments

The equipment that were used in this project are listed in Table 1 below

MATERIALS/ EQUIPMENTS	DETAILS
Wind turbine blade polymer composite	To test the property of void content
Stationary	a. Cutter b. Ruler c. Marker
Vernier caliper	To measure the thickness of the wind turbine blade polymer composite
Electrical balancer	To measure the weight of the specimen
Linear abrasive cutter machine	To cut the wind turbine blade into specimens
Rotating abrasive cutter machine	To cut the polymer composite to the desired dimension
Furnace	To burn the specimen to the required heat needed for loss ignition tes
Resin infusion equipment	a. Vacuum pump b. Resin storage and resin trap c. Plastic bag d. Sealant tape e. Net

	f. Degassing Chamber
	g. Peel ply
Reinforcement	E-glass fiber
Polymer resin	Vinyl Easter

Below are the images (Fig 3.1- Fig 3.12) of some equipment that were used in this project:

Fig 3.1 Wind turbine blade

Fig 3.2 Furnace

Fig 3.3 Glass Fiber

Fig 3.4 Vernier Caliper

Fig 3.5 Pump

Fig 3.6 Net

Fig 3.7 Electrical Balancer

Fig 3.8 Degassing Chamber

Fig 3.9 Crucible

Fig 3.10 Rotating Abrasive Cutter

Fig 3.11 Peel Ply

Fig 3.12 Bunsen burner

3.2 Process Work Flow

Figure 3.13 below show the process work flow that need to be done in order to finish the project.

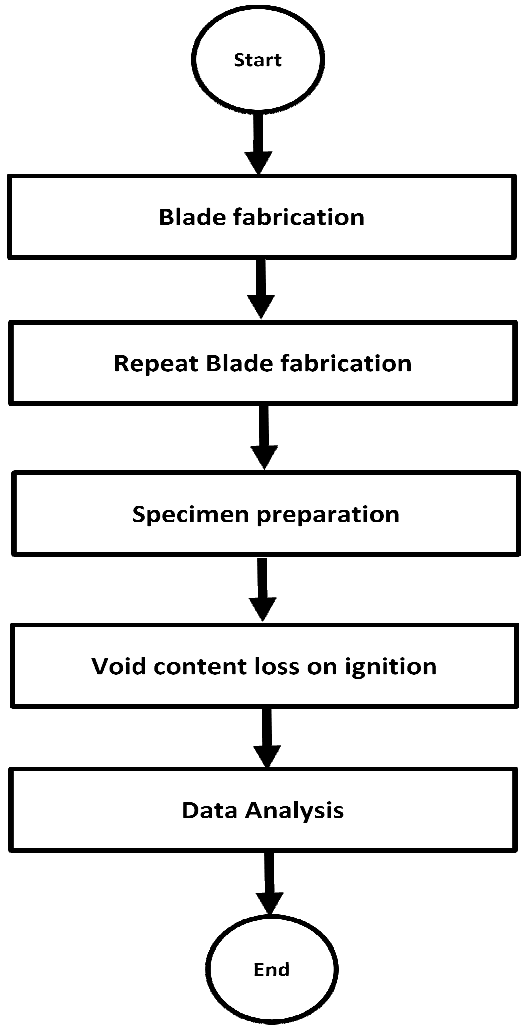

Figure 3.13*: Process work flow for the project*

3.2.1 Blade Fabrication

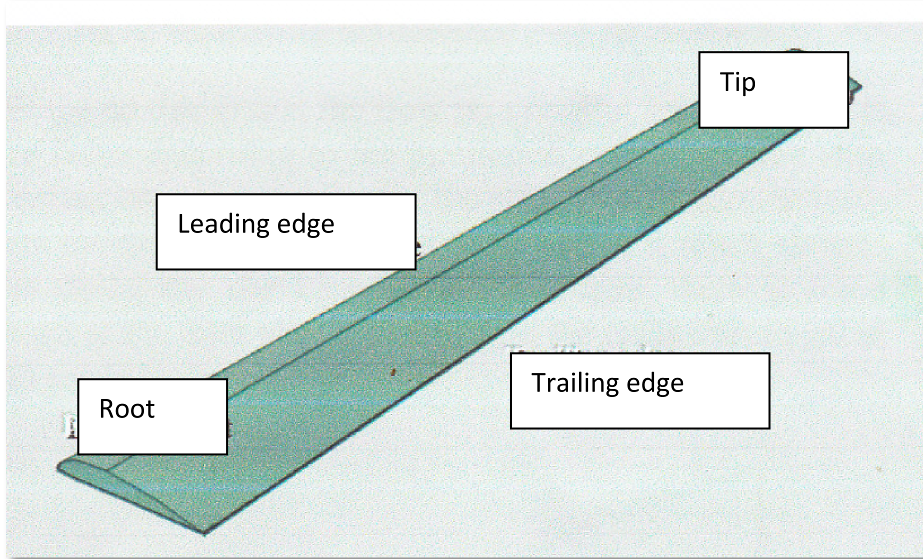

Figure 3.14: *Design of the blade used*

Based on the Figure 3.14 above, wind turbine blade can be classified into 4 portions which are leading edge, trailing edge, and root and also tip. The blade that is used in this project has some curved surface on the upper side of the blade as shown in the figure 3.15 below. In this project, the wooden wind turbine blade was laminated by eight layers of glass fibers.

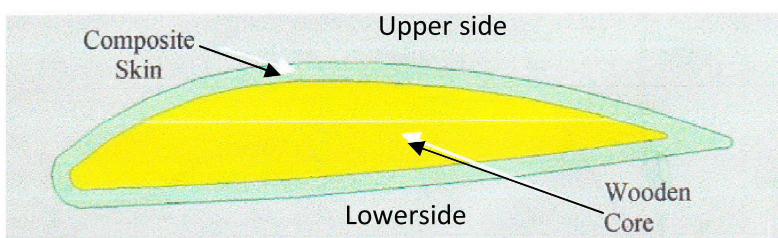

Figure 3.15: *Blade cross section*

The composite materials used as the skin of the wind turbine blade are, woven mat glass fibre with $0^{o}/90^{o}$ of weft/kerb direction with the density 2.54 g/cm^3. The resin that was used is vinyl ester with the density of 1.24 g/cm^3.The vinyl ester was mixed with methyl ethyl ketone peroxides (mekp) by 100:1 ratios with addition 0.1% of cobalt.

The blade then manufactured using the method from trailing edge to leading edge. For this method, the spiral tubes were assembled both at the leading edge and trailing edge. Tube at the trailing edge acted to channel the resin to enter to the mold (blade). Tube at the leading edge will connect with the vacuum to suck out all the air in the mold that is sealed with the peel ply. Figure 3.16 below show the example of resin flow [6].

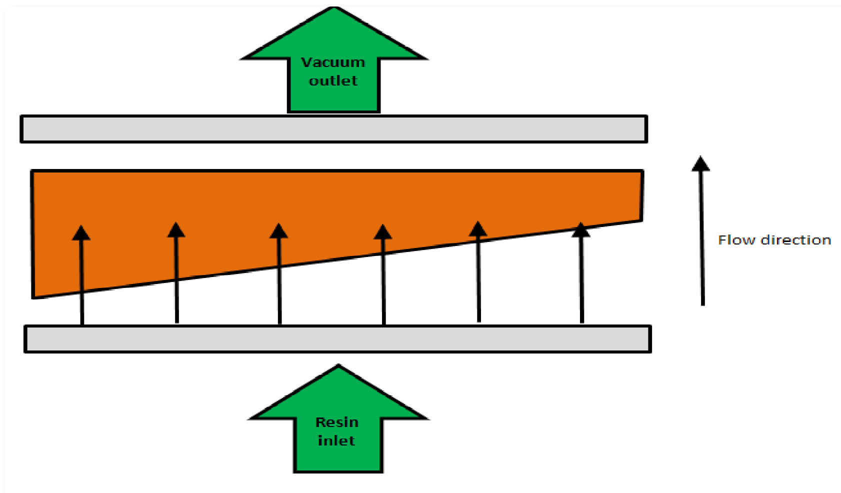

***Figure 3.16**: Line feed type, trailing edge to leading edge*

After all the remaining resin was suck out by the vacuum, the blade was left about one day for the curing process. The completed product of Resin Infusion Process can be seen on this Figure 3.17 below.

***Figure 3.17**: Final product of resin infusion process*

3.2.2 Repeat Blade Fabrication

After processes of infusion strategy which is line feed type: leading edge to trailing edge was done, the process was repeated for the repeatability test. For this project, two blades were fabricated. Repeatability test was done in order to investigate how repeatable is the Resin Infusion Process of wind turbine blade. This repeatable process will analyses the void content for each blade and compares it with another blade that was fabricated from the same process. As an example, for the blade that was done first was named as *Sample 1* and for the repeatable process of the blade was named as *Sample 2*. Both of these blades were compared in order to know the repeatability of the Resin Infusion Process.

3.2.3 Specimen Preparation

Specimen is a portion of material that was used in the testing. For this project, the wind turbine blade polymer composite was divided into 9 column X 5 row. The column started from column 1 which is from root until at the end of the tip at column 9. For the row, it was divided into 5 parts which is labeled (A,a,B,b,C). Row A was at leading area whereas Row C was at trailing area. For each wind turbine blade, a total of 54 specimens were taken. 27 are from upper side and another 27 are from lower side.

This project requires fabricating 2 wind turbine blade. The totals of 108 specimens have been analyzed to complete this project. Figure 3.18 below show the division of wind turbine blade.

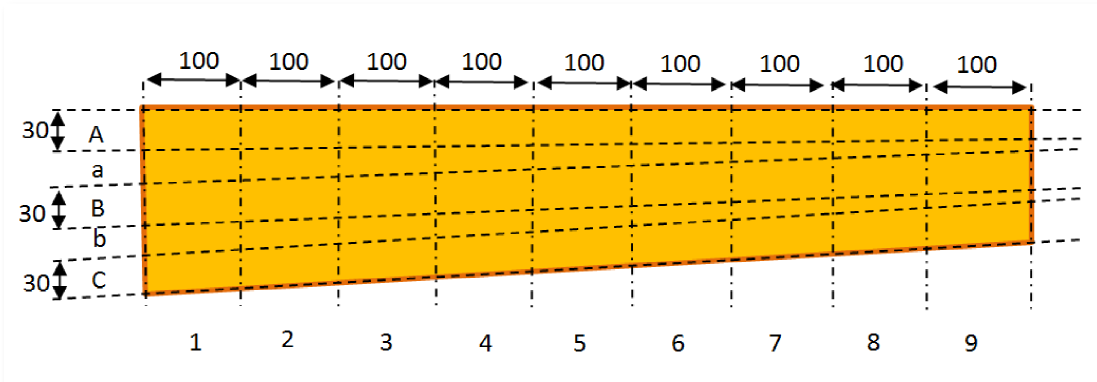

***Figure 3.18**: Division of blade*

To prepare the specimen, the lines were sketched on the wind turbine blade polymer according to Figure 3.18. Then, the blades were cut according to the line that has been sketched using the linear abrasive cutter machine. Each piece will be labeled according to its position. Figure 3.19 below show the actual view of the blade after cut using the linear abrasive cutter.

***Figure 3.19**: Blade after cutting process*

Next, the polymer composite will be split from wood by using rotating abrasive cutter machine for each block. The dimension of the required specimen is 25mm X 25mm. Then, the woods were peeled from fiber glass by using cutter. (Refer appendix 4.1)

3.2.4 Loss Ignition Test

According to the standard ASTM D2584 [11], for the loss ignition test method, the samples from the fabrication part were cut into specimen with the dimension of 25mm x 25mm. Then, weight (m1) and density of every specimen were measured. A crucible need to be heated in the furnace at the heat around 500-600°C for 10 minutes. Then the crucible was cooled and weighted (m2). The specimen was placed inside the crucible and heated by using the Bunsen. The crucible was heated inside a furnace at 565°C for 40 minute. After cooled, the crucible was weighted (m3) [2].

Figure 3.18 below shows the specimen tested using loss ignition test.

(a) (b) (c)

Figure 3.20*: Sequence of the specimen while tested in loss ignition process. (a) Before burning (b) After burned using Bunsen (c) Complete burning process in furnace*

3.2.5 Data Analysis

Data analysis needs to be done in order to measure the void content and analysis of each sample. The void content analysis was performed according to the standard test method ASTM D2734 [10]. First, the densities of each composite, resin and fiber need to be measured. Then, resin content of composite is measured by using the value that was gained from loss ignition test and the theoretical composite density was calculated. The difference between theoretical and measured density of composite will show the result of the void content [4]. Finally, after all the result has been obtained, compare the result with the repeated blade. The result will show either the Resin Infusion Process is repeatable or not. The calculations involved are:

i. Calculation for measured density

Desnsity, $\rho = \frac{A}{A-B}(\rho_o - \rho_L) + \rho_L$ (Eq. 2)

Where:

A = Mass on air,g

B = Mass in water,g

$\rho_o = density\ of\ distilled\ water$

$\rho_L = air\ density\ = 0.0012 g/cm^3$

ii. Calculation for resin and fiber content

$Rwt = \frac{(m1+m2)-m3}{m1} X\ 100$ (Eq. 3)

$Fwt = 100 - Rwt$ (Eq.4)

Where:

Rwt = weight percent of resin, %w

Fwt = weight percent of fiber, %w

m1 = weight of specimen, g

m2 = weight of crucible, g

m3= weight of crucible + residue, g

iii. Calculation for void content

$$Td = \frac{100}{\frac{Rwt}{D} + \frac{Fwt}{d}} \quad \text{(Eq. 5)}$$

$$V = \frac{Td - Md}{Td} X\ 100 \quad \text{(Eq.6)}$$

Where:

Td = theoretical composite density

Md = Measured composite density

Fwt = Fiber weight, %

d = density of fiber

V = Void content (volume %)

Rwt = Resin Weight %

D = Density of resin

CHAPTER 4

RESULT & DISCUSSION

4.1 Void Comparison from Root to Tip

Two polymer composite wind turbine has been fabricated. Void content and its distribution are then calculated using the specimen's weight and density. The average void content of the two blade samples are calculated. Comparisons between two samples are shown in the figure 4.1 and 4.2 below.

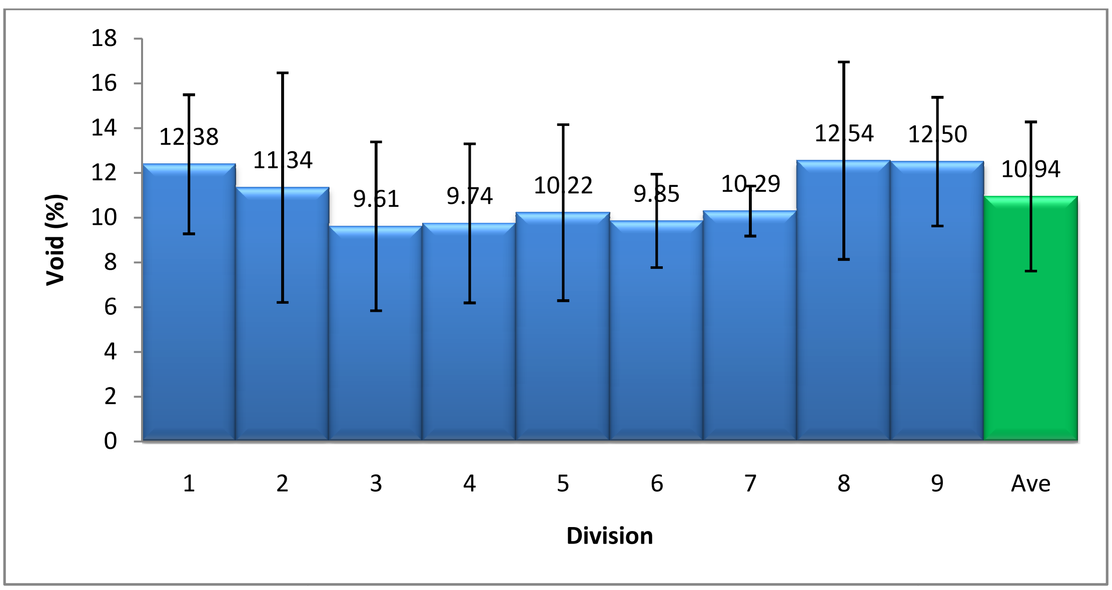

Figure 4.1: *Void content in percentage for Sample 1 (Upper side)*

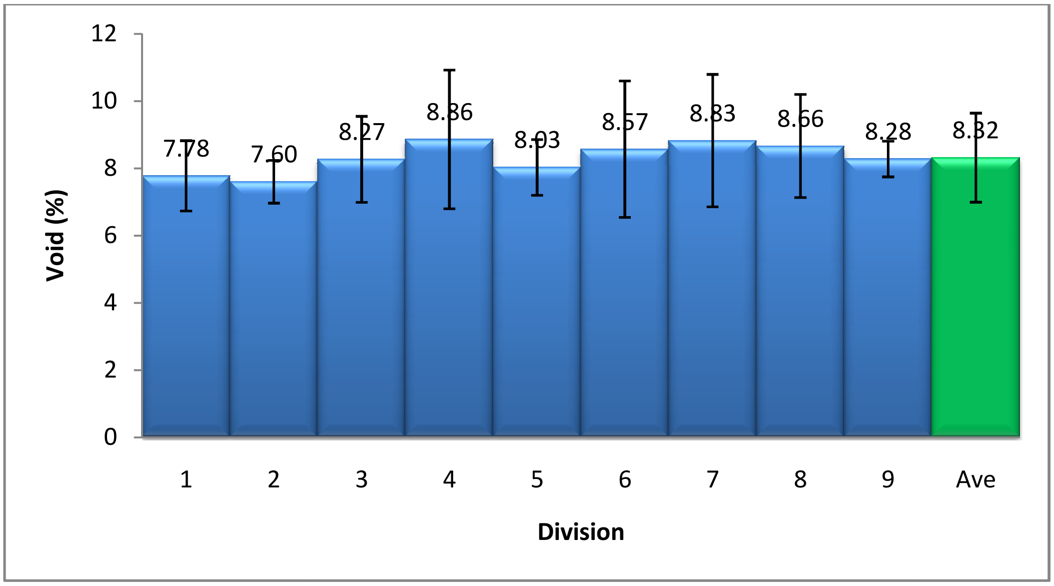

Figure 4.2: *Void content in percentage for Sample 2 (Upper side)*

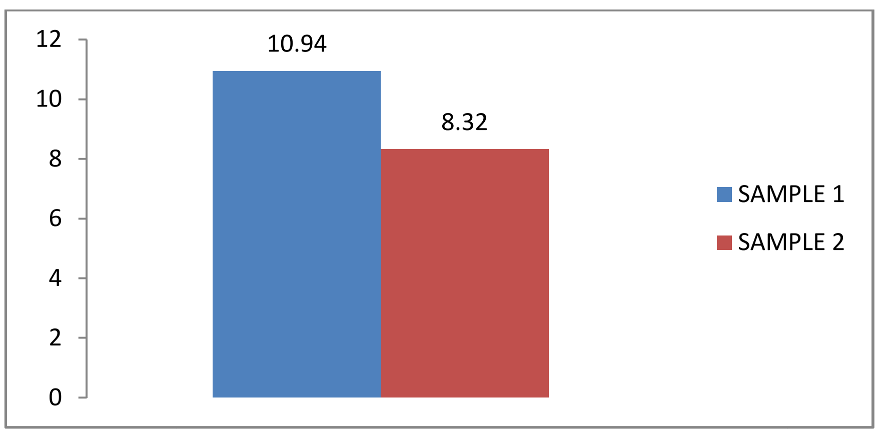

Figure 4.3: *Average of void content in percentage for Sample 1 & Sample 2 (Upper side)*

Figure 4.1 and 4.2 shows the relation between the void content in the upper side of the two blades. For this analysis, the comparison is made from root to tip point of view (upper side).

Based on the figure 4.3 above, the average of void content for these two samples is not same. For the *Sample 1*, the average for void content is 10.94%. But for the *Sample 2*, the average of void content is lower with only 8.32%. The distribution of void in each block also different when for the *Sample 1*, the void is higher at the left (root) side and right (tip) side. But, for the *Sample 2*, the distribution of void is higher at the middle area.

Based on the average void content on both samples, *Sample 2* has lower average void content compared to *Sample 1*.The void distributions for the 9 division in root to tip direction (upper side) between two samples are not showing same distribution of void. The void distribution is not repeatable for this analysis point of view.

For the lower side of void content, the comparison between two samples are shown in the figure 4.4 and 4.5 below

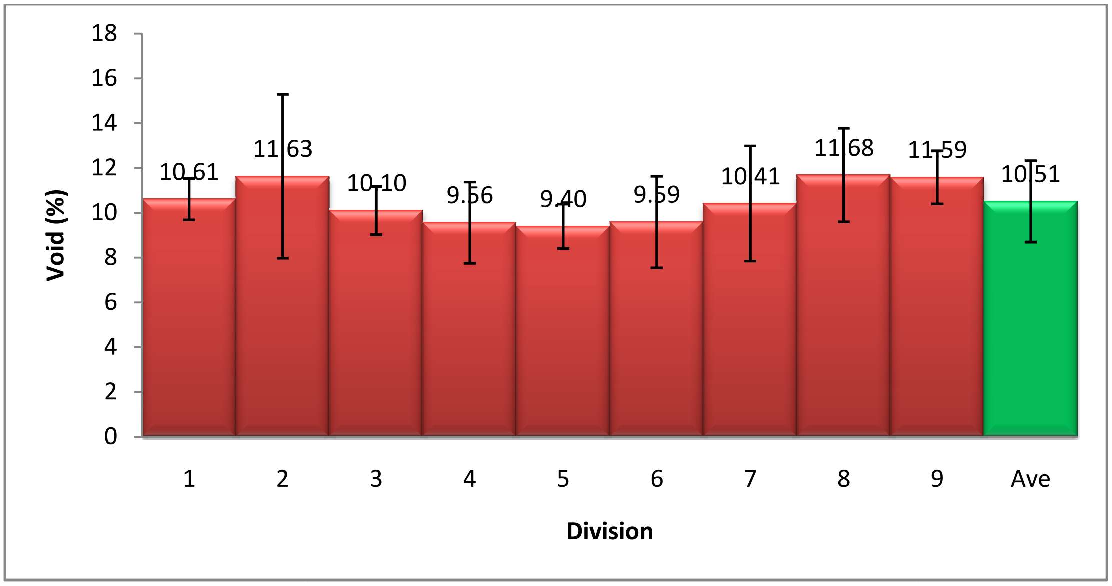

Figure 4.4: *Void content in percentage for Sample 1 (Lower side)*

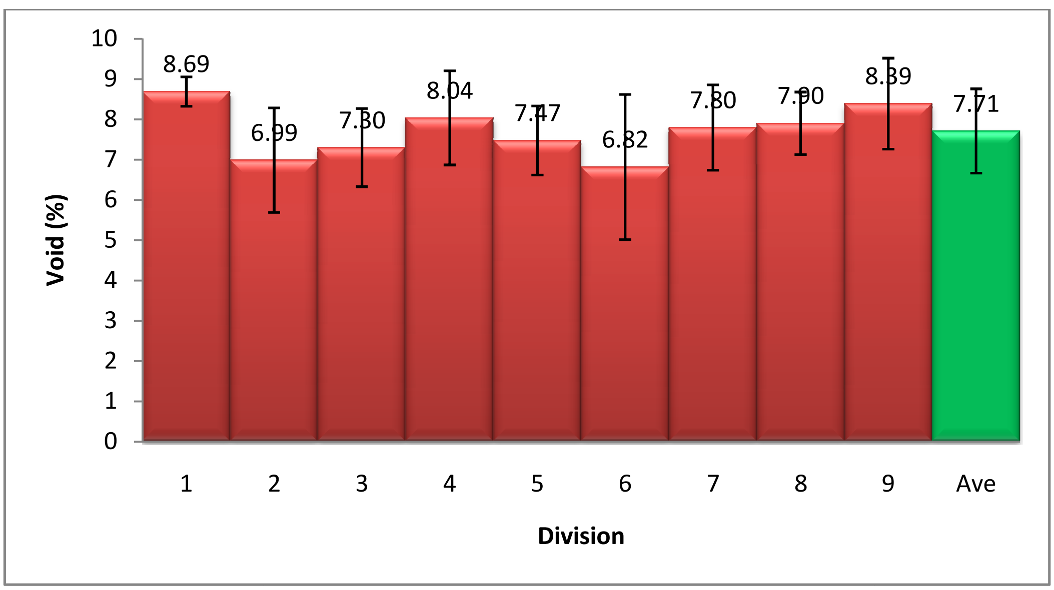

Figure 4.5: *Void content in percentage for Sample 2 (Lower side)*

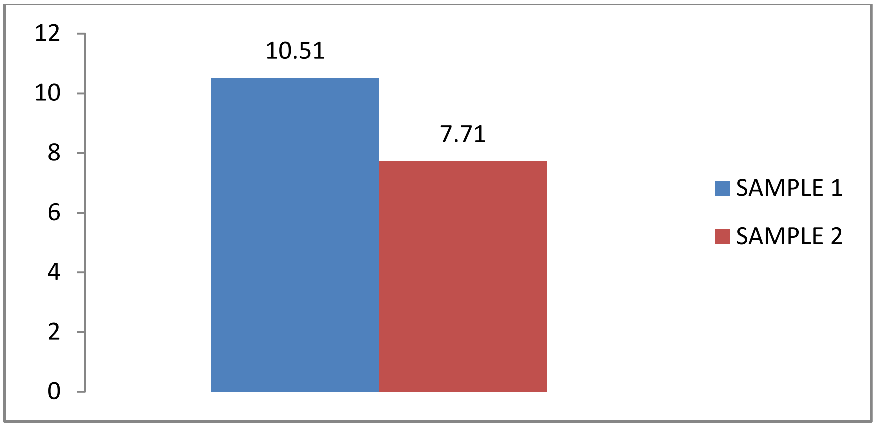

Figure 4.6: *Average of void content in percentage for Sample 1 & Sample 2 (Lower side)*

Figure 4.4 and 4.5 shows the relation between the void content in the lower side of the two blades. For this analysis, the comparison is made from root to tip point of view (lower side).

. For the comparison between these two samples, the average of void content for these two samples is not same. Based on the figure 4.6, for the *Sample 1*, the average for void content is 10.51%. But for the *Sample 2*, the average of void content is lower with only 7.71%. The distribution of void in each block also different when for the *Sample 1*, the void is higher at the left (root) side and right (tip) side. But, for the *Sample 2*, the distribution of void is higher at the left, middle and the right side.

Based on the average void content on both samples, *Sample 2* has lower average void content compared to *Sample 1*.The void distributions for the 9 division in root to tip direction (lower side) between two samples are not showing same distribution of void. The void distribution is not repeatable for this analysis point of view.

4.2 Void Comparison from Trailing Edge to Leading Edge

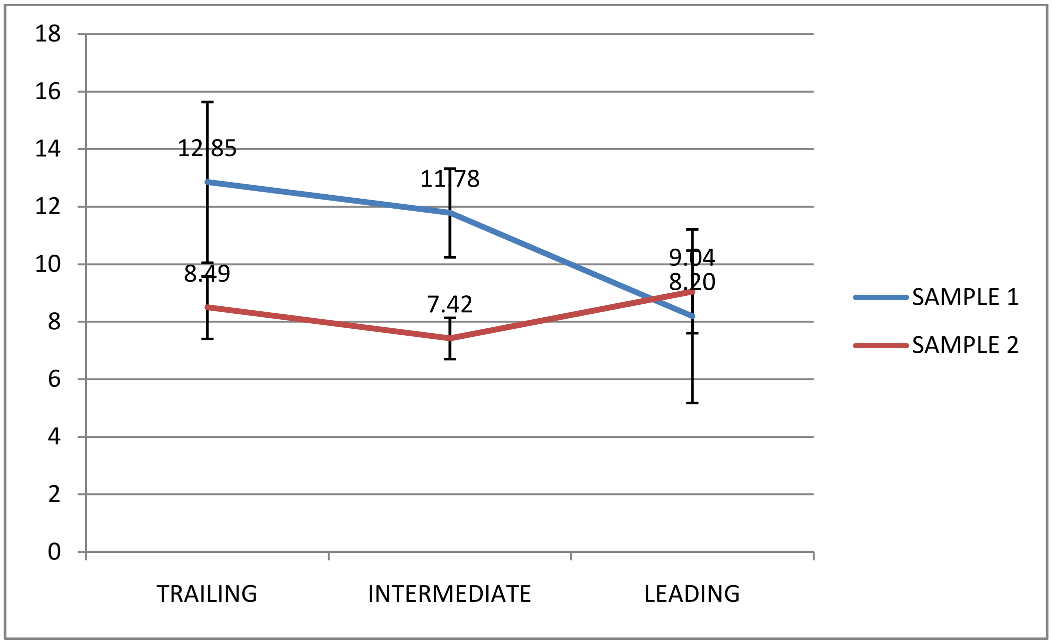

Figure 4.7: *Average void content in trailing, intersection and leading edge for upper side*

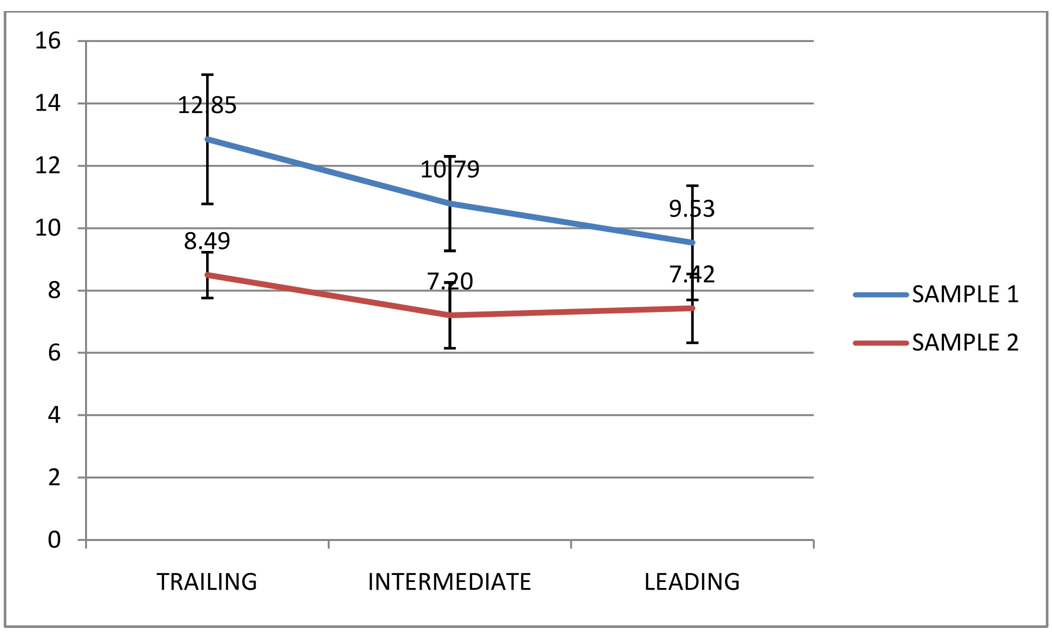

Figure 4.8: *Average void content in trailing, intersection and leading edge for lower side*

. Figure 4.7 and 4.8 shows the relation between the void content in trailing edge, intermediate area and leading edge for upper and lower side of the blade. For this analysis, the comparison is made based on three different major areas which are trailing edge (inlet of resin), intermediate area (middle) and leading edge (outlet of resin). The leading edge covers the section A area while intermediate and trailing edge cover section B and section C respectively.

For the upper side of the blade analysis, blade for *Sample 1* has higher void percentage at the inlet (trailing edge) compared to the *Sample 2* which are 12.85% and 8.49% respectively. At the intermediate area, both *Sample 1* and *Sample 2* show the decreasing of void percentage with *Sample 1* has 11.78% and *Sample 2* has 7.42% of void content. But, at the outlet area which is leading edge, sample 1 has lower void content compared to *Sample 2* when *Sample 1* has 8.20% and *Sample 2* has 9.04%.

For the lower side of the blade analysis, blade for *Sample 1* has higher void percentage at the inlet (trailing edge) compared to the *Sample 2* which are 12.85% and 8.49% respectively. At the intermediate area, both *Sample 1* and *Sample 2* show the decreasing of void percentage with *Sample 1* has 10.79% and *Sample 2* has 7.20% of void content. At the outlet area which is leading edge, *Sample 1* show the decreasing of void content with 9.53%. But, *Sample 2* shows some increment of void content at the outlet area with 7.42%.

The void distribution for the three different major areas which are trailing edge (inlet of resin), intermediate area (middle) and leading edge (outlet of resin) between two sample not showing the same distribution of void. The void distribution is not repeatable for this analysis point of view.

4.3 Mapping Void Content from Trailing Edge to Leading Edge

Figure 4.9 and 4.10 shows the mapping of void content distribution for upper side of *Sample 1* and *Sample 2* of a resin infused wind turbine blade polymer composite over distance for a single blade.

The mapping of void in *Sample 1* shows that the void content is higher at the trailing edge (inlet), when there are two spot have the red area (14% -18%) of void content. Most of the yellow areas are at the middle with (10% -14%) of void content. The green area visible at the leading edge showing that the void content is lower at this area with only 6%-10% of void content.

For the *Sample 2*, there are two main colours which are green and light green. So, the percent of the void for this blade is about from 6% to 10%. For this sample, the void distribution is higher at the outlet side when there are some areas that have yellow colour showing that the void content in that area is about 10%-12%.

From the figure 4.9 and 4.10 that are shown below, it is clear that the void distribution at the upper side is not constant. For *Sample 1*, the range of void is from 6%-18% whereas for *Sample 2* the percent of void only range from 6% to 12%. The void distributions are not same and prove that Resin Infusion Process is unrepeatable.

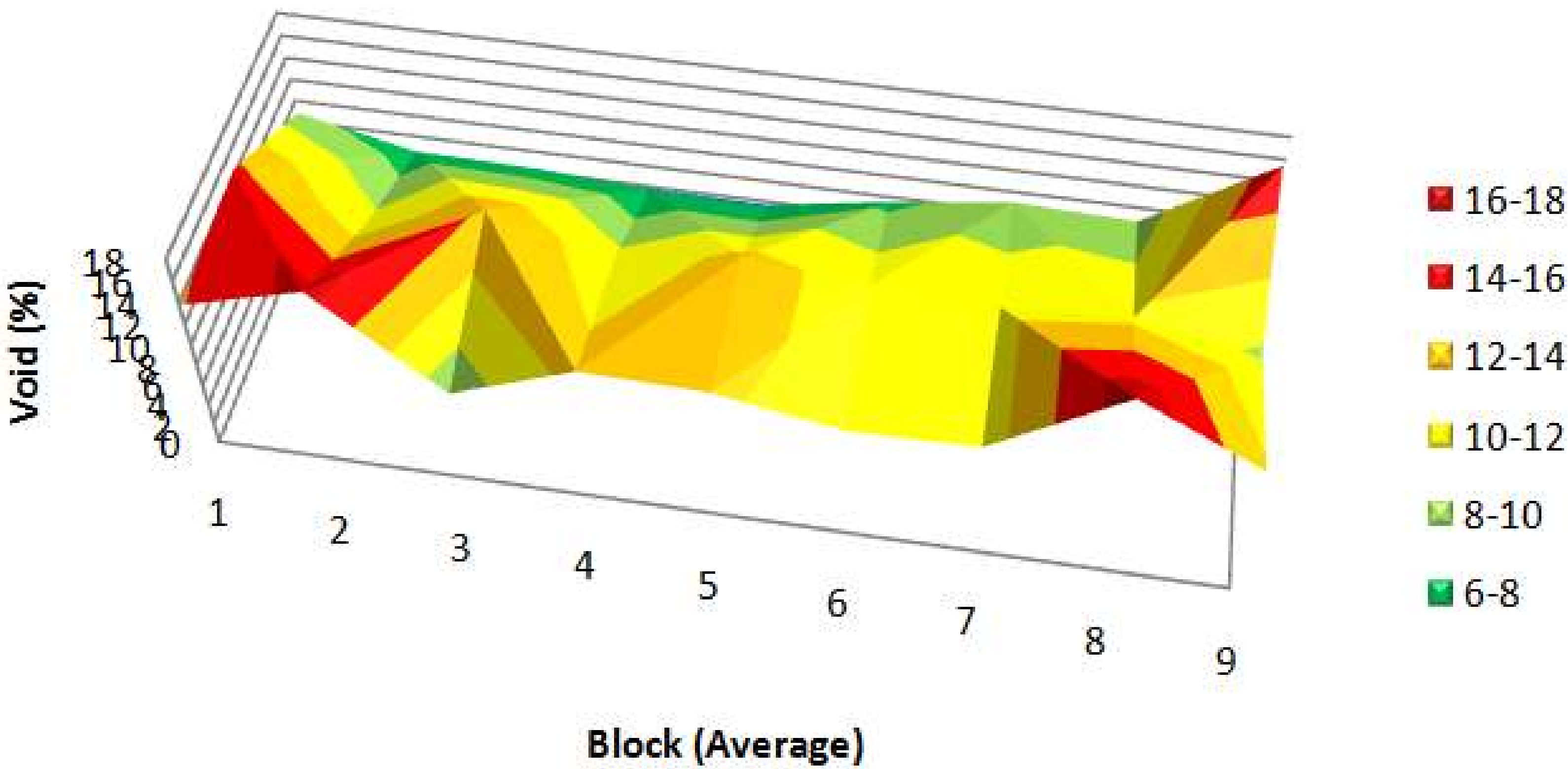

Figure 4.9: Void mapping (upper side) sample 1

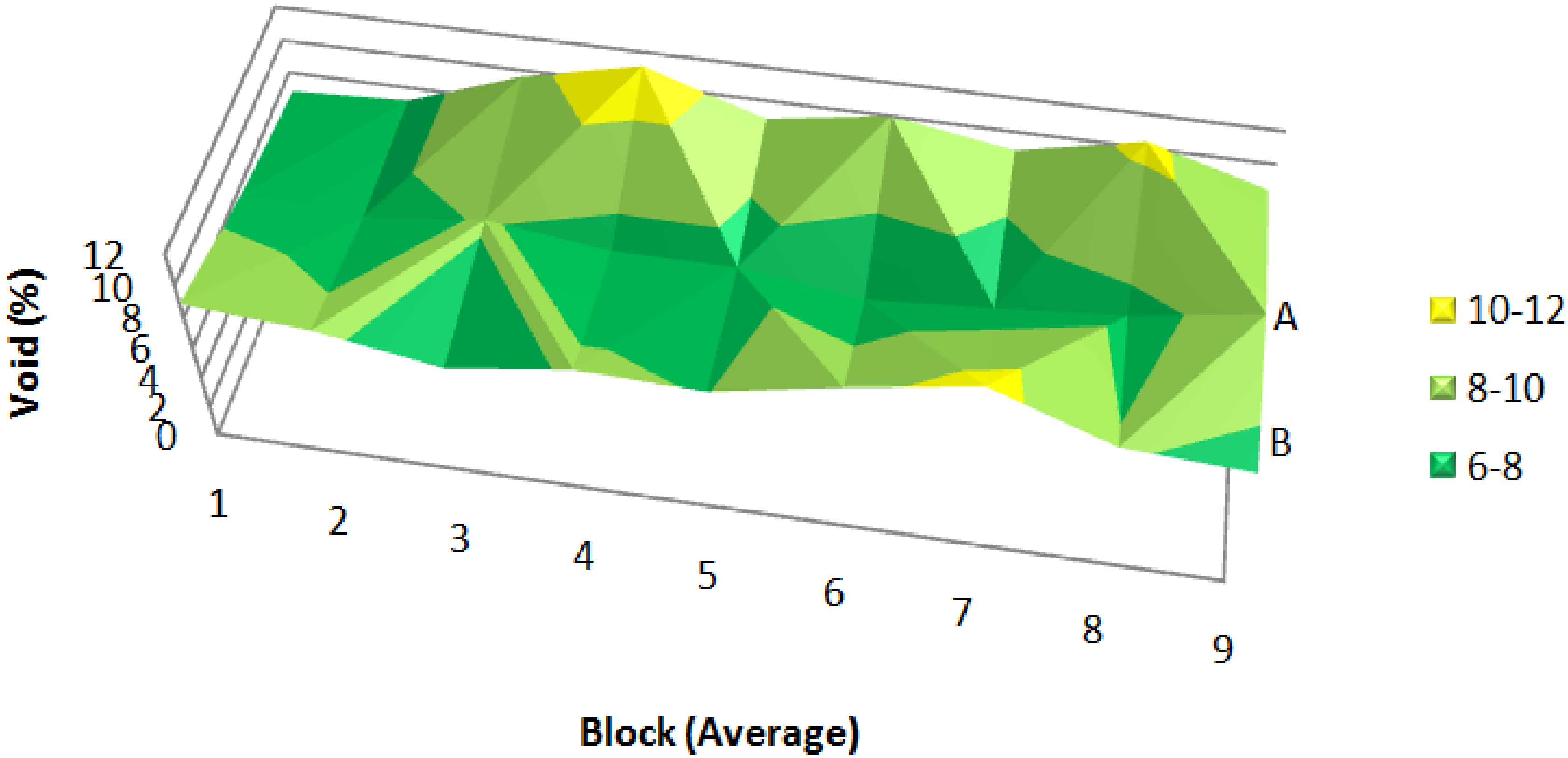

Figure 4.10: Void mapping (upper side) sample 2

Figure 4.11 and 4.12 shows the mapping of void content distribution for lower side of *Sample 1* and *Sample 2* of a resin infused wind turbine blade polymer composite over distance for a single blade.

The mapping of void in *Sample 1* shows that the void content is higher at the trailing edge (inlet) and tip area, when there are red and yellow colours in that area. The void content in that area is from 10% to 16%. At intermediate area, green colour is visible and showing that at this part has lowest void content with 6%-10%

For the *Sample 2*, there are two main colours which are green and light green. The percent of the void for this blade is range from 6% to 10%. For this sample, the void distribution is higher at the inlet side compared to the outlet side. There is one area at the middle that has the light blue showing that the percent of void in that area is about 4%-6%.

From the figure 4.11 and 4.12 that are shown below, the percent of void at each sample is different. For *Sample 1*, the range of void is from 6%-16% whereas for *Sample 2* the percent of void only range from 4% to 10%. The void distributions are not same and prove that Resin Infusion Process is unrepeatable process.

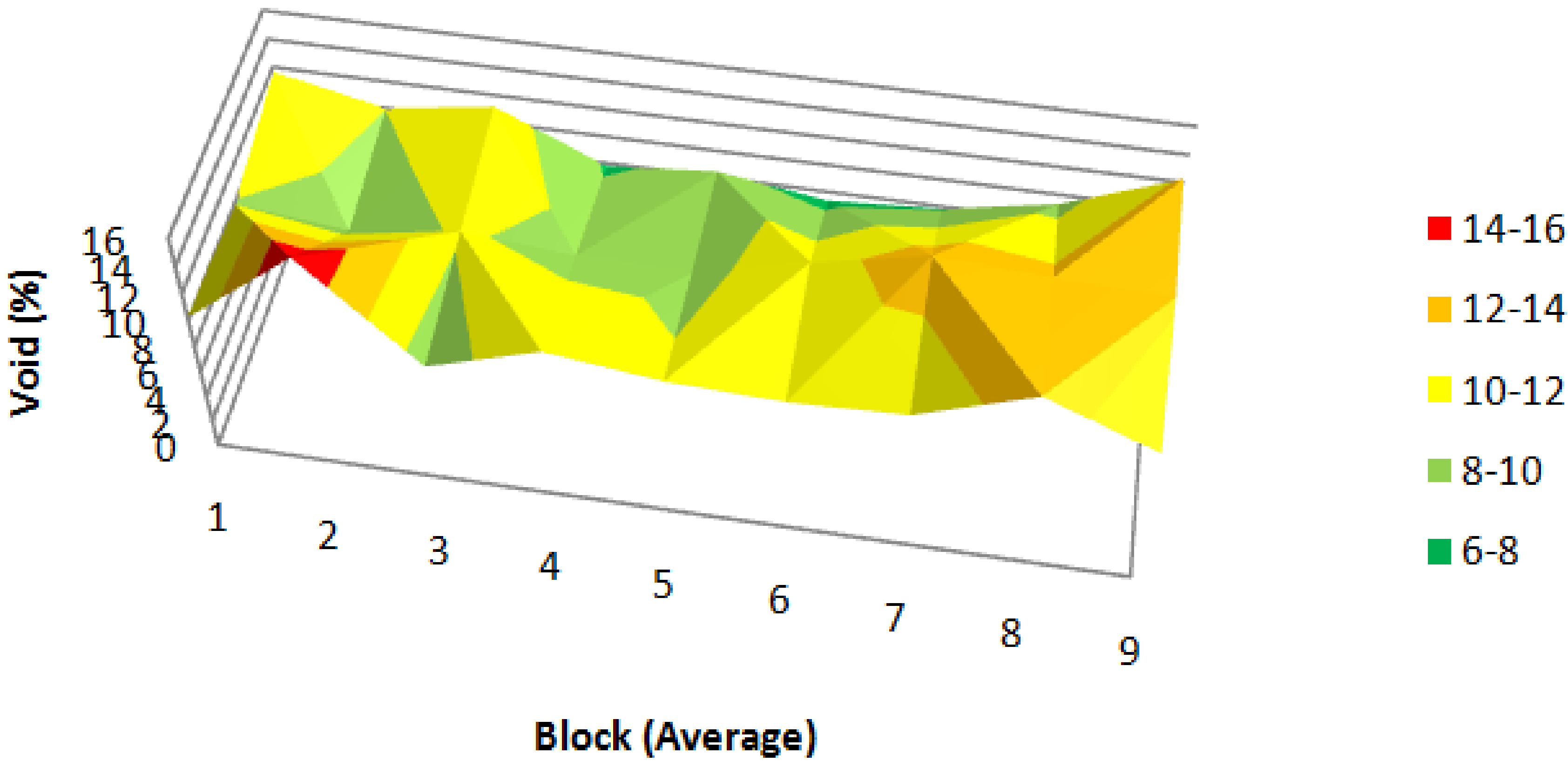

Figure 4.11: Void mapping (lower side) sample 1

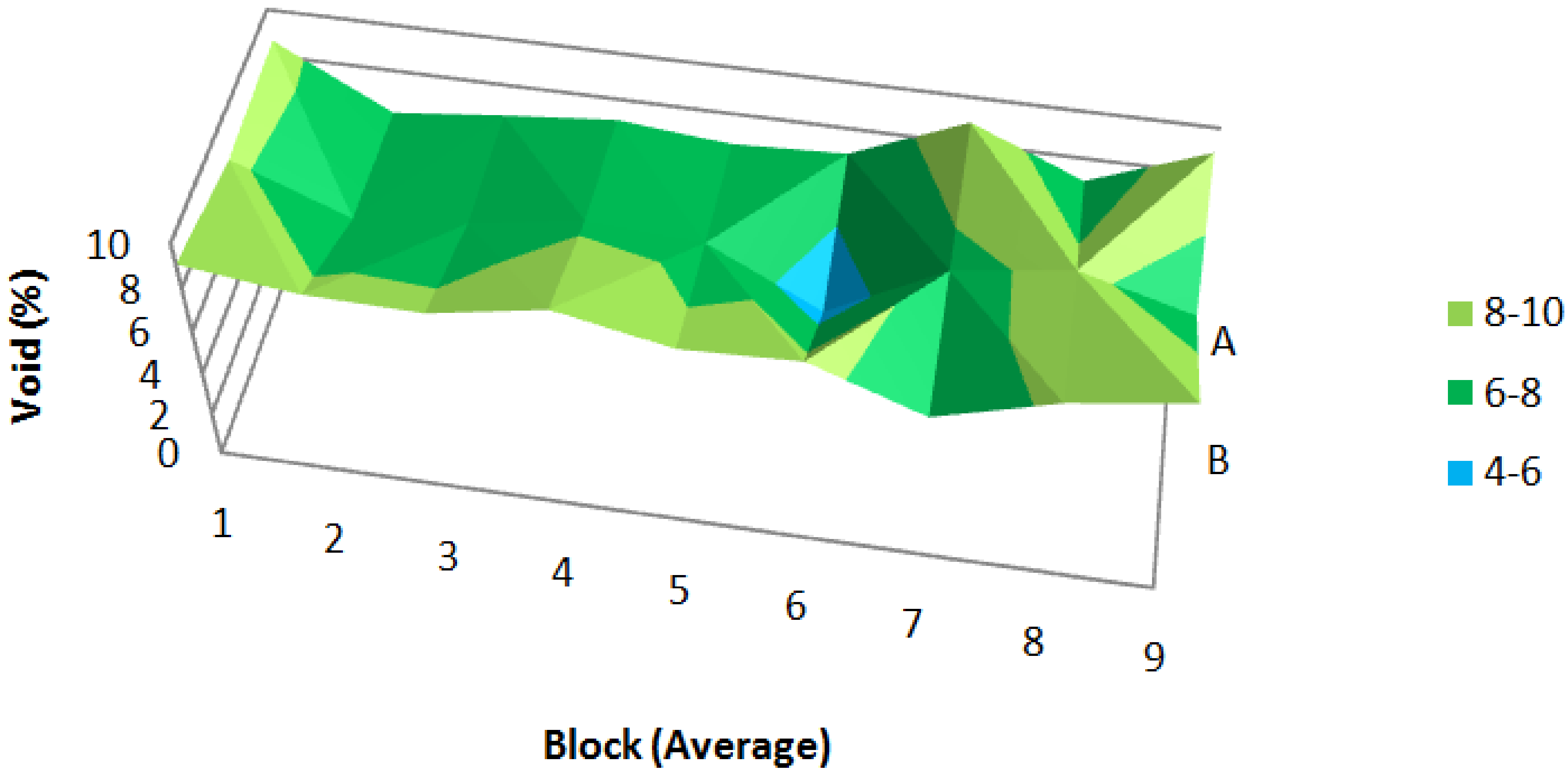

Figure 4.12: Void mapping (lower side) sample 2

CHAPTER 5

CONCLUSION & RECOMMENDATIONS

5.1 Conclusion

Repeatability is very essential in the manufacturing the product. The higher repeatability of the process, the more reliable is the product. This is because the quality of the product is always same as the previous manufactured. To study the repeatability of the product, one element will be the property of interest. That element is void content. By studying the characteristic of void content between two wind turbine blade polymers composite, which were made by same methodology, the result can be compared. According to the data that is obtained from the experiment, it can be concluded that the Resin Infusion Process is not a repeatable process since comparison between two samples not showing the consistent distribution of void based on the setup that has been done. The final result that is obtained from the experiment shows that the Resin Infusion Process is not repeatable process. *Sample 2* has lower void content percentage compared to *Sample 1*. The mapping for voids distribution for a single blade successfully created.

5.1 Recommendation

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

1. Degassing process should be done properly as it can affect the formation of the bubbles during infusion process
2. Make sure the dimension of the specimen is following the desired standard and measurement.
3. The duration of this project is very long. The fabrication of the wind turbine blade needs to be done during the FYP 1 semester.
4. Avoid the elimination of fiber glass during separation of wood as it can affect the weight and density of the specimen and affect the void content

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APPENDICES

APPENDIX 1-1

PROJECT PLANNING (GANTT CHART)

FYP 1 PROJECT GANTT CHART															
No	**Activities**	**Weeks**													
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Propose project title														
2	Project topic finalization														
3	Meeting with supervisor and team members														
4	Gather information from journals, research papers, articles														
5	Practice on how to perform resin infusion process		**Submission of Extended Proposal Defence**												
7	Proposal Defence														
8	Purchase and set up the infusion apparatus														
9	Fabricate the first blade using the first infusion strategies														
10	Mechanical testing preparation 1														
11	Submission of Interim Draft Report														
12	Submission of Interim Report														

APPENDIX 1-2

PROJECT PLANNING (GANTT CHART)

FYP 2 PROJECT GANTT CHART																	
No	**Activities**	**Weeks**															
		1	**2**	**3**	**4**	**5**	**6**	**7**		**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1	Run testing for all samples 1	→	→	→	→	→											
2	Fabricate the first blade using the second infusion strategies			→	→												
3	Mechanical testing preparation 2				→	→											
4	Run testing for all samples 2						→	→		→							
6	Analyzing data and result documentation									→	→	→	→	→	→	→	
7	Pre-EDX									△			→	→			
8	Submission of Progress Report																
9	Submission of Draft Report													△			
10	Submission of Technical Paper														△		
11	Oral Presentation															△	
12	Submission of Project Dissertation (hard bound																△

APPENDIX 2-1

SAMPLE 1 (VOID CONTENT TEMPLATE)

Section	Side	Width (mm)				Length (mm)				Thickness (mm)				Volume	Mass, m1	Mass on water, m2	Temp (T)	ρ0	Density, ρ(m)
		1	2	3	Ave	1	2	3	Ave	1	2	3	Ave	(mm3)	(g)	(g)			
1A	U	24.12	24.10	23.98	24.07	26.28	26.18	26.00	26.15	1.42	1.48	1.50	1.47	923.15	1.52238	0.62409	23.40	0.99747	1.68963
	L	24.42	24.34	24.26	24.34	26.16	26.38	26.50	26.35	1.48	1.48	1.48	1.48	949.09	1.51140	0.60399	23.40	0.99747	1.66061
1B	U	24.00	24.12	24.16	24.09	23.98	24.02	24.12	24.04	1.38	1.38	1.38	1.38	799.30	1.34172	0.51606	23.40	0.99747	1.62017
	L	24.24	24.32	24.28	24.28	24.12	24.24	24.40	24.25	1.50	1.48	1.46	1.48	871.53	1.43587	0.57850	23.40	0.99747	1.66969
1C	U	23.04	23.40	23.60	23.35	25.50	25.70	25.82	25.67	1.62	1.68	1.62	1.64	982.99	1.48234	0.54468	23.40	0.99747	1.57620
	L	22.00	22.42	22.70	22.37	25.78	25.70	25.50	25.66	1.40	1.40	1.40	1.40	803.74	1.40761	0.55798	23.40	0.99747	1.65175
2A	U	24.10	24.34	24.42	24.29	25.76	25.80	25.80	25.79	1.48	1.42	1.42	1.44	901.83	1.52980	0.64847	23.40	0.99747	1.73051
	L	24.90	24.84	24.78	24.84	26.00	26.08	26.14	26.07	1.38	1.38	1.46	1.41	911.04	1.53916	0.62996	23.40	0.99747	1.68776
2B	U	23.94	23.76	23.66	23.79	24.40	24.50	24.52	24.47	1.48	1.48	1.48	1.48	861.57	1.39125	0.55623	23.40	0.99747	1.66111
	L	24.00	24.02	24.12	24.05	24.62	24.62	24.52	24.59	1.48	1.52	1.42	1.47	871.08	1.47763	0.59155	23.40	0.99747	1.66258
2C	U	21.00	20.98	20.96	20.98	26.40	26.38	26.40	26.39	1.60	1.49	1.42	1.50	832.07	1.30810	0.47085	23.40	0.99747	1.55775
	L	20.00	20.00	20.00	20.00	26.48	26.26	26.48	26.41	1.36	1.28	1.38	1.34	707.70	1.27075	0.45788	23.40	0.99747	1.55866
3A	U	25.90	25.50	25.30	25.57	25.66	25.60	25.32	25.53	1.48	1.48	1.48	1.48	965.90	1.59080	0.67723	23.40	0.99747	1.73601
	L	25.94	25.98	26.18	26.03	25.72	25.70	25.40	25.61	1.52	1.46	1.50	1.49	995.50	1.58901	0.63324	23.40	0.99747	1.65754
3B	U	24.52	24.18	23.74	24.15	24.92	24.92	24.90	24.91	1.48	1.38	1.34	1.40	842.20	1.38927	0.54136	23.40	0.99747	1.63355
	L	25.54	25.80	26.02	25.79	25.00	25.02	25.00	25.01	1.50	1.48	1.48	1.49	958.66	1.58260	0.62784	23.40	0.99747	1.65261
3C	U	26.50	26.60	26.50	26.53	24.52	24.62	24.64	24.59	1.42	1.38	1.38	1.39	909.21	1.53123	0.62811	23.40	0.99747	1.69036
	L	25.50	25.56	25.60	25.55	24.52	24.60	24.64	24.59	1.46	1.50	1.48	1.48	929.84	1.52342	0.61750	23.40	0.99747	1.67656
4A	U	25.60	25.62	25.40	25.54	25.16	25.22	25.22	25.20	1.42	1.38	1.38	1.39	896.76	1.56233	0.66475	23.20	0.99752	1.73540
	L	25.64	25.68	25.78	25.70	25.32	25.40	25.44	25.39	1.48	1.48	1.58	1.51	987.36	1.60544	0.66074	23.20	0.99752	1.69436
4B	U	24.94	24.86	24.82	24.87	24.34	24.40	24.30	24.35	1.46	1.46	1.38	1.43	868.00	1.41705	0.57140	23.20	0.99752	1.67073
	L	25.90	25.98	25.90	25.93	24.30	24.28	24.30	24.29	1.46	1.50	1.48	1.48	932.17	1.47081	0.60345	23.20	0.99752	1.69069
4C	U	27.76	27.66	27.48	27.63	25.60	25.10	25.20	25.30	1.40	1.46	1.46	1.44	1006.74	1.62834	0.63000	23.20	0.99752	1.62625
	L	26.18	26.40	26.58	26.39	24.86	25.02	25.20	25.03	1.40	1.38	1.48	1.42	937.73	1.58838	0.62101	23.20	0.99752	1.63711
5A	U	25.50	25.50	25.70	25.57	24.60	24.62	24.64	24.62	1.48	1.44	1.42	1.45	910.61	1.52711	0.63935	23.20	0.99752	1.71505

APPENDIX 2-1

SAMPLE 1 (VOID CONTENT TEMPLATE)

	L	25.80	25.82	25.82	25.81	24.52	24.52	24.60	24.55	1.52	1.52	1.48	1.51	954.67	1.51245	0.62817	23.00	0.99756	1.70535
5B	U	25.60	25.30	25.18	25.36	23.92	24.00	24.00	23.97	1.38	1.40	1.48	1.42	863.31	1.43092	0.58809	23.00	0.99756	1.69278
	L	25.28	25.50	25.70	25.49	23.98	23.96	23.86	23.93	1.66	1.62	1.64	1.64	1000.63	1.48009	0.59794	23.00	0.99756	1.67291
5C	U	22.66	23.10	23.30	23.02	25.70	25.50	25.40	25.53	1.48	1.50	1.48	1.49	873.83	1.43359	0.55149	23.00	0.99756	1.62049
	L	23.28	23.24	23.00	23.17	25.52	25.40	25.22	25.38	1.40	1.40	1.38	1.39	819.47	1.35628	0.55319	23.00	0.99756	1.68388
6A	U	25.52	25.60	25.52	25.55	26.10	26.08	25.96	26.05	1.52	1.38	1.48	1.46	971.49	1.62164	0.67957	22.80	0.9976	1.71638
	L	26.00	26.00	26.08	26.03	26.80	26.80	26.72	26.77	1.48	1.52	1.38	1.46	1017.36	1.73210	0.71586	22.80	0.9976	1.69950
6B	U	27.88	27.70	27.50	27.69	25.50	25.72	25.90	25.71	1.48	1.54	1.48	1.50	1067.85	1.69144	0.67383	22.80	0.9976	1.65740
	L	25.20	25.40	25.58	25.39	27.66	27.90	27.96	27.84	1.54	1.58	1.64	1.59	1121.69	1.71124	0.67301	22.80	0.9976	1.64351
6C	U	25.10	25.54	25.72	25.45	24.80	24.60	24.34	24.58	1.56	1.60	1.58	1.58	988.52	1.49897	0.59292	23.00	0.99756	1.64958
	L	26.28	26.58	26.88	26.58	24.82	24.56	25.20	24.86	1.48	1.60	1.58	1.55	1026.41	1.54512	0.63556	23.00	0.99756	1.69377
7A	U	25.10	24.92	24.72	24.91	25.26	25.28	25.30	25.28	1.48	1.50	1.58	1.52	957.31	1.50376	0.62360	23.00	0.99756	1.70349
	L	25.38	25.50	25.60	25.49	25.40	25.48	25.38	25.42	1.48	1.54	1.50	1.51	976.38	1.53096	0.64642	23.00	0.99756	1.72570
7B	U	24.78	24.70	24.50	24.66	26.38	26.38	26.48	26.41	1.38	1.52	1.48	1.46	950.98	1.49619	0.61196	23.00	0.99756	1.68712
	L	25.20	25.18	25.30	25.23	26.12	26.14	26.28	26.18	1.46	1.46	1.48	1.47	968.64	1.50867	0.60238	23.00	0.99756	1.65981
7C	U	25.60	27.18	27.28	26.69	24.32	24.50	24.62	24.48	1.58	1.60	1.48	1.55	1014.78	1.53780	0.61536	23.00	0.99756	1.66223
	L	24.22	24.20	24.12	24.18	24.72	24.86	25.00	24.86	1.46	1.58	1.62	1.55	933.73	1.42319	0.58035	22.80	0.9976	1.68370
8A	U	24.94	24.92	24.90	24.92	24.58	24.66	24.68	24.64	1.52	1.50	1.46	1.49	916.95	1.44782	0.60366	22.80	0.9976	1.71014
	L	25.30	25.30	25.40	25.33	24.86	24.86	24.90	24.87	1.44	1.52	1.48	1.48	932.58	1.52621	0.61681	22.80	0.9976	1.67344
8B	U	26.40	26.40	26.48	26.43	24.84	25.00	25.00	24.95	1.40	1.48	1.48	1.45	958.12	1.54185	0.62230	22.80	0.9976	1.67192
	L	28.64	28.52	28.60	28.59	25.78	25.62	25.52	25.64	1.48	1.48	1.48	1.48	1084.78	1.72178	0.68348	22.80	0.9976	1.65352
8C	U	25.40	25.40	25.38	25.39	23.70	23.80	23.78	23.76	1.48	1.54	1.48	1.50	905.02	1.36687	0.50096	22.80	0.9976	1.57407
	L	25.48	25.30	25.10	25.29	23.84	23.90	23.80	23.85	1.50	1.66	1.48	1.55	932.89	1.42960	0.55568	22.80	0.9976	1.63117
9A	U	25.10	24.72	24.62	24.81	24.72	24.60	24.42	24.58	1.48	1.48	1.48	1.48	902.67	1.43286	0.54236	22.80	0.9976	1.60447
	L	25.50	25.70	25.90	25.70	25.00	24.90	24.70	24.87	1.48	1.48	1.48	1.48	945.83	1.53026	0.60120	22.80	0.9976	1.64239
9B	U	24.72	24.64	24.60	24.65	25.70	25.52	25.28	25.50	1.48	1.48	1.50	1.49	934.61	1.50663	0.60716	22.80	0.9976	1.67021
	L	24.42	24.34	24.40	24.39	25.98	25.90	25.60	25.83	1.48	1.50	1.48	1.49	936.34	1.52751	0.59068	22.80	0.9976	1.62586
9C	U	24.50	24.70	24.88	24.69	28.86	28.80	28.72	28.79	1.38	1.44	1.46	1.43	1014.36	1.60821	0.63640	22.80	0.9976	1.65012
	L	23.98	24.22	24.52	24.24	27.96	27.98	28.04	27.99	1.48	1.52	1.48	1.49	1013.31	1.69283	0.66798	22.80	0.9976	1.64705

APPENDIX 2-2

SAMPLE 2 (VOID CONTENT TEMPLATE)

Section	Side	Width (mm)				Length (mm)				Thickness (mm)				Volume	Mass, m1	Mass on water, m2	Temp (T)	ρ0	Density, ρ(m)
		1	2	3	Ave	1	2	3	Ave	1	2	3	Ave	(mm3)	(g)	(g)			
1A	U	25.40	25.48	25.54	25.47	25.10	24.72	24.74	24.85	1.40	1.40	1.44	1.41	894.78	1.44485	0.63032	23.20	0.9976	1.76859
	L	25.18	25.20	25.20	25.19	25.08	24.62	24.60	24.77	1.36	1.38	1.46	1.40	873.54	1.42017	0.60933	23.20	0.9976	1.74630
1B	U	25.00	25.20	25.20	25.13	24.42	26.46	26.40	25.76	1.40	1.48	1.40	1.43	923.67	1.52850	0.65539	23.20	0.9976	1.74547
	L	25.58	26.48	26.48	26.18	24.70	26.70	26.68	26.03	1.46	1.50	1.50	1.49	1012.98	1.63527	0.69368	23.20	0.9976	1.73159
1C	U	25.60	25.34	25.34	25.43	24.58	25.06	25.08	24.91	1.42	1.34	1.40	1.39	878.17	1.40943	0.59865	23.20	0.9976	1.73324
	L	25.58	25.50	25.50	25.53	24.84	24.54	24.20	24.53	1.48	1.40	1.50	1.46	914.08	1.43508	0.61414	23.20	0.9976	1.74293
2A	U	24.84	24.82	24.88	24.85	25.00	25.10	25.18	25.09	1.60	1.60	1.56	1.59	989.26	1.43790	0.61972	23.20	0.9976	1.75224
	L	25.70	25.70	25.72	25.71	25.08	25.14	25.22	25.15	1.48	1.58	1.54	1.53	991.20	1.50331	0.65258	23.20	0.9976	1.76185
2B	U	26.78	26.80	26.98	26.85	24.42	24.38	24.32	24.37	1.52	1.50	1.48	1.50	981.76	1.53199	0.65248	23.20	0.9976	1.73673
	L	27.20	27.30	27.10	27.20	24.70	25.54	24.48	24.91	1.40	1.48	1.42	1.43	971.03	1.55314	0.67410	23.20	0.9976	1.76163
2C	U	27.46	27.74	27.60	27.60	24.80	24.84	24.72	24.79	1.70	1.60	1.58	1.63	1112.82	1.56849	0.67125	23.20	0.9976	1.74296
	L	27.12	27.16	27.10	27.13	24.84	24.82	24.80	24.82	1.42	1.46	1.48	1.45	978.51	1.54000	0.66055	23.20	0.9976	1.74592
3A	U	26.00	26.00	25.90	25.97	25.62	25.64	25.60	25.62	1.48	1.40	1.40	1.43	949.11	1.50441	0.63964	23.20	0.9976	1.73453
	L	26.60	26.78	26.88	26.75	26.00	25.94	25.92	25.95	1.48	1.48	1.38	1.45	1004.48	1.63960	0.70869	23.20	0.9976	1.75608
3B	U	25.80	25.88	25.94	25.87	24.26	24.32	24.34	24.31	1.58	1.58	1.48	1.55	972.69	1.52491	0.62971	23.20	0.9976	1.69843
	L	27.10	27.12	27.20	27.14	24.42	24.52	24.52	24.49	1.48	1.48	1.48	1.48	983.56	1.54657	0.67213	23.20	0.9976	1.76340
3C	U	25.90	25.44	24.90	25.41	25.80	25.62	25.40	25.61	1.48	1.48	1.42	1.46	950.10	1.50203	0.64310	23.20	0.9976	1.74356
	L	24.18	24.22	25.00	24.47	25.96	25.70	25.50	25.72	1.48	1.48	1.48	1.48	931.34	1.43272	0.61440	23.20	0.9976	1.74563
4A	U	25.62	25.64	25.64	25.63	24.34	24.50	24.58	24.47	1.40	1.44	1.50	1.45	907.54	1.40265	0.58093	23.20	0.9976	1.70195
	L	26.74	26.70	26.70	26.71	24.40	24.50	24.60	24.50	1.50	1.48	1.50	1.49	977.35	1.53407	0.65894	23.20	0.9976	1.74778
4B	U	26.00	26.08	26.00	26.03	25.30	25.80	26.10	25.73	1.46	1.54	1.46	1.49	995.70	1.56710	0.66712	23.20	0.9976	1.73612
	L	26.24	26.28	26.36	26.29	26.32	25.90	25.52	25.91	1.44	1.48	1.48	1.47	999.31	1.55988	0.66991	23.20	0.9976	1.74755
4C	U	24.96	25.00	25.00	24.99	25.10	25.10	25.00	25.07	1.48	1.48	1.50	1.49	931.15	1.44500	0.60984	23.20	0.9976	1.72511
	L	24.02	24.16	24.10	24.09	25.42	25.30	25.14	25.29	1.48	1.50	1.50	1.49	909.80	1.37531	0.58091	23.20	0.9976	1.72615
5A	U	25.36	25.20	25.00	25.19	24.70	24.32	24.50	24.51	1.44	1.48	1.50	1.47	909.40	1.41262	0.59411	23.20	0.9976	1.72076

APPENDIX 2-2

SAMPLE 2 (VOID CONTENT TEMPLATE)

	L	26.80	27.08	27.46	27.11	24.64	24.96	25.06	24.89	1.48	1.50	1.54	1.51	1016.64	1.61226	0.68519	23.20	0.9976	1.73396
5B	U	24.78	24.80	24.78	24.79	25.30	25.30	25.24	25.28	1.48	1.46	1.48	1.47	923.20	1.45427	0.62357	23.20	0.9976	1.74548
	L	25.20	25.20	25.20	25.20	25.60	25.64	25.70	25.65	1.44	1.44	1.38	1.42	917.74	1.47935	0.63941	23.20	0.9976	1.75605
5C	U	25.48	25.70	25.78	25.65	25.78	26.08	26.46	26.11	1.44	1.48	1.48	1.47	982.26	1.53324	0.65794	23.20	0.9976	1.74650
	L	25.20	24.80	25.20	25.07	26.56	26.08	25.78	26.14	1.44	1.40	1.40	1.41	926.08	1.45543	0.62439	23.20	0.9976	1.74616
6A	U	25.48	25.26	25.12	25.29	25.78	26.56	25.58	25.97	1.52	1.50	1.44	1.49	976.41	1.50295	0.61776	23.00	0.9976	1.69290
	L	24.72	25.90	25.94	25.52	25.78	25.90	26.00	25.89	1.46	1.48	1.52	1.49	982.39	1.60029	0.68034	23.00	0.9976	1.73441
6B	U	25.18	25.20	25.20	25.19	25.52	25.44	25.40	25.45	1.40	1.42	1.46	1.43	914.86	1.40673	0.61023	23.00	0.9976	1.76091
	L	25.64	25.70	25.76	25.70	24.64	24.66	24.46	24.59	1.50	1.56	1.52	1.53	964.67	1.48881	0.62606	23.00	0.9976	1.72057
6C	U	26.62	26.80	26.64	26.69	25.26	25.24	25.32	25.27	1.48	1.42	1.48	1.46	984.71	1.52079	0.63992	23.00	0.9976	1.72138
	L	25.84	25.90	25.94	25.89	25.50	25.50	25.48	25.49	1.62	1.48	1.40	1.50	990.16	1.50567	0.63779	23.00	0.9976	1.72977
7A	U	26.00	26.38	26.08	26.15	24.22	24.30	24.22	24.25	1.48	1.40	1.40	1.43	904.69	1.39448	0.60434	23.00	0.9976	1.75963
	L	26.08	26.28	26.08	26.15	24.20	24.22	24.24	24.22	1.50	1.48	1.48	1.49	941.46	1.43600	0.61280	23.00	0.9976	1.73926
7B	U	25.36	25.32	25.28	25.32	24.70	25.10	25.52	25.11	1.40	1.38	1.40	1.39	885.74	1.41695	0.62740	23.00	0.9976	1.78930
	L	25.90	25.88	25.82	25.87	24.12	24.52	24.92	24.52	1.48	1.48	1.50	1.49	942.92	1.49228	0.63118	23.00	0.9976	1.72788
7C	U	26.40	26.40	26.58	26.46	25.38	25.20	25.00	25.19	1.50	1.50	1.50	1.50	999.92	1.56171	0.62529	23.00	0.9976	1.66287
	L	28.10	28.20	28.50	28.27	25.56	25.30	25.10	25.32	1.48	1.50	1.50	1.49	1068.80	1.70441	0.72377	23.00	0.9976	1.73293
8A	U	25.30	25.72	26.28	25.77	23.98	24.04	24.12	24.05	1.42	1.46	1.40	1.43	883.97	1.40405	0.59049	23.00	0.9976	1.72073
	L	28.20	28.58	28.84	28.54	24.24	24.14	24.00	24.13	1.40	1.44	1.48	1.44	991.55	1.58655	0.68249	23.00	0.9976	1.74973
8B	U	24.74	24.88	24.82	24.81	22.96	22.76	22.54	22.75	1.48	1.48	1.40	1.45	820.53	1.28015	0.55227	23.00	0.9976	1.75354
	L	25.20	25.30	25.40	25.30	23.14	23.00	22.76	22.97	1.40	1.40	1.40	1.40	813.48	1.30685	0.56015	23.00	0.9976	1.74500
8C	U	24.20	24.02	23.74	23.99	28.50	28.38	28.10	28.33	1.52	1.60	1.48	1.53	1041.84	1.58107	0.67061	23.00	0.9976	1.73144
	L	22.86	23.00	23.22	23.03	28.50	28.36	28.10	28.32	1.48	1.38	1.42	1.43	930.35	1.47577	0.63798	23.00	0.9976	1.75629
9A	U	25.92	25.98	25.90	25.93	24.32	24.32	24.40	24.35	1.52	1.56	1.50	1.53	963.92	1.44561	0.60525	23.00	0.9976	1.71517
	L	25.84	25.98	25.92	25.91	24.30	24.32	24.30	24.31	1.38	1.40	1.40	1.39	877.61	1.47561	0.62000	23.00	0.9976	1.71955
9B	U	24.20	24.24	24.30	24.25	23.14	23.14	23.10	23.13	1.48	1.48	1.46	1.47	826.16	1.31093	0.55454	23.00	0.9976	1.72803
	L	24.52	24.50	24.30	24.44	23.44	23.34	23.24	23.34	1.38	1.38	1.38	1.38	787.19	1.30737	0.57591	23.00	0.9976	1.78204
9C	U	28.50	28.14	27.34	27.99	22.90	22.92	23.00	22.94	1.42	1.42	1.38	1.41	903.32	1.50835	0.65320	23.00	0.9976	1.75862
	L	26.98	27.26	27.36	27.20	22.98	23.14	23.18	23.10	1.32	1.32	1.40	1.35	846.14	1.44957	0.61795	23.00	0.9976	1.73792

APPENDIX 3-1

SAMPLE 1 (LOSS IGNITION TEST RESULT)

Density of resin	1.24	g/cm3
Density of fibre	2.54	g/cm3

Section	Sample	Weight of specimen, g	Weight of crucible, g	Weight of crucible + residue, g	Weight percent of resin, %w	Weight percent of fibre, %w	Theoretical composite density	Measured composite density	Void content (volume %)
		m1	m2	m3	Rwt=(((m1+m2)-m3)/m1)(100)	Fwt=100-Rwt	Td=100/((Rwt/D)+(Fwt/d))		V=((Td-Md)/Td)(100)
Colum	Colum	Column3	Column4	Column5	Column6	Column7	Column8	Column9	Column10
1A	U	1.5224	16.8960	17.8800	35.3644	64.6356	1.8530	1.6896	8.8161
	L	1.5114	15.7230	16.7280	33.5054	66.4946	1.8797	1.6606	11.6566
1B	U	1.3417	15.9700	16.8760	32.4747	67.5253	1.8949	1.6202	14.4973
	L	1.4359	10.1770	11.1060	35.3005	64.6995	1.8539	1.6697	9.9362
1C	U	1.4823	12.5950	13.5280	37.0590	62.9410	1.8293	1.5762	13.8353
	L	1.4076	8.9420	9.8390	36.2750	63.7250	1.8402	1.6518	10.2394
2A	U	1.5298	7.9980	8.9840	35.5471	64.4529	1.8504	1.7305	6.4794
	L	1.5392	6.1150	7.1340	33.7951	66.2049	1.8755	1.6878	10.0104
2B	U	1.3913	16.8990	17.8080	34.6631	65.3369	1.8630	1.6611	10.8359
	L	1.4776	15.7230	16.6520	37.1291	62.8709	1.8283	1.6626	9.0648
2C	U	1.3081	15.9740	16.8350	34.1793	65.8207	1.8699	1.5577	16.6953
	L	1.2708	10.1790	10.9990	35.4712	64.5288	1.8515	1.5587	15.8156
3A	U	1.5908	12.6030	13.6320	35.3156	64.6844	1.8537	1.7360	6.3484
	L	1.5890	8.9440	9.9850	34.4875	65.5125	1.8655	1.6575	11.1477
3B	U	1.3893	7.9970	8.9340	32.5545	67.4455	1.8937	1.6336	13.7370
	L	1.5826	6.1150	7.1230	36.3073	63.6927	1.8397	1.6526	10.1710
3C	U	1.5312	16.9010	17.8900	35.4114	64.5886	1.8523	1.6904	8.7437
	L	1.5234	15.7250	16.6980	36.1305	63.8695	1.8422	1.6766	8.9916
4A	U	1.5623	15.9770	16.9750	36.1210	63.8790	1.8423	1.7354	5.8043
	L	1.6054	10.1800	11.2000	36.4660	63.5340	1.8375	1.6944	7.7902
4B	U	1.4171	12.6030	13.5370	34.0884	65.9116	1.8713	1.6707	10.7162
	L	1.4708	8.9450	9.9110	34.3219	65.6781	1.8679	1.6907	9.4863
4C	U	1.6283	8.0000	9.0640	34.6574	65.3426	1.8631	1.6262	12.7114
	L	1.5884	6.1170	7.1380	35.7207	64.2793	1.8480	1.6371	11.4095
5A	U	1.5271	16.9010	17.8500	37.8565	62.1435	1.8183	1.7151	5.6800
	L	1.5125	15.7220	16.7100	34.6755	65.3245	1.8628	1.7053	8.4527

APPENDIX 3-1

SAMPLE 1 (LOSS IGNITION TEST RESULT)

5B	U	1.4309	15.9710	16.9750	29.8354	70.1646	1.9348	1.6928	12.5094
	L	1.4801	10.1780	11.1260	35.9498	64.0502	1.8447	1.6729	9.3140
5C	U	1.4336	12.6000	13.5250	35.4767	64.5233	1.8514	1.6205	12.4725
	L	1.3563	8.9460	9.8480	33.4946	66.5054	1.8799	1.6839	10.4261
6A	U	1.6216	7.9990	9.0500	35.1891	64.8109	1.8555	1.7164	7.4968
	L	1.7321	6.1170	7.2130	36.7242	63.2758	1.8339	1.6995	7.3295
6B	U	1.6914	16.8970	18.0130	34.0207	65.9793	1.8722	1.6574	11.4746
	L	1.7112	15.7210	16.8270	35.3685	64.6315	1.8529	1.6435	11.3022
6C	U	1.4990	15.9740	16.9340	35.9560	64.0440	1.8446	1.6496	10.5747
	L	1.5451	10.1800	11.2130	33.1444	66.8556	1.8850	1.6938	10.1447
7A	U	1.5038	12.5990	13.5910	34.0320	65.9680	1.8721	1.7035	9.0050
	L	1.5310	8.9440	9.9540	34.0283	65.9717	1.8721	1.7257	7.8213
7B	U	1.4962	7.9980	9.0090	32.4284	67.5716	1.8956	1.6871	10.9960
	L	1.5087	6.1160	7.1470	31.6617	68.3383	1.9070	1.6598	12.9623
7C	U	1.5378	16.8980	17.9050	34.5168	65.4832	1.8651	1.6622	10.8762
	L	1.4232	15.7240	16.6710	33.4593	66.5407	1.8804	1.6837	10.4599
8A	U	1.4478	15.9740	16.9300	33.9697	66.0303	1.8730	1.7101	8.6935
	L	1.5262	10.1780	11.1560	35.9197	64.0803	1.8452	1.6734	9.3066
8B	U	1.5419	12.6020	13.6390	32.7431	67.2569	1.8909	1.6719	11.5805
	L	1.7218	8.9430	10.1010	32.7440	67.2560	1.8909	1.6535	12.5535
8C	U	1.3669	8.0000	8.9320	31.8150	68.1850	1.9047	1.5741	17.3586
	L	1.4296	6.1190	7.0690	33.5478	66.4522	1.8791	1.6312	13.1938
9A	U	1.4329	16.8990	17.8690	32.3032	67.6968	1.8974	1.6045	15.4390
	L	1.5303	15.7250	16.7340	34.0635	65.9365	1.8716	1.6424	12.2473
9B	U	1.5066	15.9720	16.9420	35.6179	64.3821	1.8494	1.6702	9.6896
	L	1.5275	10.1800	11.1680	35.3196	64.6804	1.8536	1.6259	12.2879
9C	U	1.6082	12.6000	13.6730	33.2799	66.7201	1.8830	1.6501	12.3681
	L	1.6928	8.9460	10.0180	36.6741	63.3259	1.8346	1.6471	10.2235

APPENDIX 3-2

SAMPLE 2 (LOSS IGNITION TEST RESULT)

Density of resin	1.24	g/cm3
Density of fibre	2.54	g/cm3

Section	Sample	Weight of specimen, g m1	Weight of crucible, g m2	Weight of crucible + residue, g m3	Weight percent of resin, %w Rwt=(((m1+m2)-m3)/m1)(100)	Weight percent of fibre, %w Fwt=100-Rwt	Theoretical composite density Td=100/((Rwt/D)+(Fwt/d))	Measured composite density	Void content (volume %) V=((Td-Md)/Td)(100)
1A	U	1.44485	16.901	17.880	32.2421	67.7579	1.8983	1.7686	6.8343
	L	1.42017	15.722	16.697	31.3462	68.6538	1.9117	1.7463	8.6538
1B	U	1.52850	15.975	17.001	32.8754	67.1246	1.8890	1.7455	7.5960
	L	1.63527	10.178	11.276	32.8551	67.1449	1.8892	1.7316	8.3451
1C	U	1.40943	12.601	13.560	31.9583	68.0417	1.9026	1.7332	8.8996
	L	1.43508	8.942	9.932	31.0143	68.9857	1.9168	1.7429	9.0691
2A	U	1.43790	8.000	8.964	32.9578	67.0422	1.8877	1.7522	7.1778
	L	1.50331	6.116	7.112	33.7462	66.2538	1.8762	1.7619	6.0954
2B	U	1.53199	16.903	17.915	33.9421	66.0579	1.8734	1.7367	7.2940
	L	1.55314	15.725	16.760	33.3608	66.6392	1.8818	1.7616	6.3875
2C	U	1.56849	15.975	17.041	32.0365	67.9635	1.9014	1.7430	8.3319
	L	1.54000	10.177	11.230	31.6234	68.3766	1.9076	1.7459	8.4742
3A	U	1.50441	12.604	13.644	30.8699	69.1301	1.9190	1.7345	9.6106
	L	1.63960	8.945	10.036	33.4594	66.5406	1.8804	1.7561	6.6110
3B	U	1.52491	8.001	8.982	35.6683	64.3317	1.8487	1.6984	8.1282
	L	1.54657	6.115	7.158	32.5604	67.4396	1.8936	1.7634	6.8757
3C	U	1.50203	16.901	17.896	33.7563	66.2437	1.8761	1.7436	7.0631
	L	1.43272	15.722	16.700	31.7382	68.2618	1.9058	1.7456	8.4065
4A	U	1.40265	15.972	16.939	31.0591	68.9409	1.9161	1.7020	11.1754
	L	1.53407	10.175	11.196	33.4450	66.5550	1.8806	1.7478	7.0625
4B	U	1.56710	12.601	13.634	34.0821	65.9179	1.8713	1.7361	7.2260
	L	1.55988	8.943	9.995	32.5589	67.4411	1.8936	1.7476	7.7138
4C	U	1.44500	7.997	8.957	33.5640	66.4360	1.8789	1.7251	8.1834
	L	1.37531	6.111	7.048	31.8699	68.1301	1.9039	1.7262	9.3348
5A	U	1.41262	16.904	17.852	32.8907	67.1093	1.8887	1.7208	8.8930

APPENDIX 3-2

SAMPLE 2 (LOSS IGNITION TEST RESULT)

	L	1.61226	15.725	16.772	35.0601	64.9399	1.8573	1.7340	6.6415
5B	U	1.45427	15.976	16.945	33.3686	66.6314	1.8817	1.7455	7.2397
	L	1.47935	10.179	11.180	32.3351	67.6649	1.8969	1.7560	7.4275
5C	U	1.53324	12.604	13.642	32.3002	67.6998	1.8975	1.7465	7.9560
	L	1.45543	8.944	9.937	31.7727	68.2273	1.9053	1.7462	8.3540
6A	U	1.50295	8.000	9.001	33.3977	66.6023	1.8813	1.6929	10.0137
	L	1.60029	6.117	7.162	34.6993	65.3007	1.8625	1.7344	6.8757
6B	U	1.40673	16.899	17.833	33.6049	66.3951	1.8783	1.7609	6.2482
	L	1.48881	15.723	16.640	38.4072	61.5928	1.8109	1.7206	4.9852
6C	U	1.52079	15.974	17.007	32.0748	67.9252	1.9008	1.7214	9.4400
	L	1.50567	10.175	11.189	32.6546	67.3454	1.8922	1.7298	8.5848
7A	U	1.39448	12.600	13.575	30.0815	69.9185	1.9310	1.7596	8.8755
	L	1.43600	8.944	9.928	31.4763	68.5237	1.9098	1.7393	8.9288
7B	U	1.41695	8.000	8.981	30.7668	69.2332	1.9205	1.7893	6.8329
	L	1.49228	6.115	7.098	34.1276	65.8724	1.8707	1.7279	7.6337
7C	U	1.56171	16.903	17.924	34.6229	65.3771	1.8636	1.6629	10.7689
	L	1.70441	15.723	16.833	34.8748	65.1252	1.8600	1.7329	6.8294
8A	U	1.40405	15.975	16.947	30.7717	69.2283	1.9205	1.7207	10.3998
	L	1.58655	10.179	11.236	33.3775	66.6225	1.8816	1.7497	7.0078
8B	U	1.28015	12.602	13.467	32.4298	67.5702	1.8955	1.7535	7.4913
	L	1.30685	8.945	9.836	31.8208	68.1792	1.9046	1.7450	8.3805
8C	U	1.58107	8.000	9.056	33.2098	66.7902	1.8840	1.7314	8.0996
	L	1.47577	6.117	7.134	31.0868	68.9132	1.9157	1.7563	8.3195
9A	U	1.44561	16.904	17.858	34.0071	65.9929	1.8724	1.7152	8.3990
	L	1.47561	15.723	16.713	32.9091	67.0909	1.8885	1.7196	8.9440
9B	U	1.31093	15.975	16.859	32.5670	67.4330	1.8935	1.7280	8.7390
	L	1.30737	10.180	11.083	30.9300	69.0700	1.9180	1.7820	7.0909
9C	U	1.50835	12.604	13.633	31.7798	68.2202	1.9052	1.7586	7.6948
	L	1.44957	8.944	9.940	31.2900	68.7100	1.9126	1.7379	9.1326

APPENDIX 4-1

SAMPLE PREPARATION