CHARACTERISATION OF INTER-LAMINAR SHEAR STRENGTH (ILSS) OF A RESIN INFUSED WIND TURBINE BLADE POLYMER COMPOSITE

by

Mohamad Fahmi Bin Md Bekery

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,

____

(Mr. Muhamad Ridzuan Abdul Latif)

Date:

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

MAY 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I, Mohamad Fahmi Bin Md Bekery (I/C No: 891016-08-6323), 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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ABSTRACT

Resin infusion technique is one of the common techniques in the industrial applications nowadays. This report discuss about characterisation of inter-laminar shear strength (ILSS) of a wind turbine polymer composite blade that have been fabricate using this technique. In this project, two different infusion strategies, which are the infusion flow form leading edge to trailing edge and from root to tip, were used in the fabrication of the polymer composite wind turbine blade and to determine if the different infusion strategies will affect the ILSS of this blade, the three point bending test must be done. This project comprise of four main processes. First is the blade fabrication followed by the preparation of the samples needed. Next is the three point bending test done on the samples and finally the analysis of the data gathered from the test done to analyze the distribution of the ILSS from distribution from roof to tip, from leading edge to trailing edge also both upper and lower side of the blades. After the analysis, the result shows that different infusion strategies do affect the ILSS of the blade where Strategy 2 gives better result than Strategy 1, however there is no conclusive evidence that show exactly Strategy 2 is better, means that there are a lot of studies need to be done in order to prove the fact. The mapping of ILSS distribution on a single blade also done for both upper side and lower side for each blade.

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CHAPTER 1

INTRODUCTION

1.1. Project Background

Wind turbine is a device that converts the kinetic energy in wind into the mechanical energy and one of the important components in wind turbine is the blades. Wind turbine blades are subjected to static and dynamic lift, drag and inertial over a wide range of temperatures and other severe environmental such as UV light, rain hail bird strikes and etc (Walcyk, 2010). Thus the characteristic of the wind turbine blades are high strength-to-weight ratio, corrosion resistant, high rigidity, fatigue and wind resistant. In order for the wind turbine to accelerate quickly if the wind keeping the tip ration nearly constant, the blades must have low rotational inertia. The composite materials such as glass fiber reinforce plastic (GFRP) is widely used to construct the outer layer of wind turbine blade due to its outstanding mechanical properties. GFRP material also is the best material used to construct the outer sin of blade as it ease to manufacture at low cost.

The resin infusion technique is used in the industry to produce wind turbine blade polymer composite nowadays. It is a process that uses vacuum pressure to drive resin into a laminate. Materials are laid dry into the mold and the vacuum is applied before resin is introduced. Once a complete vacuum is achieved, resin is literally sucked into the laminate via carefully placed tubing. It is an advanced laminating technique that highly improves the strength and quality of glass fiber parts against conventional hand lay-up. By applying laminate engineering and resin infusion technology simultaneously allows for optimization of a part in term of strength and weight ("Resin Infusion Explained", 2012). Different strategies can be made to manufacture this polymer composite such as by flowing resin in different feed type (line or point) and by changing direction of the resin flow (tip to root or trailing edge to leading edge). By using this technique, numerous benefits and significant strength gains are essentially due to the method of reinforcing the materials within a vacuum all at once. The tremendous clamping pressure of the vacuum (approximately 1 ton/meter square) helps fuse the materials together with any air voids being replace by resin. The advantage of this type of technology is that it allows the infusion process for close profile and sandwich arrangement material. Besides that, the strength to weight ratio produced by this approach is high and it is claimed that at one-quarter of the weight, the same tensile strength as steel is obtained. In addition this technique also produces low void content and reduces operator exposure to harmful emissions.

Inter-laminar shear strength (ILSS) property is an indicator used to measure the quality and strength of polymer composite structures. It is maximum shear stress existing between layers of laminated material. There are different test methods used for the evaluation of mechanical properties based primarily on strain rate required (Sierakowski et al, 1997). The short beam method (ASTM Standard D2344) is commonly employed to measure the apparent ILSS of fiber-reinforced composite materials. A short beam specimen of rectangular in cross section is utilized, the specimen resting on two steel support cylinders that allow lateral motion, the load being applied by means of a steel loading cylinder at the centre length of the specimen. A short beam shear test using two loading cylinders to apply the load called four point shear test, is an alternative to standard short beam shear test, which is also called the three point shear test method.

1.2. Problem Statements

Wind turbine blade must have high strength-to-weight ratio and high rigidity to withstand high force over wide range of temperature and severe environment which is very hard for it to achieve without any reinforcement. Appropriate process need to be considered as the wind turbine blade has a curve shape, close profile and sandwich arrangement material. The process of manufacturing the glass fiber reinforced composite wind turbine blade is executed by using the resin infusion process. By using this process, the formation of void is unavoidable fact and each of the strategy produce different inclusion of the void. The inclusion of voids in the will have a detrimental impact on the mechanical properties of the composites such as Inter-laminar Shear Strength (ILSS) even at a very low volume fraction (Samsudin, 2010). However, how the effect of different infusion strategy to the ILSS must be analyze properly. Further studies of ILSS's distribution on wind turbine blade need to be done to know the quality of current manufactured wind turbine blade.

1.3. Objective and scope of the study

1.3.1. Objective

The objectives of this project are:

1. To investigate how the different infusion strategies effect on the characterization of the ILSS in a wind turbine blade polymer composite manufactured by resin infusion process.

2. To map the ILSS distribution in each blade manufactured.

1.3.2. Scope of Study

This study concentrates 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 fiber reinforce plastic. In this process, the resin used was vinyl-ester, and the two different infusion flows were form leading edge to trailing edge and from root to tip. The focus of this study is to investigate how the characteristic of ILSS in the wind turbine blade polymer composite varied when two different infusion strategies are used and also to map the ILSS distribution in each blade manufactured. This analysis is done by using ASTM Standard D2344 also known as Short Beam Shear Test. The machine used in this test is the universal testing machine with three point bending fixture and all the information related such as the span length and dimension of specimen were based on this standard. The analysis made to this wind turbine blade polymer composite includes the whole part of the blade, covers from root to tip, trailing edge to leading edge and both upper and lower side of the blade.

CHAPTER 2

LITERATURE REVIEW

2.1. Resin Infusion Process

Resin infusion is an environmentally friendly alternative to open molding and it produces consistent, high-quality parts for products like boats and windmill blades. Large and complex structures can be produced by using this process ("Resin Infusion Process", 2012). 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 (Samsudin, 2010). Besides that, other benefits can be gain from this process includes better fiber-to resin ratio, less wasted resin, very consistent resin usage, unlimited setup time and it is cleaner ("Vacuum Infusion", 2012). There are also several potential pitfalls while doing this process because of the complicated setup and it also easy to ruin a part when the process has start. Several methods are used in operating the resin infusion, some of them are Resin Transfer Moulding (RTM), SCRIMP, RIFT and VARTM. In this project the resin used to manufacture the polymer composite wind turbine blade was vinyl-ester. 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 to create vacuum condition 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 was used. By applying the resin infusion technology, it allows for optimization of a part in terms of strength and weight. Figure below shows the steps of the resin infusion process.

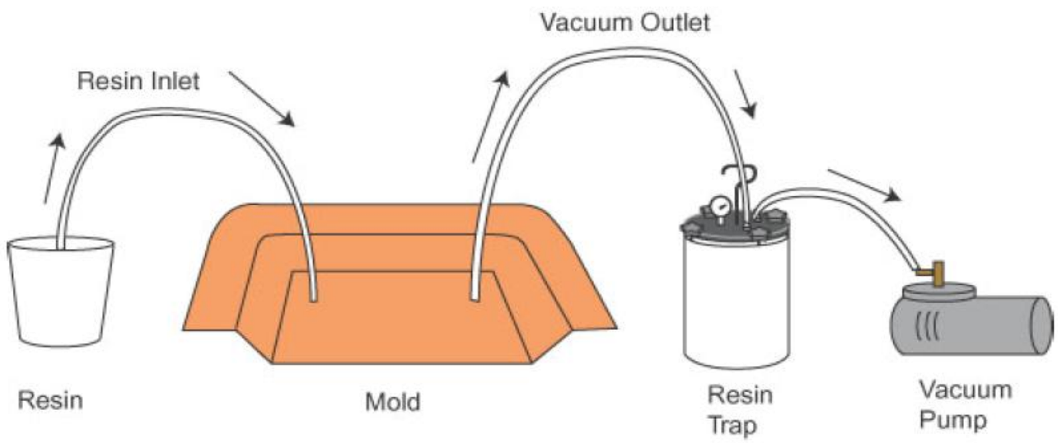

Figure 2.1: Sequence of steps of vacuum infusion.

2.2. Resin Infusion Strategy

Resin infusion strategy technique operates by flowing resin from inlet to outlet across the interested area which is the wind turbine blade and glass fiber. This process can be conducted in various strategies and each strategy has different influence on the quality of the wind turbine blade. As for this project, the first strategy used is the line feed type by flowing resin from leading edge to trailing edge and the second strategy used is the lines feed type by flowing resin from root to tip. Each strategy influences the quality of the wind turbine blade polymer composite. By using resin infusion process, the formation of void is unavoidable but each of the strategy produces different inclusion of void. The formation of void is due to entrapment of air during the formulation of resin system, in resin rich areas, and due to moisture absorbed during the material storing and processing. The inclusion of voids in the final part will have a detrimental impact on the mechanical properties of the composites such as ILSS.

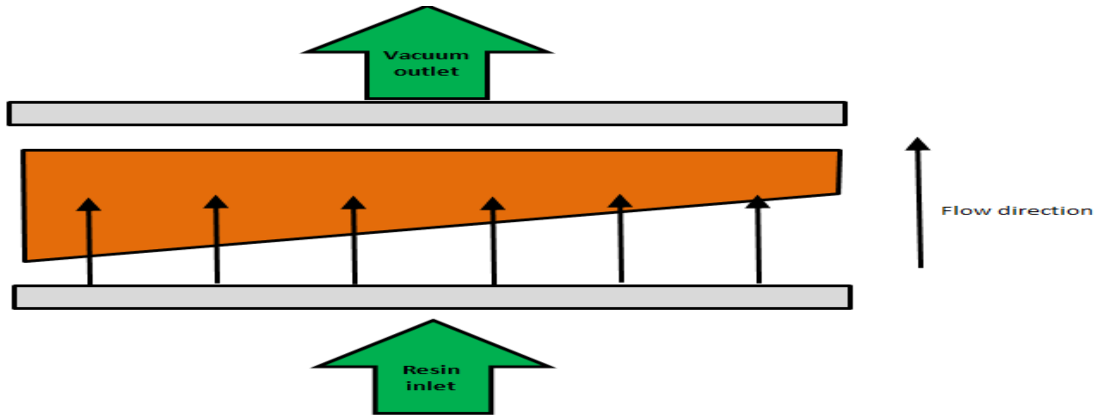

Figure 2.2: Strategy 1- Line feed type, flowing resin from leading edge to trailing edge.

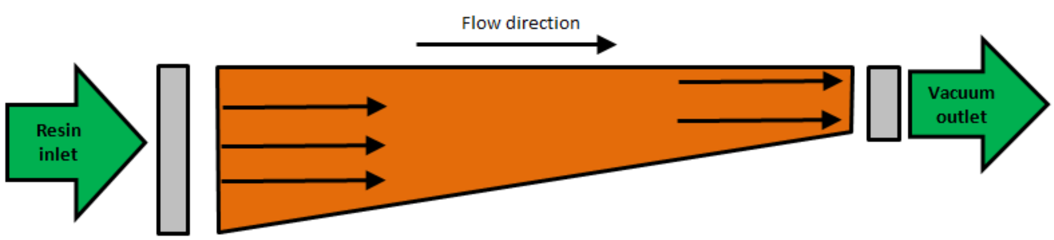

Figure 2.3: Strategy 2- Line feed type, flowing resin from root to tip.

2.3. Inter-Laminar Shear Strength (ILSS)

Inter-laminar shear strength (ILSS) property is the best indicator used to measure the quality and strength of polymer composite structures. It is the maximum shear stress existing between layers of laminated material. There are different test methods used for the evaluation of mechanical properties based primarily on strain rate required (Sierakowski et al, 1997). For this study, the short beam method (ASTM Standard D2344) is commonly employed to measure the apparent ILSS of the fiber-reinforced composite materials. There are several limitations on the short beam shear method in conjunction with advanced composites vinyl-ester. When this method is used to test thin beams, it does not usually yield inter-laminar failures. Such data often reported in the literature without mentioning the failure was attained. Furthermore, other study proved that high shear stresses in the upper portion of beam near concentrated load and short beam shear configuration yields stress-concentration effects which are never fully dissipated. Thus these conditions are not satisfying the principle in a highly orthotropic beam of low span-to-depth ratio (Kadir, 2011).

However, the further experiment and analysis done shows that there is evidence that compression stresses in regions where high shear stress components exist tend to suppress inter-laminar shear failure modes. Thus, initial damage in the form of vertical cracks appears to be necessary in order to induce mixed mode horizontal inter-laminar failures (Whitney and Browning, 1985). For specimen without damage, the failure mode is essentially compressive buckling or yielding in the upper portion of the beam under combined compression and shear. The uniform shear stress present along a segment of the beam centre line does suggest that the apparent ILSS determined from three point shear test may represent minimum values.

Figure 2.4: Three-point bending fixture.

CHAPTER 3

METHODOLOGY

3.1. Project Work Flow

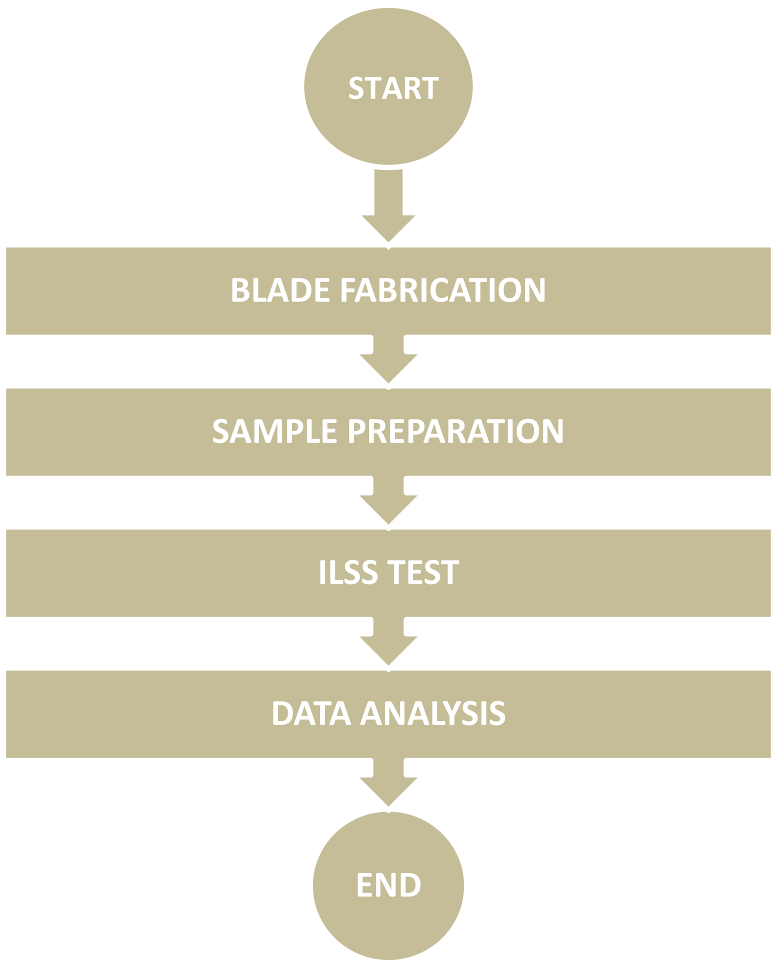

Figure 3.1: Project work flow.

Figure 3.1 shows the simplified project work flow. The main step of this project can be divided into four main processes. First step of this project is the fabrication of the blade using resin infusion process. The blade made of wooden core is laminated with fiber glass by vinyl-ester using this process. Since this project using two different infusion strategies, so the fabrication process must be done twice using different blade for each strategy. Next is the preparation of the sample according to ASTM Standard D2344. The sample is cut according to the ILSS test standard that it will go through later which is 20mm x 4mm in rectangular shape. After the cutting process, the wooden core will be peel to make sure only fiber glass remains to be tested later.

After that, the ILSS test also known as short beam shear test will be done to obtain the maximum load per each specimen. The specimen is place on the universal testing machine with three point bending fixture. The load is then applied at the centre length of the specimen. All data obtained were in load value and need to be converted into ILSS value using ILSS equation. The ILSS value for entire specimens are calculated and recorded based on its location. Finally the data collected from this test will be analyzed to get the ILSS distribution from root to tip, from leading edge to trailing edge and both upper and lower side for both blades. The results are then discussed to determine the factors that influence the ILSS distribution along the blade.

3.2. Materials and Equipments

Table 3.1: Materials and Equipments

Materials / Equipments	Details
Vinyl-ester and hardener.	To act as substance for glass fiber reinforcement.
Net, wax, breather, sealant tape, vacuum bag, resin inlet line and vacuum line.	To perform the infusion process.
Sketch tool (pencil, ruler and marker pen).	To sketch the division line on the wind turbine blade polymer composite for cutting process.
Vernier caliper.	To measure the thickness of the wind turbine blade polymer composite and dimension of 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.
Universal Testing Machine with Three Point Bending Fixture.	To measure the ILSS of the polymer composite.

3.3. Blade Fabrication

Firstly the blade, fiber, breather and net were arranged similar as the arrangement in Figure 3.2. For the first infusion strategy which is line feed type from leading edge to trailing edge, the first spiral tubing was cut similar length of the leading edge length and placed at the leading edge of the blade. This is the resin inlet line. After that second spiral tubing was cut similar length as the trailing edge length and placed at the trailing edge of the blade. This is vacuum line. Vacuum bag was wrapped around to cover the whole surfaces of the blade and then sealed using sealant tape. Next, the vacuum pump was started and the air trapped inside the vacuum bag was evacuated. Hissing sound from the seal around the vacuum bag and tube was checked to make sure no leak occur before resin infusion process started. The resin which is the vinyl-ester was prepared properly and then it was degassed to eliminate bubbles. Then the resin tube was placed inside the mixture. Vacuum pump was ensured off before the tube was placed inside the mixture. The vacuum pump was started and it will turn off right after the resin covers the entire blade. The blade was left for curing process until the resin hardened. Finally the breather and net were removed from the blade. All of this process is repeated for the second infusion strategy which the line feed type from root to tip. The spiral tube location and length is change according to the resin inlet which is the root and the vacuum line which is the tip length.

Figure 3.2: Important materials (1: Vinyl ester resin, 2: Fiber, 3: Blade).

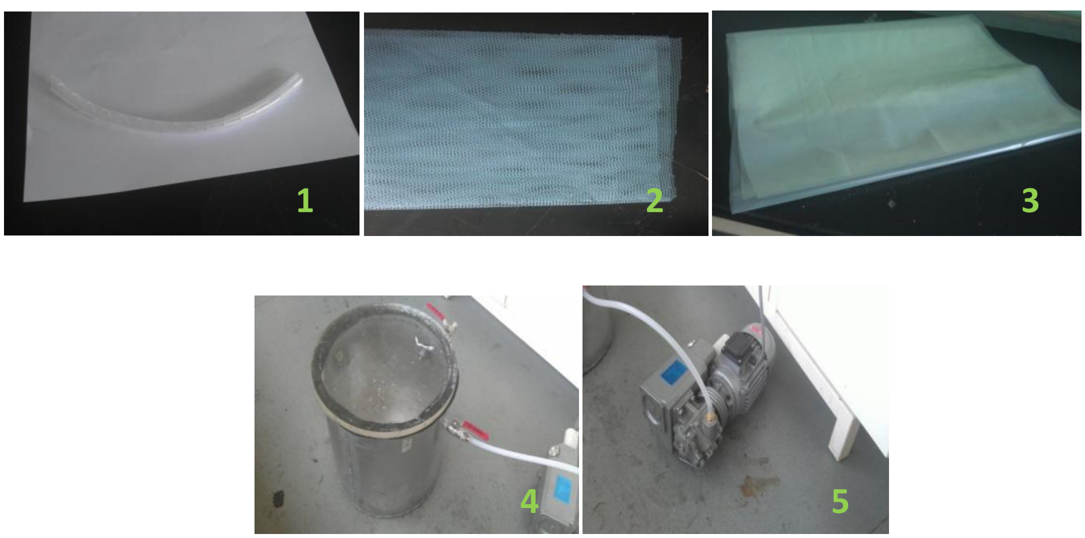

Figure 3.3: Important tools (1: Spiral tube, 2: Net, 3: Vacuum bag, 4: Resin trap, 5: Pump).

Figure 3.4: Arrangement of materials.

3.4. Sample Preparation

First, sketch the line on the wind turbine blades polymer composite according to the Figure 3.5. The blades were then cut using Linear Abrasive Cutter Machine in vertical direction in to 9 pieces. The pieces were then labeled starting from number 1 at the largest piece until number 9 at the smallest piece. Then the thickness of the polymer composite and the wood were measured for each piece. All pieces of the blades were cut in horizontal direction using Linear Abrasive Cutter Machine. The pieces were labeled with A, a, B, b and C with A starting from leading side until C, the trailing side. After that, the polymer composite was split from the wood blades using Rotating Abrasive Cutter Machine for each block. Note that the polymer composite must be free from wood residue. Grind the polymer composite by using grinder if required. The dimension of required specimen was sketched according to ASTM 2344 for polymer composite. The composite then cut into specific dimension by using Rotating Abrasive Cutter Machine. Note that the edge of each specimen must have a good finishing. The specimen then labeled according to respective line and column and finally the length, width and thickness 3 times per specimen.

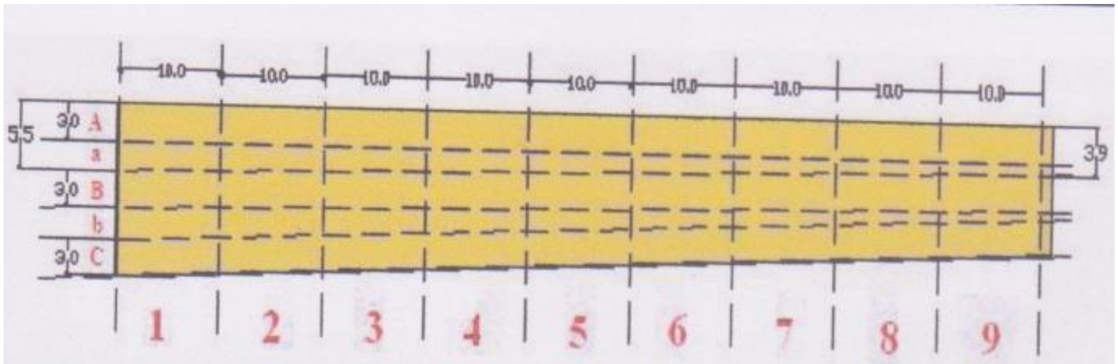

Figure 3.5: Division of blade.

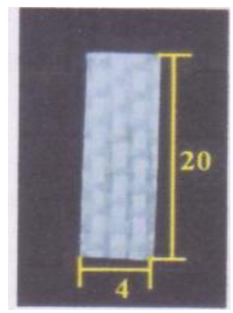

Figure 3.6: Specimen size (in mm).

3.5. ILSS Test (Three Point Bending Test)

The specimens were stored in the conditioned environment until test time. The speed of testing was set at a rate of crosshead movement of 1.0mm/min. Test the specimens under the same fluid exposure level as used for conditioning if possible. The test temperature was monitored by placing an appropriate thermocouple at the specimen mid-length to be located on the underside of beam. The specimen was inserted into three point bending fixture, with tool side resting on the reaction supports. Then the load is applied to the specimen at the specified rate while recording the data. Continue to load until either of a load drop-off 30%, two piece specimen failure or the head travel exceeds the specimen nominal thickness. Finally the load versus crosshead displacement data throughout the test method was recorded. The maximum load, final load and the load at any obvious discontinuities in the load-displacement data was recorded.

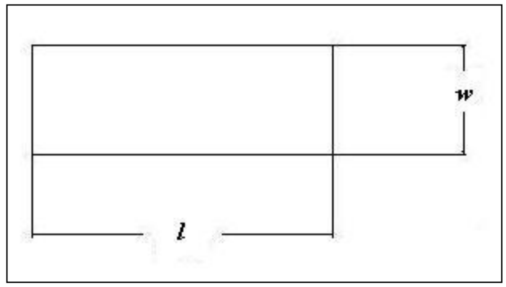

Figure 3.7: The dimension of the specimen for short beam shear test.

Length, l = min span length + thickness x 2 (Eq. 1)

Width, w = thickness x 2 (Eq. 2)

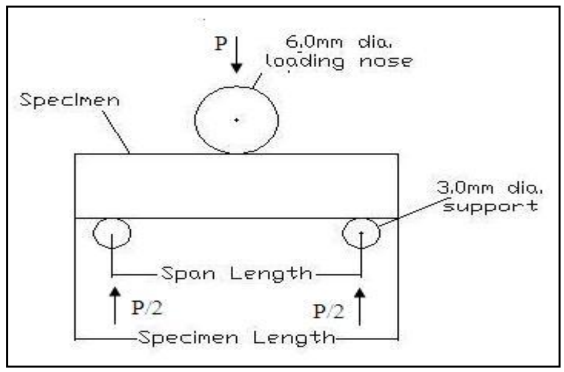

Figure 3.8: Horizontal shear load diagram.

Span length, l_s = thickness x 4 (Eq. 3)

3.6. Data Analysis

Equation 4 shows the ILSS Equation that convert the maximum load observed during the short beam shear into ILSS value. This equation uses the basic pressure equation which dividing force value with the cross section area and multiplying it with correction factor of 0.75.

Short Beam Strength- Calculates the short-beam strength using equation 4 as follows:

$F^{sbs} = 0.75x\ P_m / (b \times h)$ (Eq. 4)

Where:

F^{sbs} = short-beam strength, MPa

P_m = maximum load observed during the test, N

b = measured specimen width, mm

h = measured specimen thickness, mm

Finally the ILSS distribution was mapped for both blades. The purpose of ILSS distribution mapping in the blades is to display the ILSS value of each specimen tested in a single view. By this technique, it is easier to compare the ILSS distribution between different points. The distributions were made for both upper and lower side of the blades over distance and block. Microsoft Excel software was used to tabulate the entire ILSS value of specimens. The x-axis refer to the distance and block, y-axis refers to line A, B and C while z-axis refers to the ILSS value.

CHAPTER 4
RESULT

4.1. Introduction

There were four blades that have been fabricated using the resin infusion process, 2 blades for each strategy. However, there is a major error occurs on the second blade for Strategy 2, where there are a lot of air enter the vacuum bag after the fabricating process before the resin not fully cured yet. Due to shortage of time and materials, the experiment cannot be repeated again. For Strategy 1, the average of the ILSS values for the first and second blade is taken in doing the analysis. For Strategy 2, only the ILSS values of first blade is taken for the analysis process because of the major error occurs on the second blade and if the second blade is included in the analysis, it may affect the result majorly.

4.2. ILSS Analysis from Root to Tip

The relation of the average ILSS values of specimen A, B and C over division for upper and lower side of the blade is shown in Figure 4.1 and Figure 4.2 for both Strategy 1 and Strategy 2 respectively. Each division is the average ILSS values a total of 9 specimens from section A, B and C in the same division. For Strategy 1, the highest value is 8.96 MPa for upper side and for lower side is 8.87 MPa while the lowest value is 8.01 MPa and 7.16 MPa for upper side and lower side respectively. For strategy 2, the highest value is 14.65 MPa for upper side and for lower side is 12.70 MPa while the lowest value is 9.78 MPa and 8.60 MPa for upper side and lower side respectively.

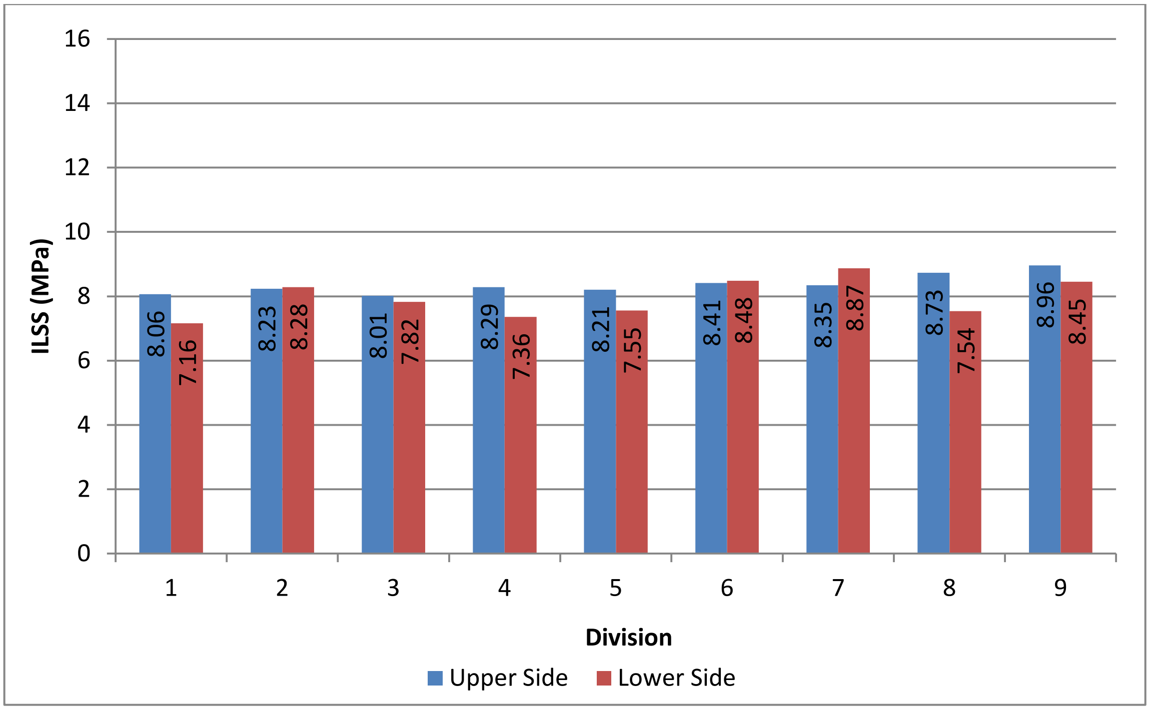

Figure 4.1: Comparison of ILSS values from root to tip for Strategy 1.

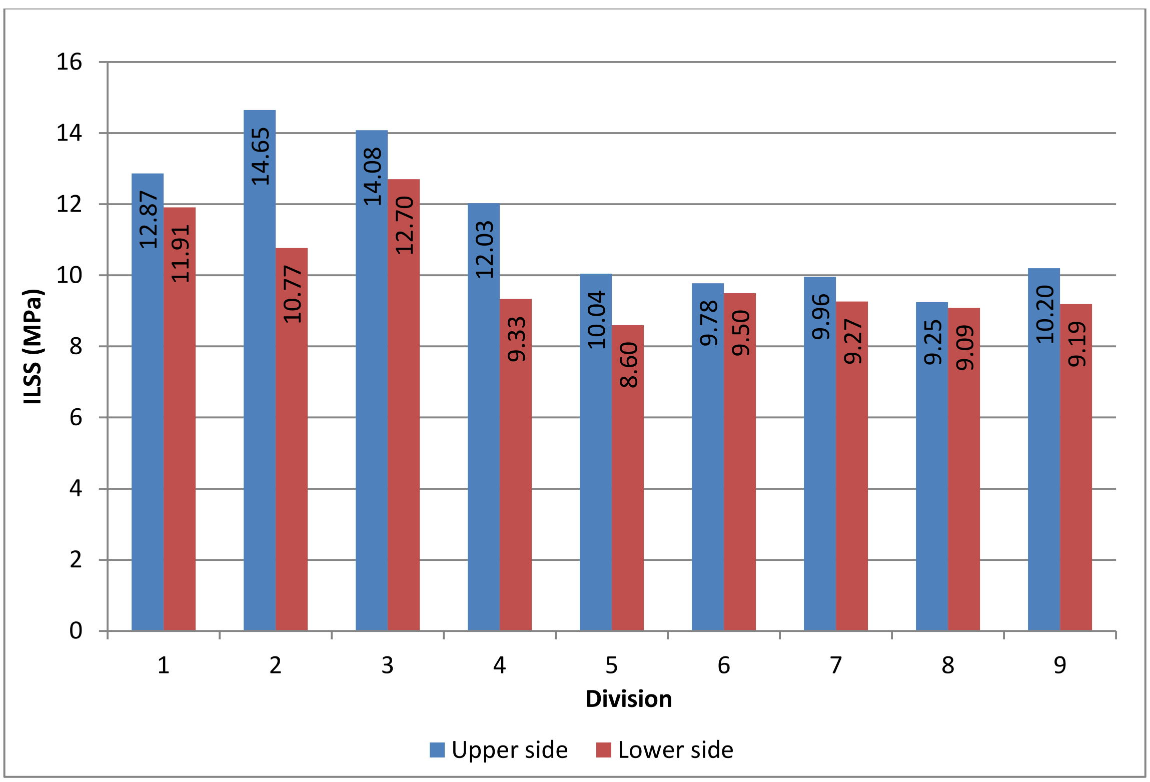

Figure 4.2: Comparison of ILSS values from root to tip for Strategy 2.

The relation of the average ILSS values of specimen A, B and C over location for upper and lower side of blade is shown in Figure 4.3 and Figure 4.4 for Strategy 1 and Strategy 2 respectively. For this analysis, the comparison made base on three different major locations which are the root, middle and tip area. Each area comprises of 27 specimens or three divisions starting from Division 1 to Division 3 for root area, Division 4 to Division 6 for middle area and Division 7 to Division 9 for tip area. This analysis is made to obtain the over view of the wind turbine blade polymer composite ILSS distribution from these area. The ILSS values showed the values of the upper side, lower side and also the average for both side. The ILSS values generally increasing from the root to the tip area which include the middle area for Strategy 1 means that the value for the tip area is highest followed by the middle area and the lowest is the root area. For Strategy 2 the ILSS value is decreasing from root to tip area means that the root area has the highest value followed by the middle area and the lowest is the tip area. For Strategy 1 the different of the ILSS value for upper and lower side is not too obvious because the values for all area are almost the same while for Strategy 2 the ILSS value for the root area shows a significant different compare to other area where the value at the tip area only have small different for the upper and lower side.

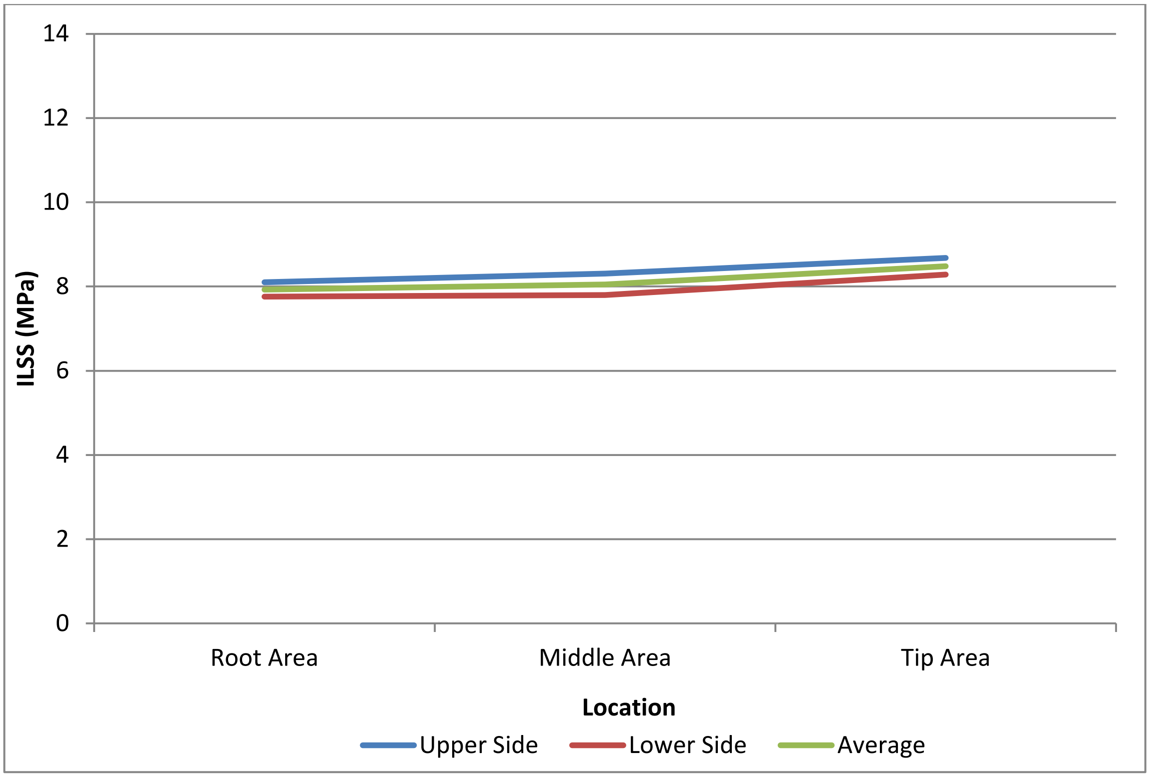

Figure 4.3: Comparison of ILSS values for root, middle and tip area for Strategy 1.

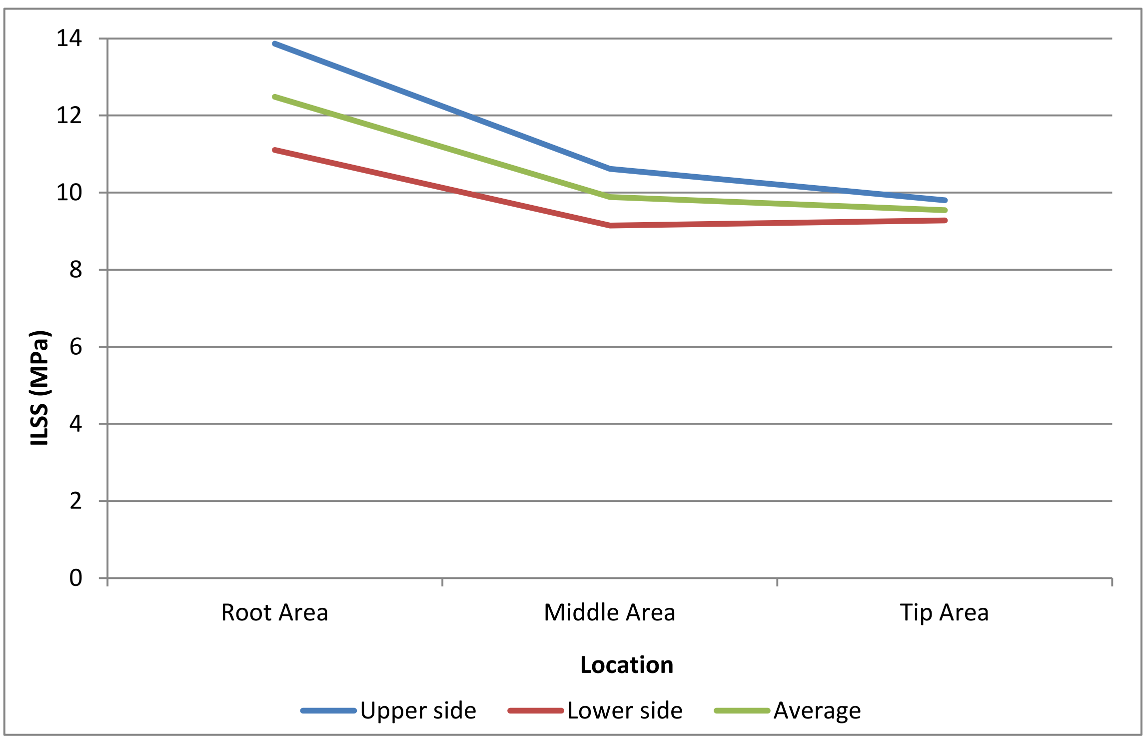

Figure 4.4: Comparison of ILSS values for root, middle and tip area for Strategy 2.

4.3. ILSS Analysis from Leading Edge to Trailing Edge

The relation between the average ILSS values of specimen A, B and C over line for upper and lower side of the blade is shown in Figure 4.5 and Figure 4.6. For this analysis, the comparison made based on the three different major areas in horizontal direction which are leading edge, intermediate area and trailing edge. The leading edge covers the Section A area while intermediate and trailing edge cover Section B and Section C respectively. The ILSS value for each section is the average of 27 specimens located in the same line. For both strategies, the ILSS values are averagely almost the same for the leading edge. For trailing edge, it shows little different on the Strategy 1 while it shows high different on the Strategy 2 for upper and lower side where the upper side have higher ILSS compare to lower side for both strategies.

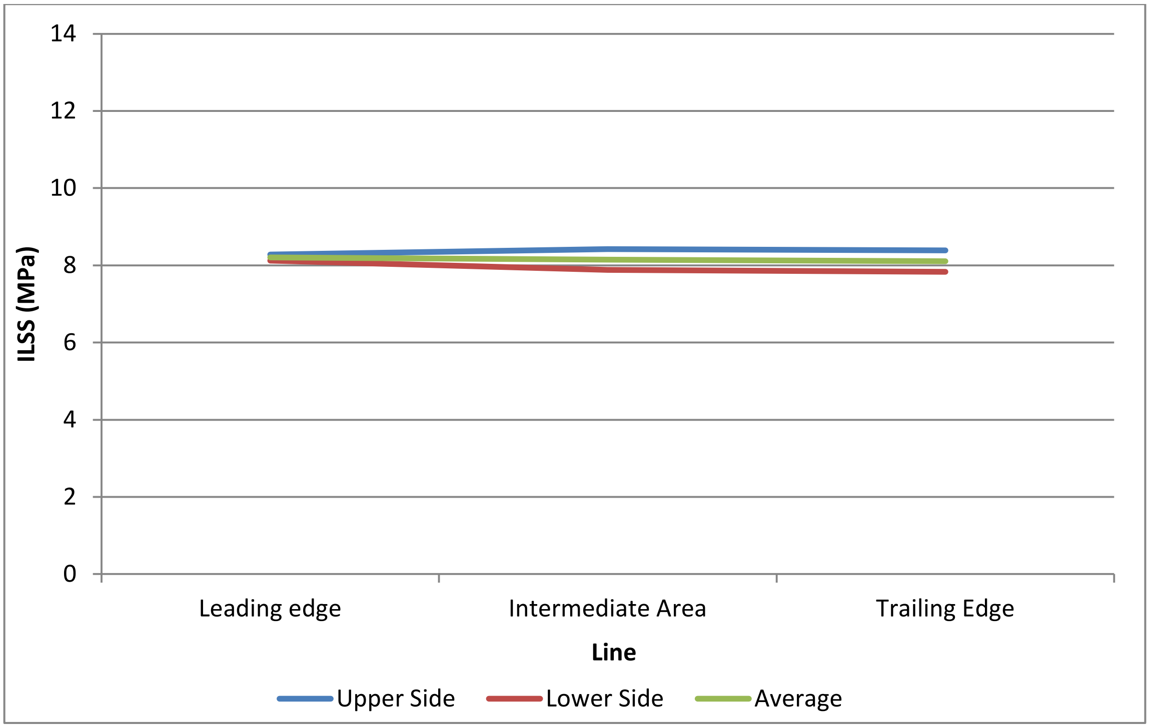

Figure 4.5: Comparison of ILSS values from leading edge to trailing edge for Strategy 1.

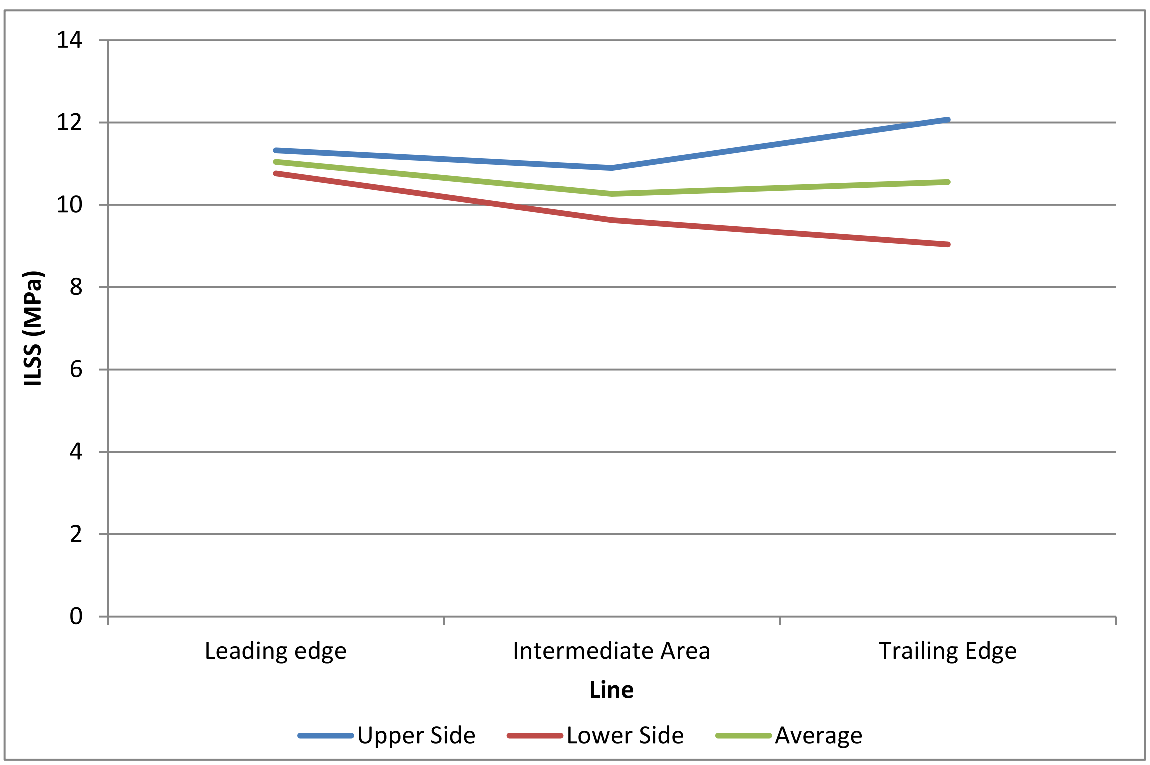

Figure 4.6: Comparison of ILSS values from leading edge to trailing edge for Strategy 2.

4.4. ILSS Analysis of Section Area over Location

The ILSS values of section areas from root area to tip area of the blade are shown in for the upper side and the lower side for both strategies. Figure 4.7 and Figure 4.8 show the values of the upper side for Strategy 1 and Strategy 2 respectively. Figure 4.9 and Figure 4.10 show the values for lower side for Strategy 1 and Strategy 2 respectively. The section area covers the leading edge, intersection area and trailing edge. Each of the line is the average ILSS value of 6 specimens located from upper and lower side of the blade in the same section area. For the upper and lower side of both strategies, generally there was no trend in the distribution of the ILSS value from the root area to the tip area through the middle area for leading edge, intermediate area and trailing edge.

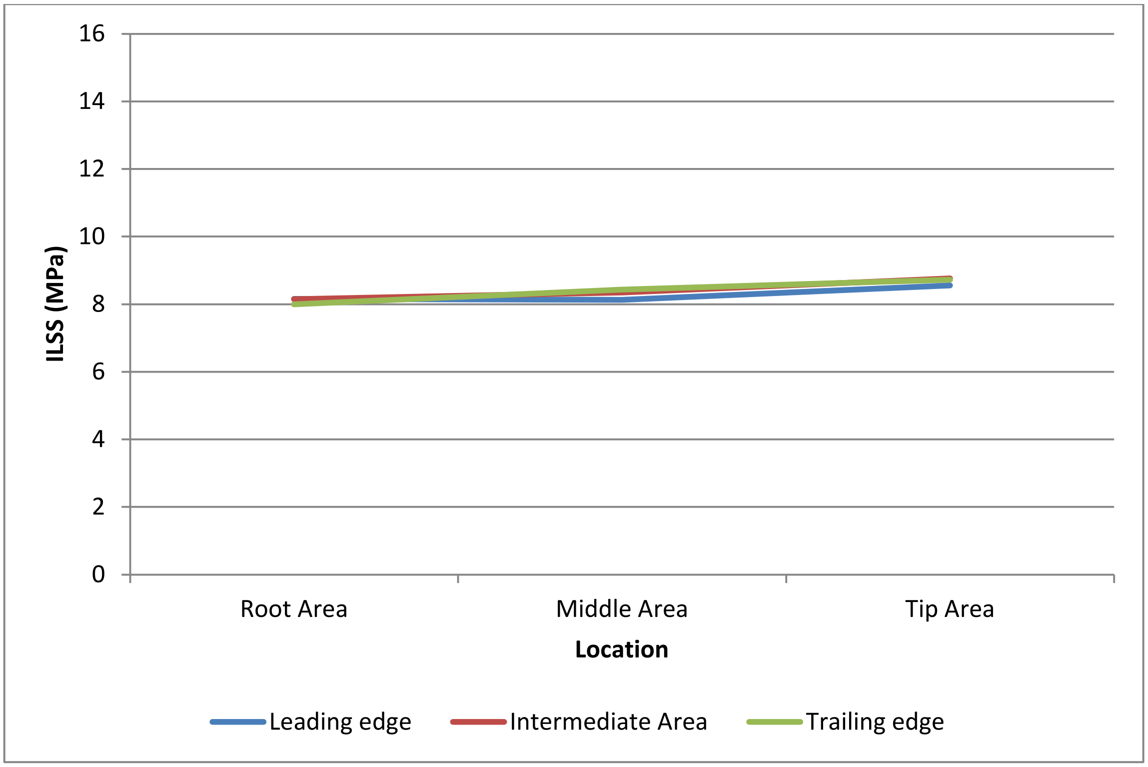

Figure 4.7: ILSS values of section area from root to tip (Upper Side) for Strategy 1.

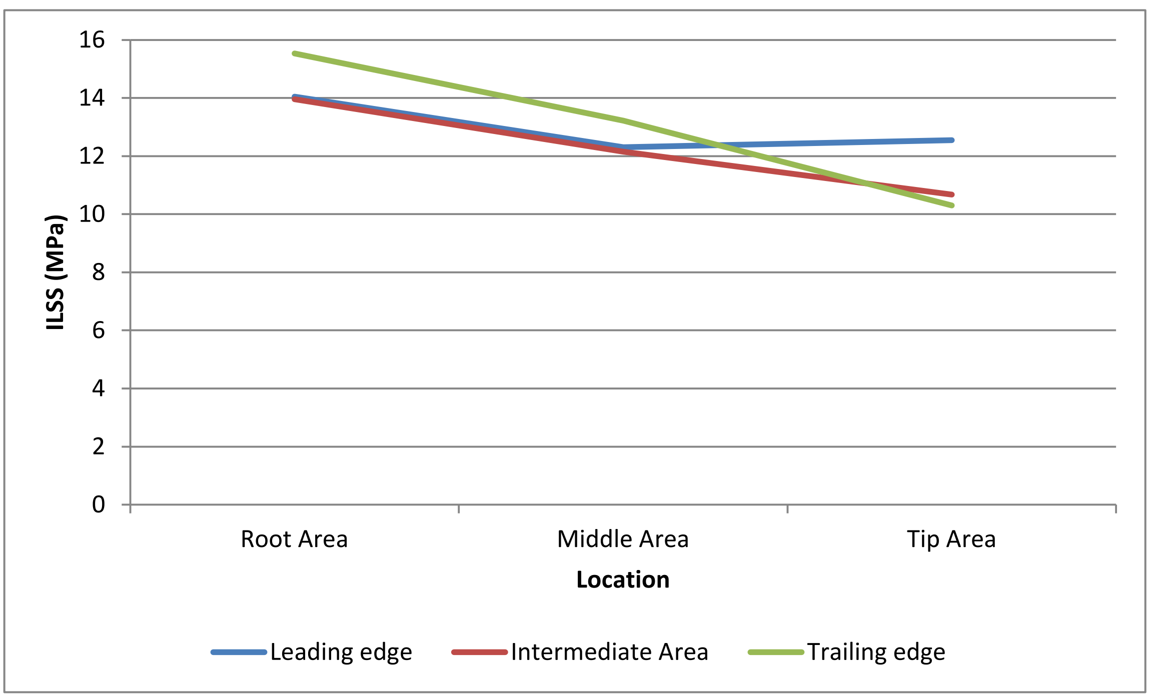

Figure 4.8: ILSS values of section area from root to tip (Upper Side) for Strategy 2.

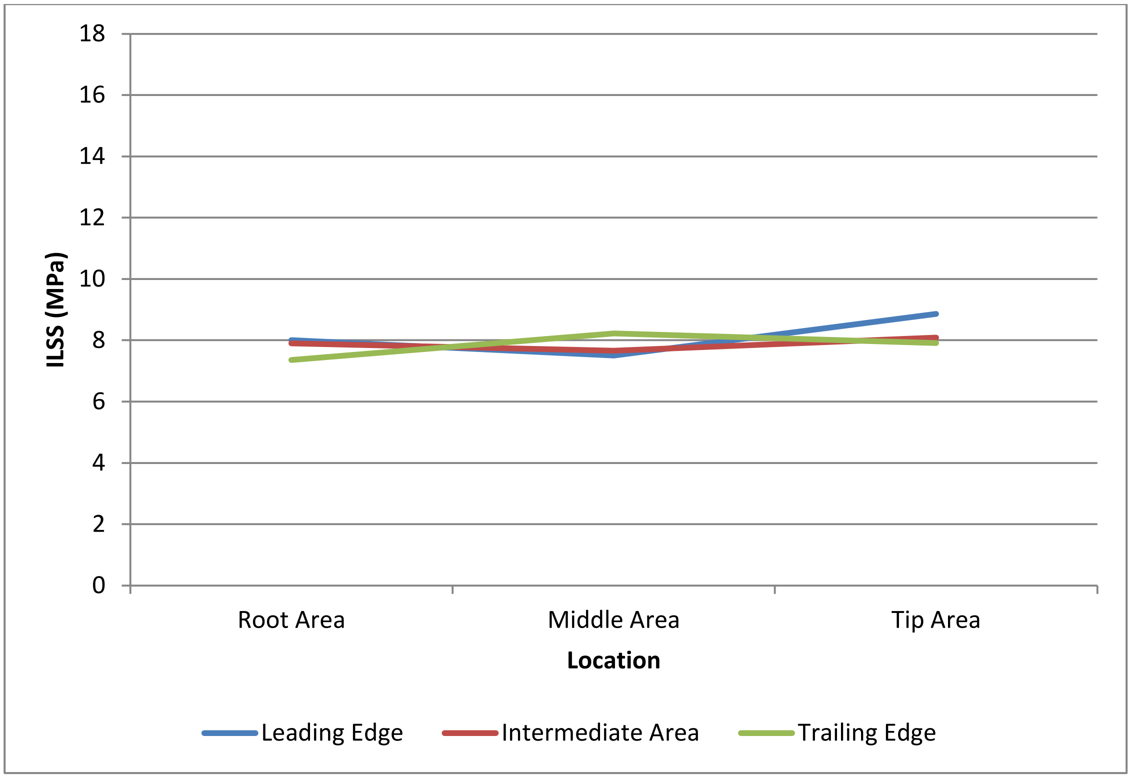

Figure 4.9: ILSS values of section area from root to tip (Lower Side) for Strategy 1.

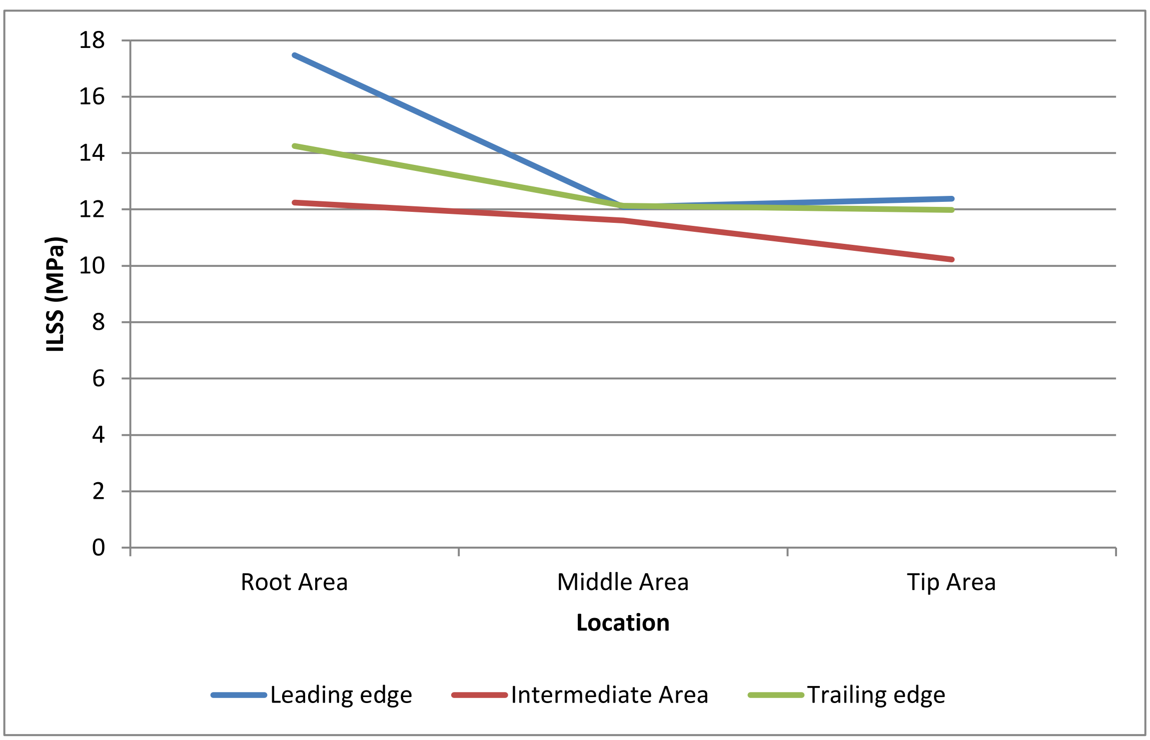

Figure 4.10: ILSS values of section area from root to tip (Lower Side) for Strategy 2.

4.5. ILSS Comparison of Strategies over the Blade

The comparison of the average ILSS values over the blade is shown in Figure 4.11. For this analysis, the comparisons made on both Strategy 1 and Strategy 2. The average of the ILSS values of one blade is taken for the upper side, lower side and also the average for both sides. The ILSS value of the upper side and lower side is the average value of 54 specimens in the entire blade over the side. The error bars is the standard deviation of all the ILSS value in the blade for each strategy. By doing the error bars, the intersection of the values for both strategies can be seen clearly. Figure shows clearly that even though Strategy 2 value is better, the error bar shows there are still a lot of intersection value between both strategies. For the upper side, the percentage of Strategy 2 is better than Strategy 1 is about 36.7% while for the lower side the percentage of Strategy 2 is better than Strategy 1 is about 23.4% and averagely, Strategy 2 gives better ILSS value compare to Strategy 1 for about 30.1%.

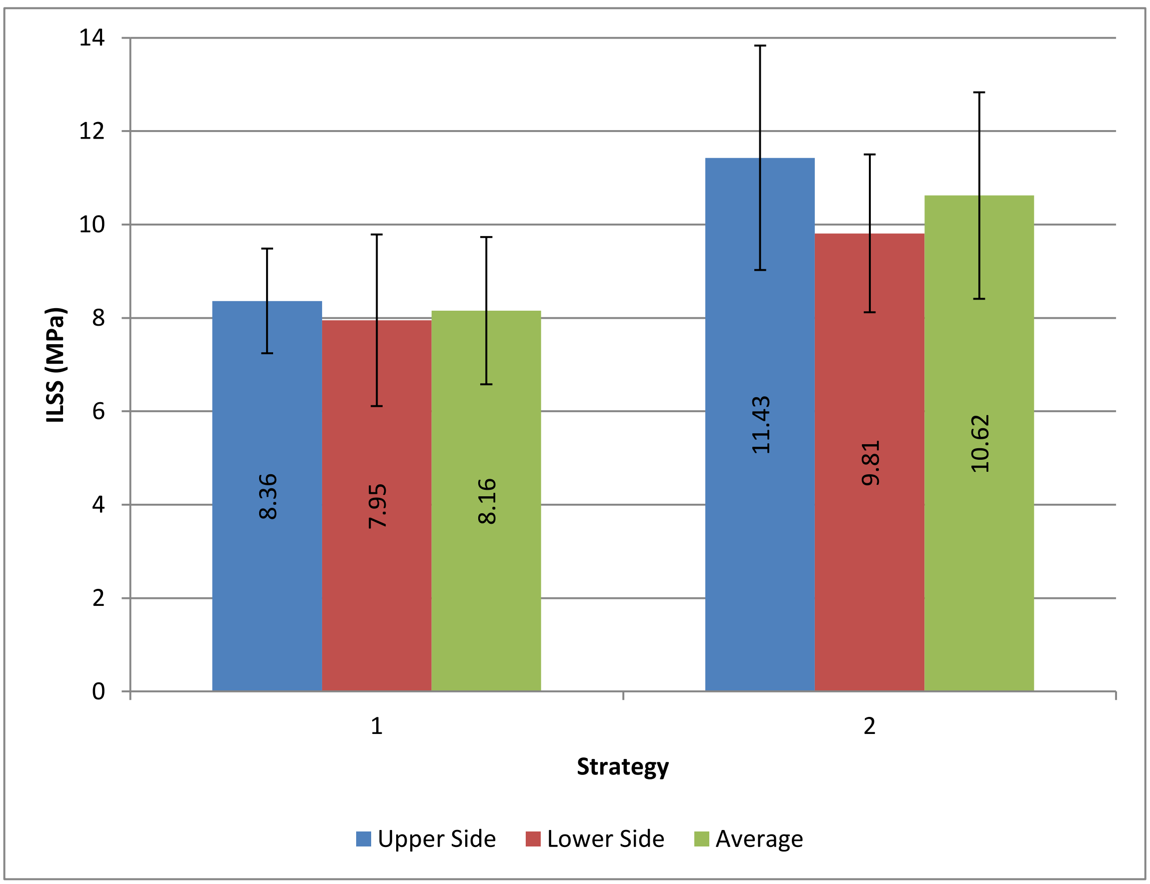

Figure 4.11: ILSS values comparison between Strategy 1 and Strategy 2 over a blade.

4.6. Mapping ILSS Distribution on a Single Blade

Figure 4.12 and Figure 4.13 show the mapping of ILSS distribution of the first blade of Strategy 1 for upper side and lower side over division respectively while Figure 4.14 and Figure 4.15 show the mapping of the second blade of Strategy 1 for upper side and lower side respectively. Meanwhile, Figure 4.16 and 4.17 show the mapping for first blade of Strategy 2 for the upper side and lower side respectively. The difference of ILSS between the specimens is not the same which is some of the difference are low and some of them are high. For the first blade of Strategy 1 there is no pattern in the distribution and from the figure, it clearly shows that the highest and the lowest value is at the lower side of the blade. For the second blade of Strategy 1, there is also no pattern in the distribution along the blade but it does not show the highest and lowest value clearly. For the first blade of Strategy 2, the ILSS value is higher at the root area compare to the other area for both upper and lower side. The highest value is at the upper side while the lowest value is at the lower side of the blade.

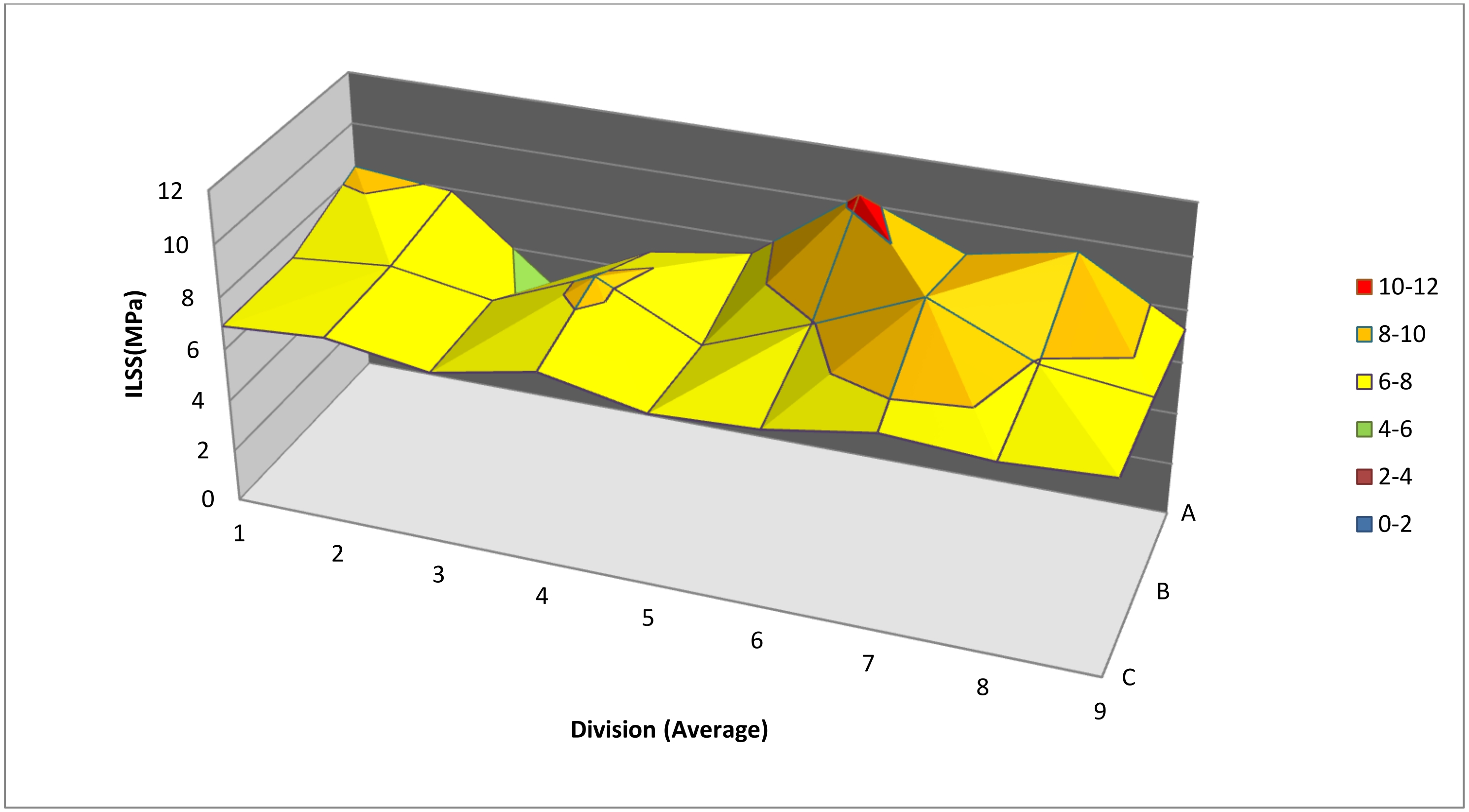

Figure 4.12: ILSS distribution of the upper side of the blade over division for first blade of Strategy 1.

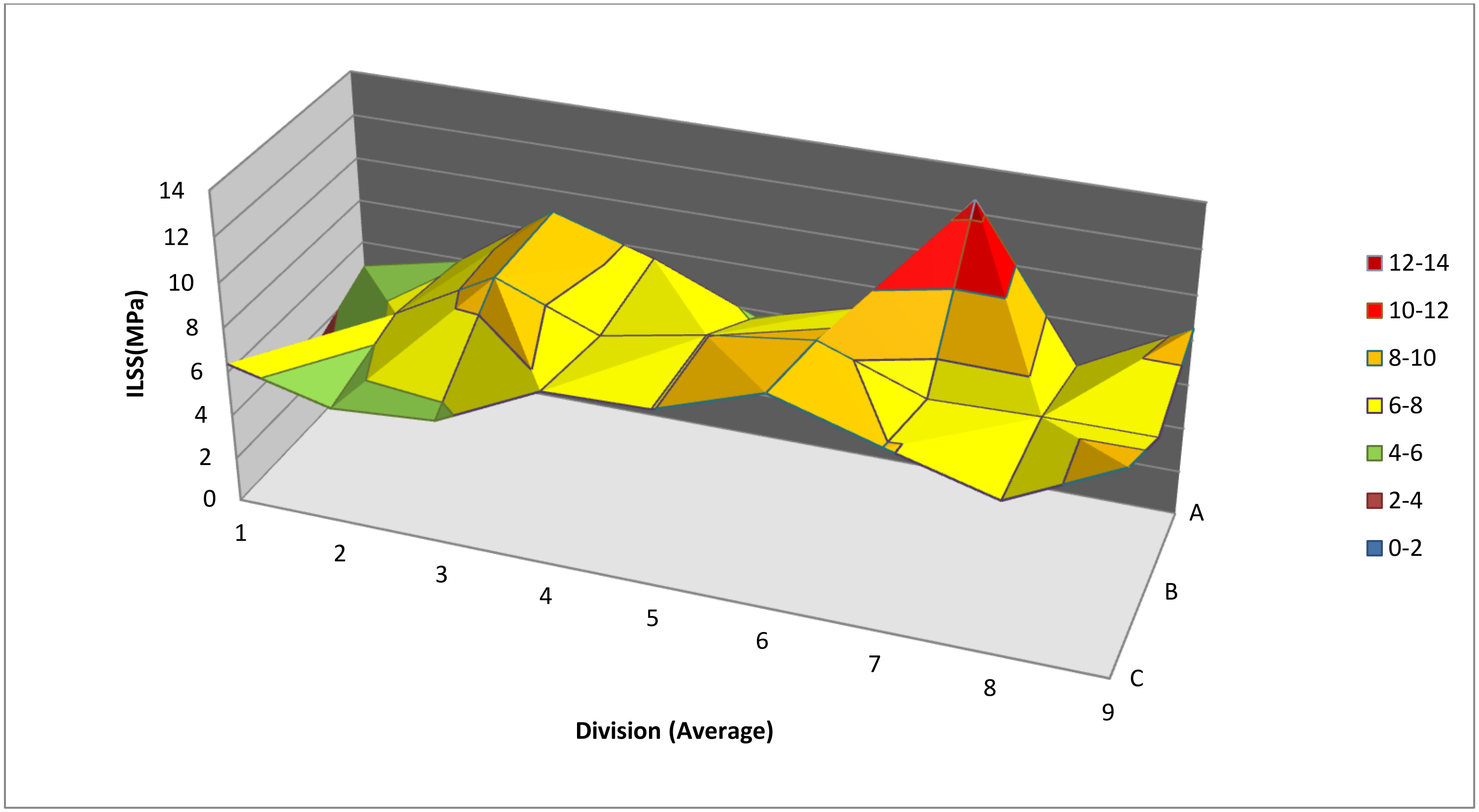

Figure 4.13: ILSS distribution of the lower side of the blade over division for first blade of Strategy 1.

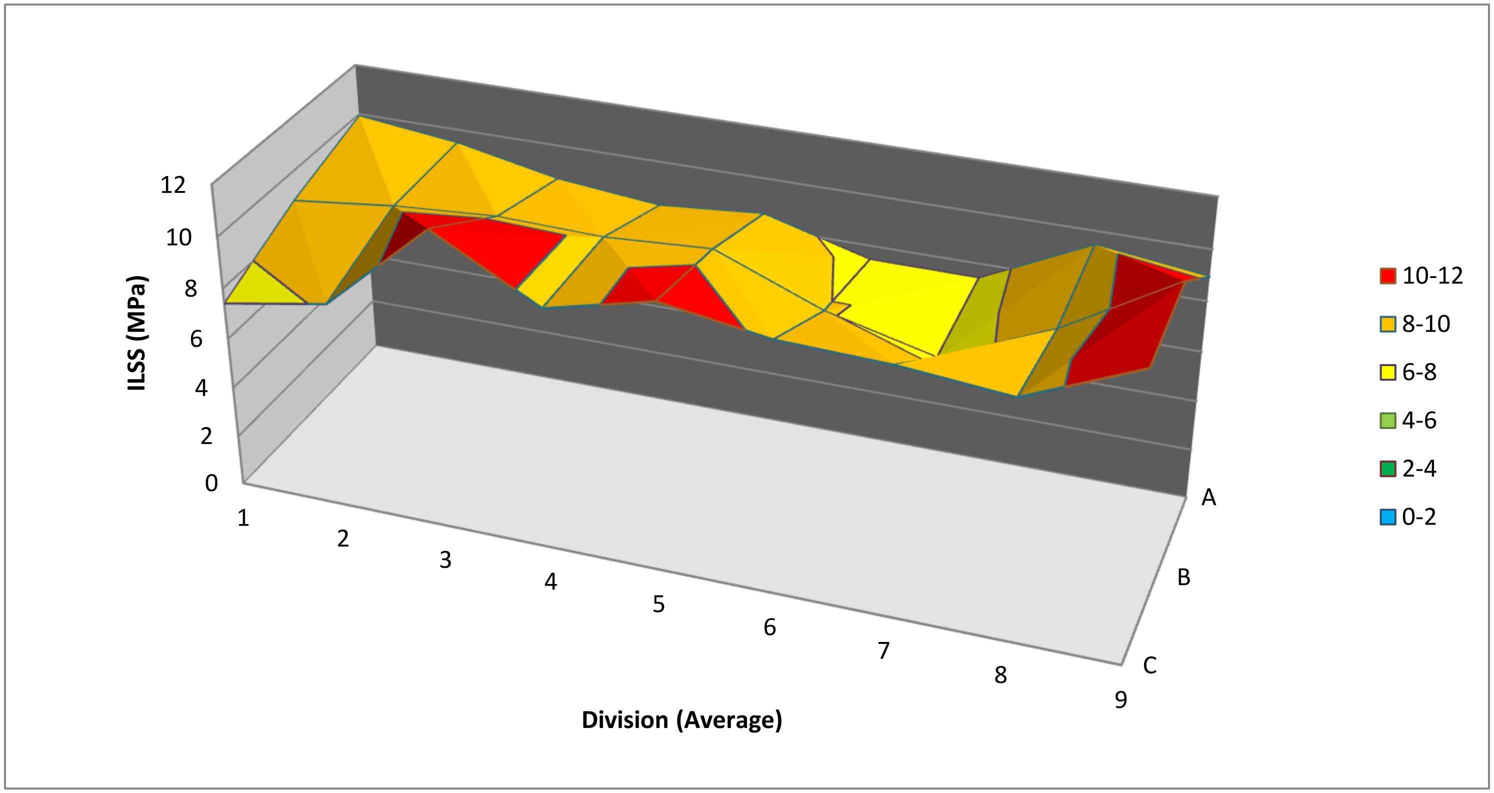

Figure 4.14: ILSS distribution of the upper side of the blade over division for second blade of Strategy 1.

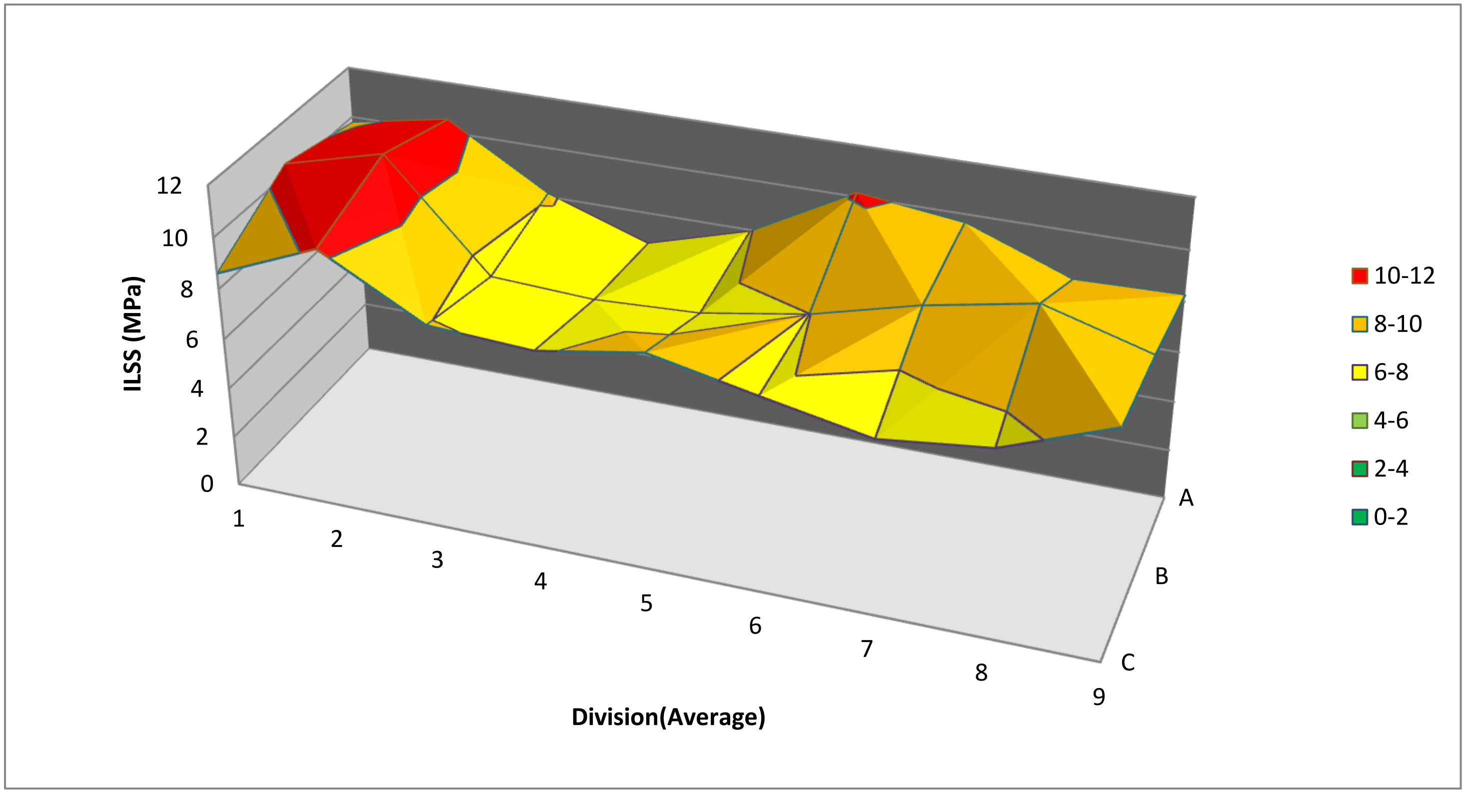

Figure 4.15: ILSS distribution of the lower side of the blade over division for second blade of Strategy 1.

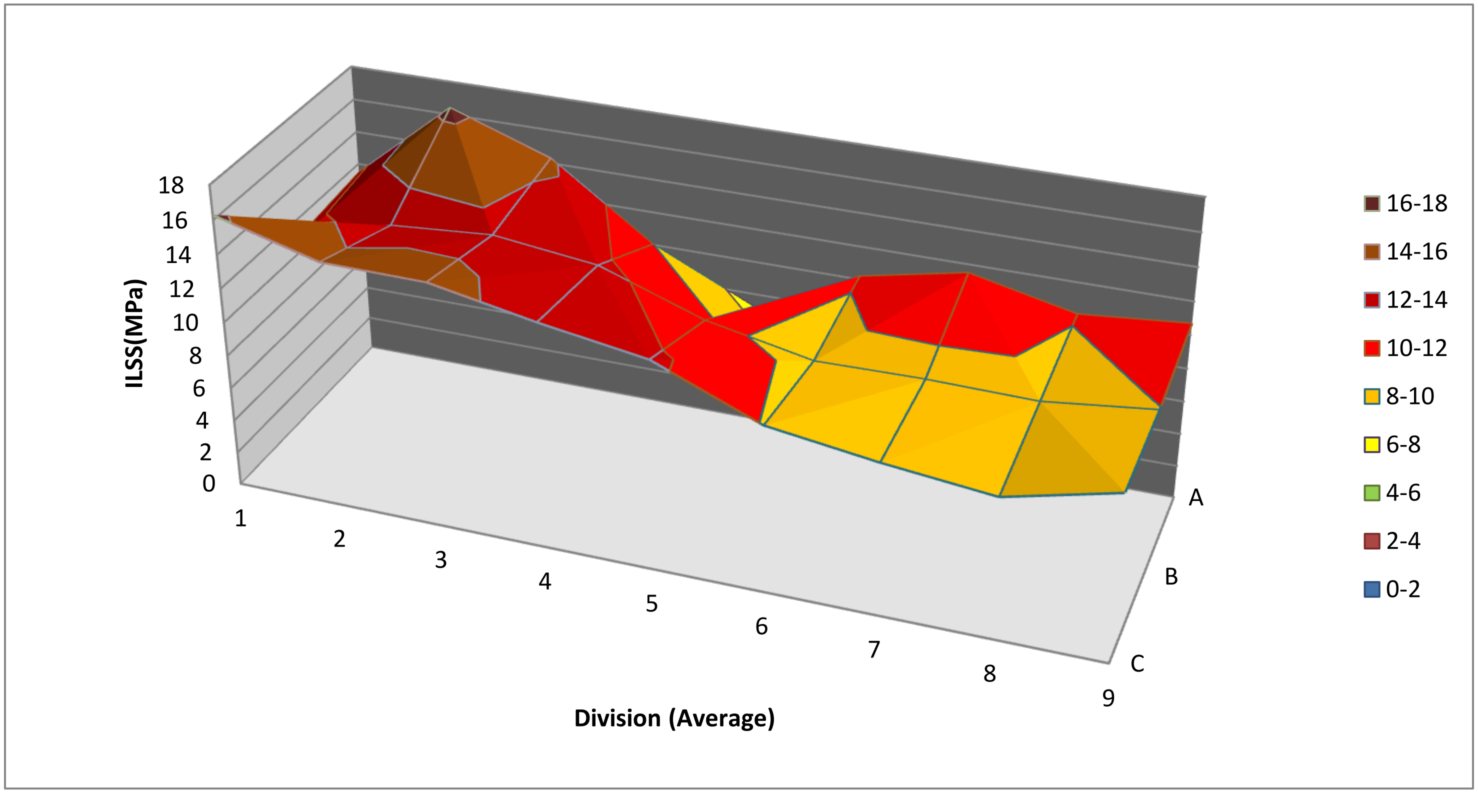

Figure 4.16: ILSS distribution of the upper side of the blade over division for first blade of Strategy 2.

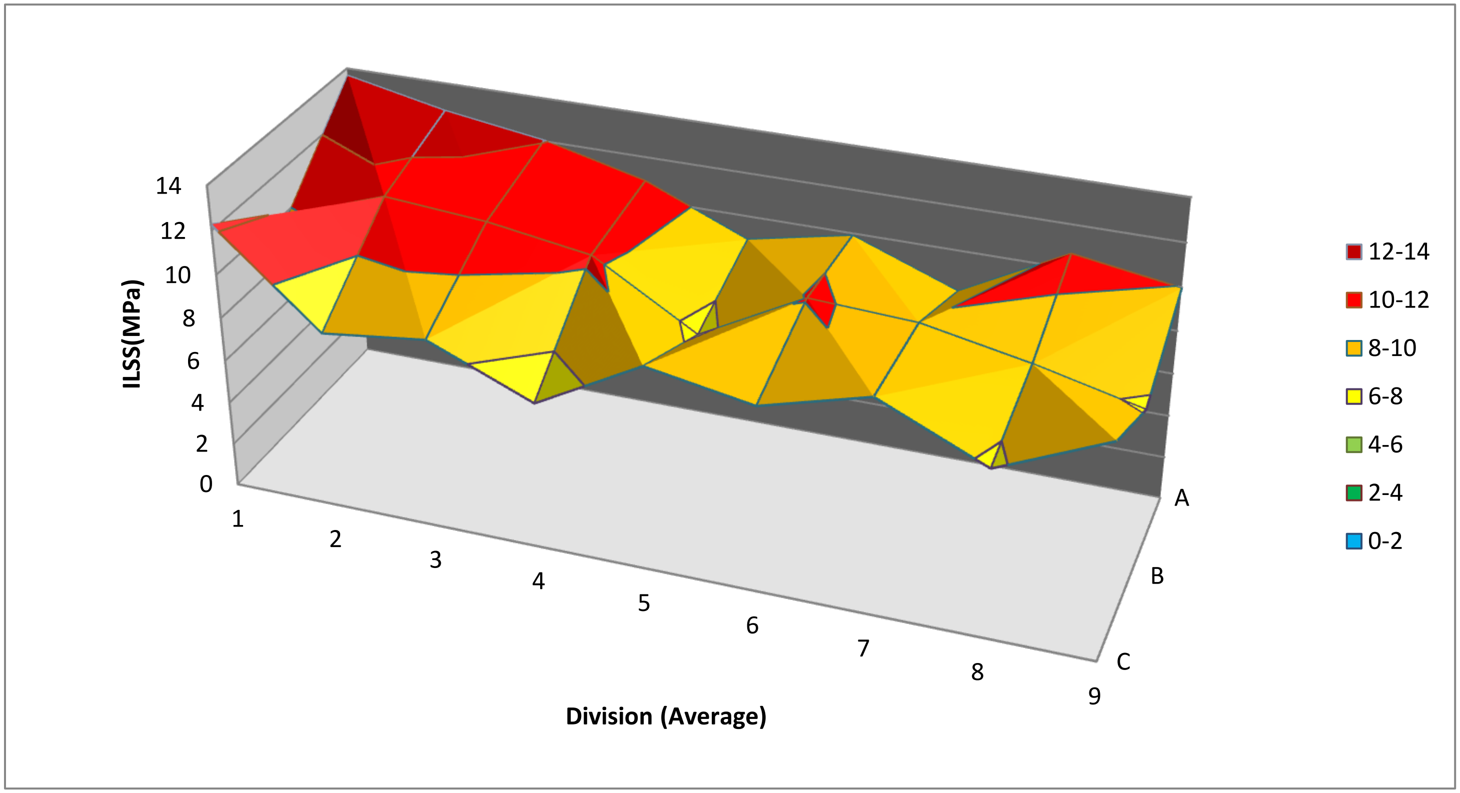

Figure 4.17: ILSS distribution of the lower side of the blade over division for first blade of Strategy 2.

CHAPTER 5

CONCLUSION & RECOMMENDATIONS

5.1. Conclusion

The study of different strategies to manufacture certain product is very important to know which strategy gives better result. However as for this project, after the analysis is done, there is evidence that the Strategy 2 is better than Strategy 1 but further analysis shows that there is no conclusive evidence that say the Strategy 2 is better than Strategy 1, means that further studies must be done in order to prove this fact.

The mapping process is done successfully where the ILSS distribution can be seen for all the blades. There is no pattern in the distribution of the ILSS along the blade.

5.2. Recommendations

For the recommendations there are several aspect must be stress in the future experiment.

- Smaller scale of three point bending fixture used in short beam shear test required in order to obtain more accurate ILSS value.
- More suitable software must be used for the mapping of the ILSS distribution on a single blade for better display of the distribution pattern.

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APPENDICES

APPENDIX 1-1: FINAL YEAR PROJECT I GANTT CHART

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

APPENDIX 1-2: FINAL YEAR PROJECT II GANTT CHART

No.	Activities /Weeks	1	2	3	4	5	6	7	Mid-Semester break	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											Submission of Progress Report						
5	Run testing for all samples 2																
6	Analyzing data and result documentation																
7	Pre-EDX																
8	Submission of Draft Report									Submission of Draft Report							
9	Submission of Dissertation (soft bound)											Submission of Dissertation					
10	Submission of Technical Paper											Submission of Technical Paper					
11	Oral Presentation																
12	Submission of Project Dissertation (hard bound)													Submission of Project Dissertation			

APPENDIX 1-3: EXAMPLE OF DATA GATHERED

Specimen	Sample	Thickness, t		Width, w		Max load, P(m)	Short beam shear strength
		Average	Specimen Average	Average	Specimen Average		
A1	U1	1.440	1.4533	5.107	4.6133	75.889	7.7400
	U2	1.473		4.540		71.263	7.9904
	U3	1.447		4.193		73.045	9.0308
	L1	1.527	1.5356	4.900	4.6600	30.114	3.0192
	L2	1.567		4.533		46.958	4.9588
	L3	1.513		4.547		59.406	6.4754
B1	U1	1.547	1.5178	5.140	5.3022	61.240	5.7775
	U2	1.573		4.920		57.955	5.6152
	U3	1.433		5.847		107.159	9.5904
	L1	1.733	1.6533	5.453	5.4933	30.745	2.4394
	L2	1.620		5.000		34.076	3.1552
	L3	1.607		6.027		44.252	3.4276
C1	U1	1.620	1.6067	4.220	4.2289	73.245	8.0355
	U2	1.660		4.087		34.706	3.8370
	U3	1.540		4.380		79.740	8.8663
	L1	1.467	1.5133	4.913	4.5089	45.983	4.7858
	L2	1.553		4.033		64.236	7.6897
	L3	1.520		4.580		61.532	6.6291
A2	U1	1.453	1.4778	4.687	4.9822	47.536	5.2343
	U2	1.460		5.147		123.802	12.3569
	U3	1.520		5.113		63.240	6.1025
	L1	1.533	1.5111	4.687	4.9244	78.608	8.2040
	L2	1.573		5.313		40.742	3.6552
	L3	1.427		4.773		51.261	5.6455
B2	U1	1.440	1.4600	5.140	5.0578	76.334	7.7349
	U2	1.487		4.787		38.807	4.0900
	U3	1.453		5.247		104.284	10.2572
	L1	1.573	1.5800	5.333	5.0089	49.412	4.4165
	L2	1.593		4.627		46.979	4.7796
	L3	1.573		5.067		106.070	9.9795
C2	U1	1.513	1.5778	4.113	4.4400	83.961	10.1160
	U2	1.600		4.313		67.509	7.3365
	U3	1.620		4.893		43.811	4.1450
	L1	1.480	1.4978	5.207	4.9289	53.613	5.2181

	L2	1.500		4.513		49.433	5.4763
	L3	1.513		5.067		51.183	5.0065
A3	U1	1.453	1.4778	5.520	5.2644	45.819	4.2835
	U2	1.487		5.493		44.864	4.1201
	U3	1.493		4.780		56.932	5.9818
	L1	1.533	1.5556	5.700	5.2711	114.840	9.8547
	L2	1.540		5.587		124.680	10.8689
	L3	1.593		4.527		59.961	6.2351
B3	U1	1.493	1.4867	5.280	4.8667	70.524	6.7082
	U2	1.473		3.940		58.020	7.4962
	U3	1.493		5.380		63.360	5.9148
	L1	1.567	1.5756	5.307	4.7800	97.797	8.8224
	L2	1.547		3.740		55.620	7.2115
	L3	1.613		5.293		120.780	10.6073
C3	U1	1.480	1.4733	4.347	4.7711	41.796	4.8728
	U2	1.473		4.727		73.001	7.8620
	U3	1.467		5.240		72.609	7.0858
	L1	1.520	1.5489	4.460	4.7733	41.436	4.5842
	L2	1.513		4.667		64.630	6.8636
	L3	1.613		5.193		59.609	5.3358
A4	U1	1.467	1.4911	5.487	4.6000	78.794	7.3437
	U2	1.520		4.647		43.907	4.6624
	U3	1.487		3.667		60.468	8.3196
	L1	1.580	1.5500	5.827	4.5422	95.426	7.7741
	L2	1.523		4.273		70.912	8.1699
	L3	1.547		3.527		49.502	6.8065
B4	U1	1.493	1.4689	6.080	5.5489	92.173	7.6139
	U2	1.473		4.840		87.688	9.2226
	U3	1.440		5.727		89.830	8.1699
	L1	1.560	1.5778	6.427	5.6067	109.950	8.2252
	L2	1.580		4.713		71.917	7.2428
	L3	1.593		5.680		68.738	5.6964
C4	U1	1.473	1.4533	5.700	4.9311	78.767	7.0344
	U2	1.467		4.520		75.898	8.5866
	U3	1.420		4.573		56.791	6.5587
	L1	1.573	1.5933	7.180	5.3733	99.434	6.6016
	L2	1.600		4.353		79.344	8.5435
	L3	1.607		4.587		81.337	8.2780

A5	U1	1.493	1.4933	5.407	5.3556	66.004	6.1312
	U2	1.527		4.760		66.361	6.8489
	U3	1.460		5.900		106.140	9.2414
	L1	1.533	1.5311	5.520	5.5867	45.545	4.0358
	L2	1.527		5.167		39.606	3.7659
	L3	1.533		6.073		114.120	9.1909
B5	U1	1.420	1.4644	4.787	5.3667	77.448	8.5457
	U2	1.487		5.500		49.464	4.5371
	U3	1.487		5.813		70.718	6.1369
	L1	1.553	1.5533	5.293	5.5400	73.667	6.7196
	L2	1.527		5.760		121.190	10.3362
	L3	1.580		5.567		79.710	6.7971
C5	U1	1.427	1.4911	5.713	5.2511	99.918	9.1938
	U2	1.467		4.700		58.903	6.4087
	U3	1.580		5.340		47.185	4.1944
	L1	1.613	1.5333	5.873	5.2733	110.850	8.7738
	L2	1.520		4.587		65.062	6.9992
	L3	1.467		5.360		84.086	8.0221
A6	U1	1.593	1.5778	5.073	4.8244	74.159	6.8806
	U2	1.607		4.033		101.720	11.7727
	U3	1.533		5.367		135.330	12.3343
	L1	1.500	1.5267	5.207	4.5511	101.600	9.7567
	L2	1.547		3.747		48.321	6.2540
	L3	1.533		4.700		46.354	4.8241
B6	U1	1.500	1.5067	5.573	4.9889	100.070	8.9776
	U2	1.527		4.480		71.248	7.8129
	U3	1.493		4.913		68.786	7.0312
	L1	1.560	1.5911	5.813	5.1933	150.520	12.4482
	L2	1.627		4.687		94.461	9.2929
	L3	1.587		5.080		42.933	3.9949
C6	U1	1.520	1.5200	5.293	4.8067	61.920	5.7719
	U2	1.520		3.747		61.401	8.0863
	U3	1.520		5.380		71.303	6.5395
	L1	1.587	1.6200	5.200	4.6156	114.500	10.4082
	L2	1.700		3.747		66.096	7.7829
	L3	1.573		4.900		106.980	10.4075
A7	U1	1.587	1.5333	4.627	4.9178	75.314	7.6945
	U2	1.500		4.920		89.198	9.0648

	U3	1.513		5.207		98.928	9.4164
	L1	1.527	1.5289	4.547	4.8533	146.390	15.8174
	L2	1.547		4.940		111.700	10.9645
	L3	1.513		5.073		112.470	10.9868
B7	U1	1.453	1.4311	4.607	4.7622	72.177	8.0855
	U2	1.393		4.853		102.620	11.3815
	U3	1.447		4.827		88.794	9.5374
	L1	1.487	1.5289	4.040	4.7533	62.844	7.8475
	L2	1.540		5.133		71.202	6.7551
	L3	1.560		5.087		63.194	5.9728
C7	U1	1.467	1.4889	4.820	4.9867	81.378	8.6336
	U2	1.527		5.300		36.921	3.4223
	U3	1.473		4.840		98.242	10.3327
	L1	1.513	1.5489	4.600	4.5822	57.893	6.2373
	L2	1.573		3.980		85.323	10.2194
	L3	1.560		5.167		85.414	7.9480
A8	U1	1.533	1.5378	4.667	4.5800	91.602	9.6011
	U2	1.500		4.000		107.210	13.4013
	U3	1.580		5.073		59.139	5.5333
	L1	1.560	1.4911	4.847	4.8533	38.925	3.8612
	L2	1.420		4.200		64.443	8.1040
	L3	1.493		5.513		65.497	5.9664
B8	U1	1.473	1.4689	4.893	4.9178	51.550	5.3627
	U2	1.420		4.180		63.011	7.9618
	U3	1.513		5.680		119.630	10.4380
	L1	1.573	1.5489	4.487	4.6756	59.001	6.2687
	L2	1.513		4.100		64.635	7.8129
	L3	1.560		5.440		77.809	6.8765
C8	U1	1.527	1.5400	5.653	4.9867	94.341	8.1981
	U2	1.520		4.553		45.016	4.8781
	U3	1.573		4.753		85.540	8.5785
	L1	1.520	1.5400	5.580	4.7511	90.606	8.0120
	L2	1.520		3.773		40.110	5.2450
	L3	1.580		4.900		75.112	7.2764
A9	U1	1.493	1.5289	5.833	4.8022	79.966	6.8848
	U2	1.547		4.273		61.894	7.0234
	U3	1.547		4.300		69.982	7.8919
	L1	1.567	1.5933	6.193	4.7556	143.960	11.1276

	L2	1.607		4.367		81.498	8.7123
	L3	1.607		3.707		45.658	5.7500
B9	U1	1.480	1.5200	3.927	4.9889	75.269	9.7139
	U2	1.487		5.260		73.888	7.0866
	U3	1.593		5.780		68.704	5.5951
	L1	1.600	1.5911	3.840	4.9933	51.409	6.2755
	L2	1.633		5.493		80.385	6.7193
	L3	1.540		5.647		93.117	8.0311
C9	U1	1.553	1.5400	4.753	5.0022	59.307	6.0243
	U2	1.533		5.640		72.360	6.2754
	U3	1.533		4.613		94.964	10.0686
	L1	1.500	1.5667	4.733	4.9911	96.876	10.2334
	L2	1.593		5.633		107.880	9.0143
	L3	1.607		4.607		82.817	8.3921