CERTIFICATION OF APPROVAL

The Effect of Resin Viscosity in Vacuum Infusion Process

by

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CERTIFICATION OF ORIGINALITY

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

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(MOHD KHAIRUL ANUAR BIN ZAINAL ABIDIN)

ABSTRACT

Vacuum resin infusion process is a technique in advanced composite manufacturing. The technique uses vacuum pressure to draw the matrix into the reinforcements; results in better compaction of resin thus improving the quality of composite. This technique is widely used in manufacturing of boat hulls because of its low cost and high efficiency. In order to obtain a good quality of composite, it is essential to recognize the factors that may affect the quality of infusion process. One of the factors needed to be studied is the viscosity of the resin itself. This project is aimed at studying the effect of resin viscosity to the resin infusion process in terms of filling time and mechanical properties of the composites. Acetone is used as a viscosity modifier to dilute the resin so that the viscosity decreases. The reinforcements were woven glass fiber and the matrix used was epoxy resin. The infusion set up was laid onto a metal plate mold and sealed tightly to avoid leakage. During the infusion, a video camera recorded the filling time and flow front of the matrix. The infused composites panels were cut into specimens and tested for mechanical properties. The result showed that, to complete 50% of the reinforcement, the filling time decreased from 35 minutes to 1.2 minutes as the acetone is increased from 5% acetone to 20%. The stiffness and strength of the composites decreased as the content of acetone inside the resin increased. Therefore, it is shown that the viscosity of resin affects filling time and the use of acetone changed the mechanical properties of the composites.

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Also, I would like to thank all the staff of Building 4, 5, 15, and 17 for their helps in teaching me how to use the equipments and machines such as viscometer, abrasive cutter, and universal testing machine. Luckily, no accident happened while operating the equipment.

And of course thanks to my family for their support that made me strong to fulfill my bachelor degree in Universiti Teknologi PETRONAS (UTP).

LIST OF FIGURES AND TABLES

CHAPTER 1
INTRODUCTION

1.1 Project Background

Vacuum infusion (also known as resin infusion) technique has become common among the industrial applications nowadays. The technique has been used in many applications such as in making the wind blades, hull of boats, gun shields, and even in aerospace applications. The processing technique is simple yet capable enough to produce high quality composite products with higher mechanical strength in less manufacturing cost.

In typical vacuum infusion process (VIP), a dry reinforcement will be placed in an open mold. A laminate bag is then laid onto the reinforcement and sealed to avoid any leakage during sucking process. Then, the vacuum pressure is introduced to pull the resin into the lamination section. Once a complete vacuum is achieved, the resin is literally sucked into the laminate thorough the inlet pipe and distributed through the composite material. As the penetration process goes on, the remaining resin will then sucked by the vacuum (usually using pump) and discharged into the outlet basin. The process will continue until the complete infusion is obtained. The result is a reinforced composite material with higher mechanical strength [1].

Because of its effectiveness, this method has then undergone several improvements and new techniques have been developed prior to improve the quality of the end products. Until now, Resin Transfer Molding (RTM), Controlled Vacuum Infusion (CVI), Resin Infusion under Flexible Tooling (RIFT), Vacuum-Assisted RTM (VARTM), and Bill

Seeman's Composite Resin Infusion Molding Process (SCRIMP) are among the techniques applied by the researchers and manufacturers [2].

However, this project will only use the typical VIP by using the woven-type fibreglasses as the reinforcement, epoxy resin, and solvent. Some of the working papers and ASTM standards have been referred to make this project referable and reasonable.

1.2 Problem Statement

Viscosity of resin is one of the most important factors that need to be considered during the infusion process. Typically, lower resin viscosity will allow easier resin permeation into the reinforcement compared to higher viscosity of resin. However, it is suspected that the impact of using low-viscosity resin will result in worse mechanical properties compared to high-viscosity resin. A thorough research will be done to investigate the effect of viscosity with the filling time and mechanical properties of the final products according to relevant testing standard.

1.3 Objectives

This project is mainly held to achieve a certain objective that is; to investigate the effect of resin viscosity on the vacuum infusion process in term of filling behavior and the subsequent effect on the mechanical properties of the composites.

This project will focus on studying the relationship between the addition of viscosity modifier (acetone) and the mechanical properties of the composite samples as well as the progression of the matrix through the infusion set-up.

CHAPTER 2
THEORY AND LITERATURE REVIEW

2.1 General Theory

2.1.1 Composite Materials

Composite materials have been known to human for thousands of years, and used widely by many living things. The earliest composite materials were straw reinforced brick, which was similar to modern steel reinforced concrete [3]. Some composites that exist naturally are wood bone. A composite is generally any material that is made up of different constituent materials. Typically, the composites are now being used in almost every industry as the demands on materials continue to increase and become more specific. They are used for applications in aerospace, sports, boats, wind-turbines, and automobiles.

Because the composite is made up of two or more materials, there is almost an infinite amount of possible combinations. Because of the, composites can be engineered for requirements I stiffness, strength, damage to tolerance, corrosion resistance, conductivity, and many others. One property that is important is the stiffness to weight ratio, where carbon fiber has excelled. Carbon fiber can have a five times higher stiffness to weight ratio than aluminum [3]. This has encouraged its use in the aerospace industry where weight is something that matter.

Besides, composites have also been chosen for reasons that are related to mechanical performance. They are been use to create materials with almost zero thermal expansion for use in space applications, and have also been used for corrosion-free tanks and piping [3].

Composite are often combined in pairs where materials is in the form of a fiber, and other creates a matrix to support the fiber. Typically, the material with the highest stiffness and tensile strength is used as the fiber to give the material its strength [4]. The matrix can serve several purposes. Mainly, it keeps the fibers aligned and provides compressive and shear strength. Since the fiber would easily buckle in compression, the matrix is intended to stabilize the fiber. In addition to support the fiber, the matrix also protects it. The matrix protects the fiber from abrasion between fibers, a well as from environmental degradation. See Figure 1.

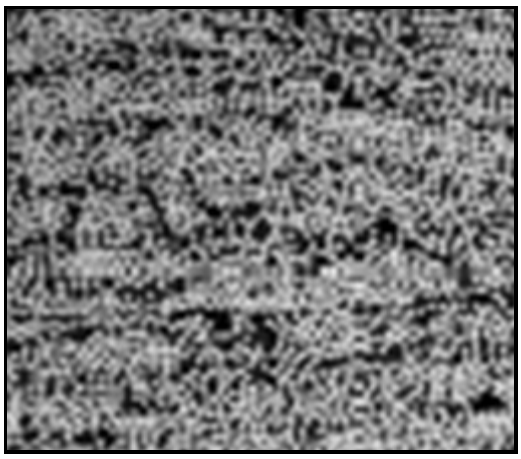

Figure 1: Micrograph (500x) of fibers distributed uniformly in resin matrix. (*Source from http://www.fibersonixx.com/Composites%20101.htm*) [14].

2.1.2 Matrix Materials

Composites utilize many different materials to form the matrix. There are metal matrix composites (MMC), ceramic matrix composites (CMC), and polymer matrix composites (PMC). The first two can be very difficult to process, and have been used for very specific applications. The most common structural composite materials are fiber reinforced plastics (FRP) [5]. Typically, these materials use one of two types of plastic for the matrix. The first type is thermosetting plastics such as epoxy. It is also known as thermostes. Thermosets are polymer chains infused into the reinforcement in the liquid form where they become strongly cross-linked over a short period of time. Due to the cross-linking, these materials tend to become stiff, and resistant to creep. Unfortunately, they can also be very brittle. The second type of polymer used is the thermoplastic such as nylon.

Thermoplastics are also combined with the reinforcement in the liquid form. However, they contain much longer polymeric chains which give them a very high viscosity. As a result, thermoplastics cannot be used in many of the manufacturing processes that thermosets can. The bonding structure is also different in thermoplastics. They form much weaker secondary bonds to holds the polymer chains together [5]. For this reason, thermoplastics can be reshaped and reused to some extent. At the same time, they are also less stiff and prone to creep.

2.1.3 Fiber Materials

The most common reinforcement materials used are glass fibers and carbon fibers. E-glass is the most widely used glass fiber (Figure 2). The principal ingredient is silica (SiO_2), with additions of other oxides to improve workability and corrosion resistance. Glass reinforced plastics have a moderately high strength at a relatively low cost. Typically, bulk glass is considered to be a very weak material. However, this is primarily

due to the presence of flaws in the glass and its low fracture toughness. Any flaws present quickly turn to cracks which can propagate with very little stress. The use of very small fibers in a plastic matrix alleviates this effect in a couple of ways. First, by using very small fibers the average flaw size in the glass can be dramatically reduced [4]. Secondly, fiber failure is isolated by the matrix. If a single fiber breaks, the crack will not propagate through the matrix, and the remaining fibers will carry the load.

Meanwhile, carbon fibers (Figure 2) are the second most common type of reinforcements that has been used. It is famously used in the aerospace industries and big companies as well. Also, the usage is also spreading into sport industries especially for making some items such as bicycle frames, tennis, and badminton rackets. Carbon fiber also has very good fatigue resistance which is important in many designs such as wind turbines. The primary disadvantage of carbon fiber is because of its cost. This factor has limiting the use of carbon fibers in many industries. Besides, carbon fiber also has disadvantage for its high degree of anisotropy. Because the fibers are typically oriented in a single direction, the part is very stiff in that direction, but not in others. For this reason, any waviness or misalignment of the fibers can cause high stress concentration.

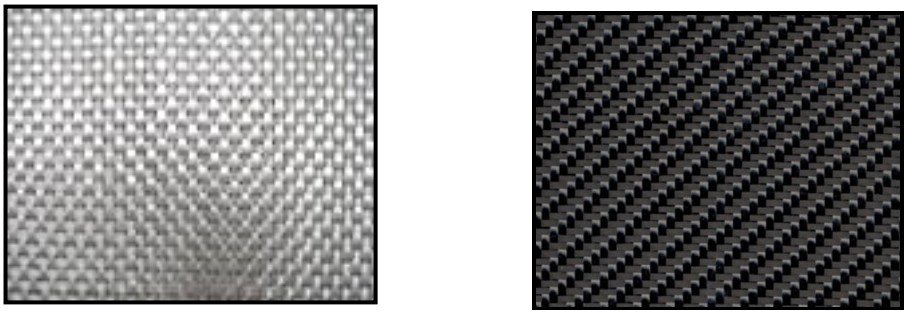

Figure 2: Woven glass fiber (left) and carbon fiber (right). (*Source from http://carbonsales.com/Carbon-Fiber-Panel*).

2.1.4 Resin Infusion Process

Laminated and composites can be produce in a number of ways. One of the most common methods today is resin infusion method also known as vacuum infusion method. Vacuum Infusion (VI) produce low cost process and particularly suitable for low volume production of large components. Compared to hand lay-up, it offers many advantages such as higher fiber volume fraction, lower voids content, and cleaner work environment. If the process is automated, laminates do not vary much in quality, producing higher rate of element fabrication, and increased in precision [6].

During the process, VI method utilizes a vacuum bag to compact a bundle of laminates such as fiberglass or core materials laid, onto the mold. After debulking, the resin is allowed to be infused by the vacuum to completely wet out the reinforcements and eliminate all air voids in the laminate structure. High quality composite parts made from a wide range of fiber and resin combinations can be utilized to infuse laminates up to six inches thick. Typical resins used are polyester, vinyl ester, and epoxy with many being UV cure initiated. This process can routinely produce large 2000 square feet parts such as boat hulls, bus bodies, and railcar panels [7].

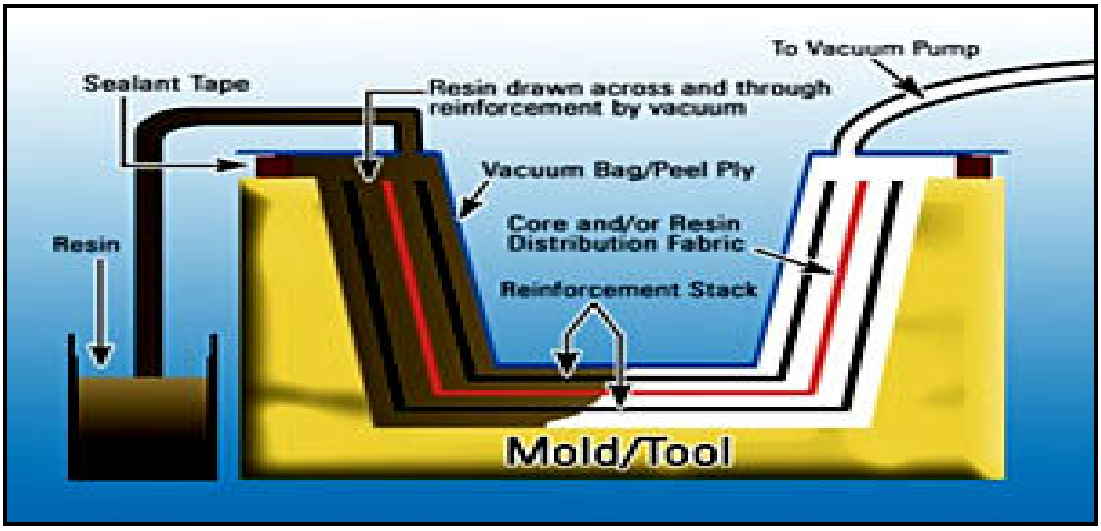

Figure 3: Typical layout of vacuum infusion process. (*Source from www.composites.ugent.be/home_mad...hop.html*).

Table 1 below, will briefly explain the difference between the infusions processes commonly applied.

Table 1: Different type of infusion processes.

Process	Basic Principles	Advantages	Disadvantages
Hand lay-up	• Open mold • Manual infusion • One side mold	• Low cost • Fastest implementation	• Volatile emission • Health risks • Inconsistent results • Material waste
RTM	• Closed mold • In-plane resin flow • Two-sided mold	• Higher dimensional consistency • Both side finished • Less volatile emissions	• Higher mold cost • Resin flow pattern critical • Costly equipment • Lowest volume per part
VARTM	• Closed mold • In-plane flow • Evacuated mold	• Higher dimensional consistency • Less volatile emissions • Higher quality products	• Higher mold cost • Resin flow behavior critical • Complexity of vacuum porting

2.2 Literature Review

There are many research papers and journals can be found regarding vacuum infusion process. The references can be accessed from any means of sources such as libraries, research webs, magazines, and public webs. Researchers from many nations have their studies in many interesting topics especially focusing on analysis of void contents, flow front, mechanical properties, alternative infusion methods, and so on. Most of the reinforcement materials used are glass fibers and carbon fibers which infused either with thermostes, thermoplastics, or latex.

As an example, Crivelli Visconty [8] with his team have done an analysis flow front of resin impregnation resin infusion process. In their studies, they used Resin Infusion under Flexible Tool (RIFT) method to distribute the resin through the glass fiber laminates. In the study, a FEM program named RTM-Worx also being used to give theoretical result. In the experiment, the result of resin flow front was represented by a graph of filling time versus distance.

However, the experiment used in this study is quite different as what Crivelli's team has done. The experiment would be using resin infusion vacuum process which is a simple method. Plus, the experiment done by Crivelli is only focusing on the filling time of the resin, without involving variety of resin's viscosity which what have been done in this study.

Some other similar experiments also been viewed from others researcher such as Patrick E. Mack [9] and Dhiren Modi [6]. Patrick as in his published paper has studied on the effect of volumetric flow rate of a vacuum pump on the resin flow viscosity. The approach was brought by developing standard laminae cell in which flow velocity was characterized by a distance over time (mm versus minutes). The graphs of results was plotted by comparing the resin flow front velocity between that of the control

(19.05 mm Vac.) and of the reduced (9.525 mm Vac.) vacuum volumetric flow rate. The results clearly explained that higher flow front velocity will cover more distance in specified time.

Meanwhile, in many research papers, the experiment done involved mechanical testing of the composite materials. Wonderly *et al* for example, have done a research of comparing the mechanical properties of glass fiber-vinyl ester and carbon fiber-vinyl ester composites. In the experiment, the strength of the glass and carbon fibers specimens were evaluated through tension (ASTM D3039), compression (ASTM D6641), open-hole tension (ASTM D5766), open-hole compression (Northrop 1.5 in.), transverse tension, indentation and ballistic impact.

As for the tested specimens, they used 25.4mm wide-250mm long specimens with fiber orientation of (0, 90). The experimental results from tensile strength testing shown that the glass fiber specimens typically produced XGM failures (explosive failure in gauge area) while carbon fiber specimens shown lateral failure near a tab (LAT).

They calculated the failure stress by dividing the failure load with the cross sectional area of the original specimen. The average failure stress with one standard deviation was 958.0±109.3 MPa for the carbon fiber and 544.4±10.6 MPa for the glass fiber specimens. Figure below shows the summary of the tests.

Table 2: Mechanical properties of glass and carbon fiber specimens from different test configuration by Wonderly at al [10].

Strength of carbon fiber and glass fiber specimens for different test configurations						
		Tension	Com-pression	OHT	OHC	Trans tens
Carbon	Average (MPa)	958	328	621	235	17.8
	Std dev (MPa)	109	37.9	39.9	18.0	1.0
	Std dev (%)	11.4	11.5	6.4	7.7	5.7
	# Specimens tested	10	10	11	14	8
Glass	Average (MPa)	544	396	367	239	23.6
	Std dev (MPa)	10.6	20.3	13.6	14.2	1.9
	Std dev (%)	1.9	5.1	3.7	5.9	8.1
	# Specimens tested	8	11	8	14	8
Carbon strength/glass strength		1.76	0.83	1.69	0.98	0.75

Based on the researches, it would give this study project a better guide. Most of the reviews are much related to this study and can be used as an effective reference. Some of the testing methods like in Wonderly (2005) will also been implemented during this project experiments.

CHAPTER 3
METHODOLOGY

In order to complete this project, several steps and activities are involved, including preparation for dry lay-up, varying the resin viscosity, mixing, degassing, vacuum infusion, recording the filling time, and mechanical testing. All these activities play a significant role in ensuring the quality of the experiment as well as the samples that going to be tested. The samples to be tested necessarily showing a good finishing and fair to be accepted. Once the sample fail either the quality is so poor or impair, it will be rejected and new experiment will be run again.

3.1 Preparation for Dry Lay-Up

The dry lay-up consist of glass fibers, peel plies, net, and breathers (alternative). The peel ply is functioning as a protective layer for the glass fibers. By putting the peel ply above and bottom of glass fibers, it protects the glass fibers from sticking to the mold plate and the net. The peel ply also helps in the permeation of resin into the fiber. The net is used as a flow medium for the resin to travel along the fibers. Figure 4 below shows the configuration of the dry layup.

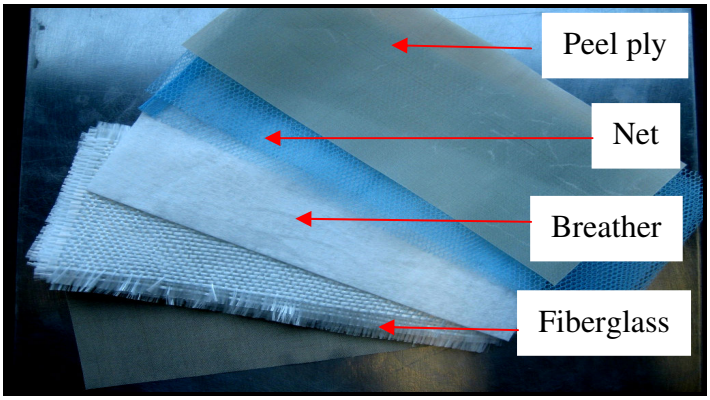

Figure 4: The arrangement of dry lay-up.

The lay-up must be accordingly arranged to ensure smooth infusion progress. Any missing of the items could possibly results in incomplete infusion or problem of fiber sticking to the mold and vacuum bag. In this experiment, the dimension of glass fiber is fixed at 10 plies, width of 200mm (±2cm), and length of 300mm (±2cm).

3.2 Preparation of Matrix

To fulfill the objectives of this project, it is important to emphasize on the viscosity of the resin. The resin used in this experiment was epoxy resin with hardener (supplied by S&N Chemicals Sdn. Bhd). The mixing ratio of epoxy to hardener is 10:6 without an additional of dispersion aid. To vary the viscosity, acetone (produced by Merck KGaA) was used as a dilution agent. Acetone was used because of its potential to dilute the resin without affecting the mixture properties. Moreover, acetone is easier to be obtained and low cost as well.

The acetone was manually stirred with the resin mixture with a described amount of percentage as follows:

Table 3: The percentage of acetone in the resin and hardener.

Sample	**1**	**2**	**3**	**4**
% of Acetone by Weight	5%	10%	15%	20%

Note: The percentage of acetone was respect to the total weight of the epoxy and hardener.

Then, the measurement of viscosity was done by using the viscometer. The measurement was obtained by using Brookfield Viscometer and the parameters set are as follows:

Table 4: Parameters set for Brookfield Viscometer.

Parameter	**Setting**
Temperature	25^{o}C
Running time	60 seconds
Spindle speed	60 RPM
Spindle number	2

Before starting the infusion process, it is necessary to calculate the amount of resin (in weight) that going to be used. This is to reduce resin wastage, and promote a good moral of practice. Then, the calculation is shown as below;

Volume of fiberglass (10 plies) = width x thicknes x length
= 200mm x 2.0175mm x 300mm
= 121050 mm^3

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

$\mathbf{v_m = v_f}$ = 121.05 cm^3

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

$\mathbf{w_m}$ = 1.24 g/cm^3 x 121.05 cm^3 = 150.288 g ≈ 150.3 g

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

= 30% (150.3) + 150.3

= 195.4g ≈ 200g …Then, .apply to mixing ratio of epoxy: hardener (10:6)

3.3 Mixing

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

3.4 Process of Degassing

The degassing process is important during the resin infusion process. After the mixture of matrix is prepared, it was then inserted into the vacuum chamber namely degassing chamber (Figure 5). In the degassing chamber, the vacuum suction will pull out all the bubbles that reside in the matrix. A good suction pressure is needed to surpass the cohesive force between the air into the resin mixture.

Degassing process took about 10 to 15 minutes until all the bubbles pull out of the matrix and the pressure was 61 kPa to 70 kPa (18 inHg to 21 inHg).

Figure 5: The degassing chamber connected to the vacuum pump.

3.5 Vacuum Infusion Process

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

3.6 Recording the Filling time

In order to meet the objectives, a good strategy to record the filling time is necessarily important. For the purpose of recording the filling time, a scaled peel (Figure 6 and 7) ply was used. Grid lines were drawn onto the peel ply and put on top of the net (flow media). This simple method helped a lot in providing a clear visual on matrix flow front during the infusion process.

A video recorder was positioned on vertical top of the infusion lay-up to record the flow of the matrix over time.

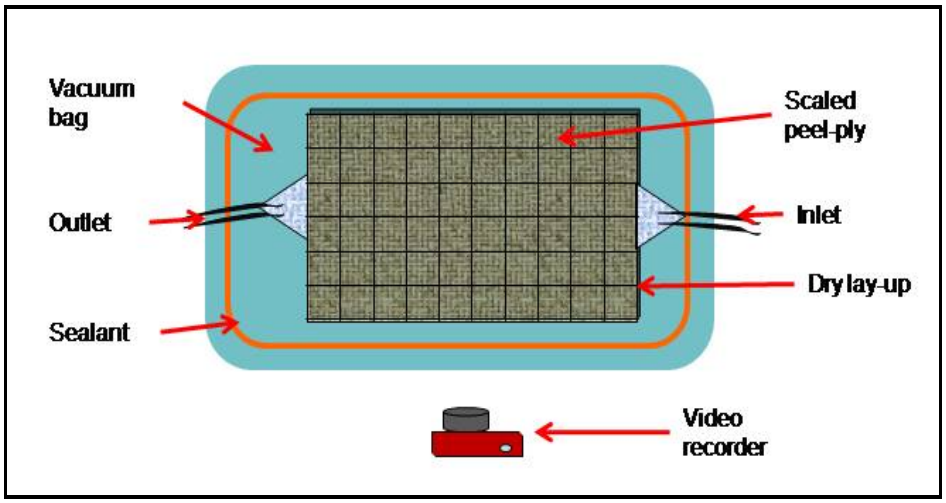

Figure 6: The illustration of scaled peel-ply in infusion set-up

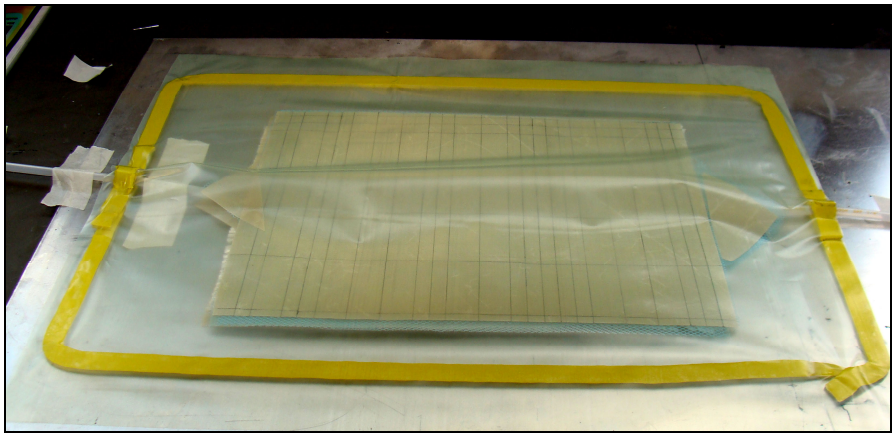

Figure 7: Actual picture of reinforcement set-up.

3.7 Cutting of Specimens

All the cured composites were cut into samples for mechanical testing purposes. The dimensions for each sample were 175.0mm ± 1mm (length), 25.0mm ± 1mm (width), and 2.0 mm ± 0.5mm (thickness).

To cut the composites into samples, diamond-abrasive cutter was used in order to minimize cracks within the sides of the samples which can cause defect during mechanical testing.

3.7 Mechanical Testing

The purpose of mechanical testing is to investigate the stress and strain behavior of the produced composites (samples). The testing was according to ASTM D3039 or BS2782-10 as an alternative [10]. For the testing purpose, Zwick Roell (100KN) testing machine was used. The results obtained from the machine were presented in Chapter 4.

3.8 Brief Infusion Set-up

The figure below explains the overview of place for resin infusion experiment.

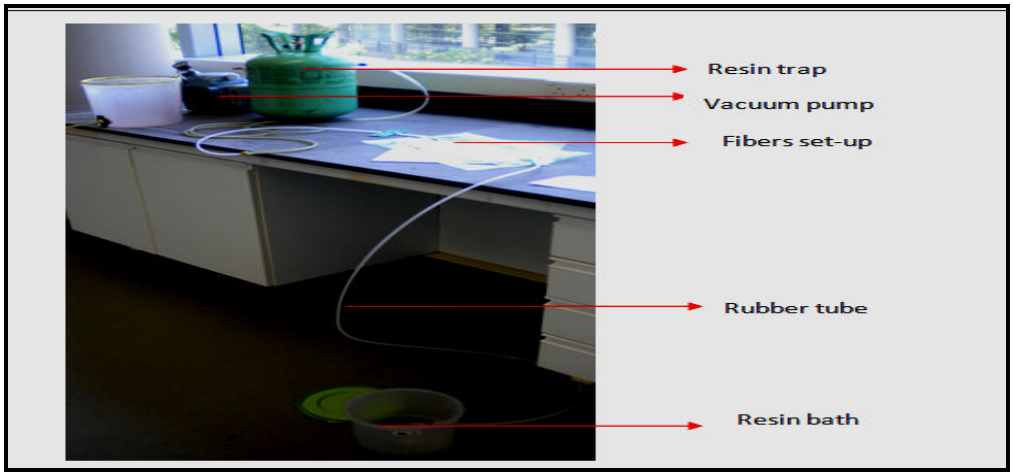

Figure 8: Resin infusion in lab Resin basin

CHAPTER 4
RESULTS AND DISCUSSIONS

There are two major results that are going to be presented; filling time and mechanical testing results. Besides that, this section will also conclude some other experimental results that been obtained from extra experiments that been carried out to check the potential or feasibility of using natural rubber latex with the resin. These extra experiments are mainly aim to achieve an optimum mixture of resin with expectation of better composite properties. However, as the results are not so convincing, then the experiments proceed with normal plan which is by using only epoxy and hardener as a matrix's composition.

4.1 Viscosity of Matrixes

The viscosity for each different percentage of acetone was obtained from Brooklyn viscometer is shown in Table 5.

Table 5: Measured viscosity for each sample.

	Reading	**% of Acetone**			
		5%	**10%**	**15%**	**20%**
Viscosity (Pa. s)	1	0.69	0.57	0.34	0.31
	2	0.69	0.50	0.35	0.40
	3	0.73	0.52	0.43	0.48
	4	0.80	0.58	0.45	0.43
	5	0.81	0.70	0.44	0.47
	Average	**0.75**	**0.57**	**0.40**	**0.42**
	Std dev	0.06	0.08	0.05	0.07

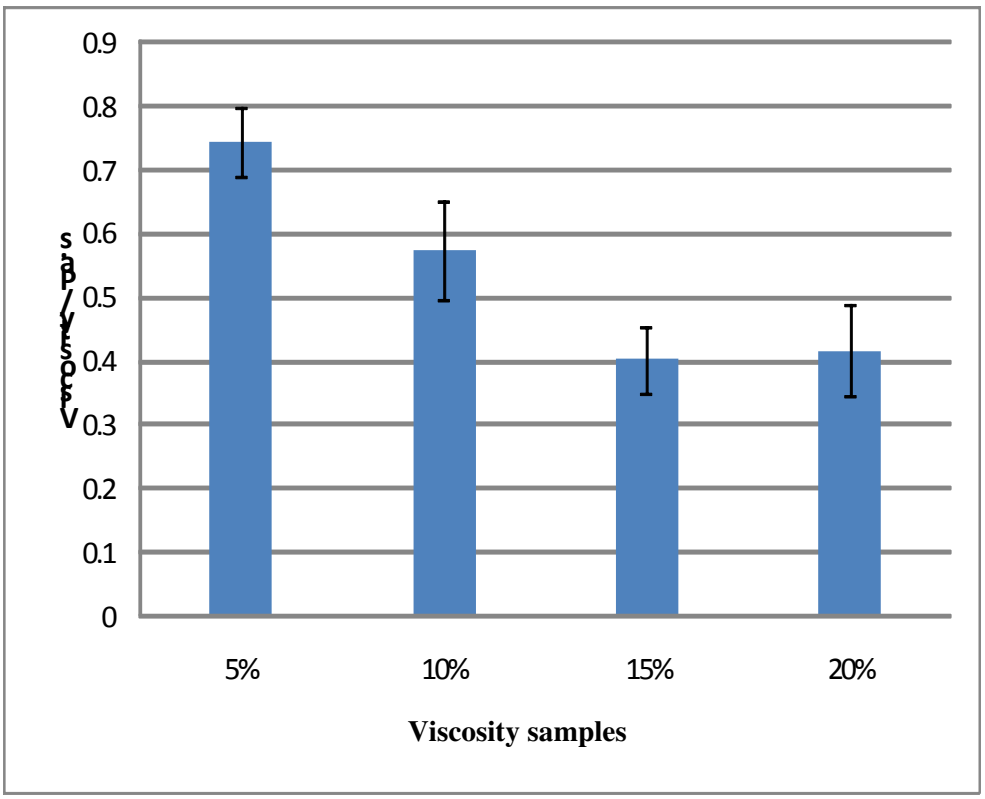

Figure 9: Accumulated data on viscosity of matrixes with the standard error.

4.2 Plotted Graph of Filling Time with Respect to Viscosity

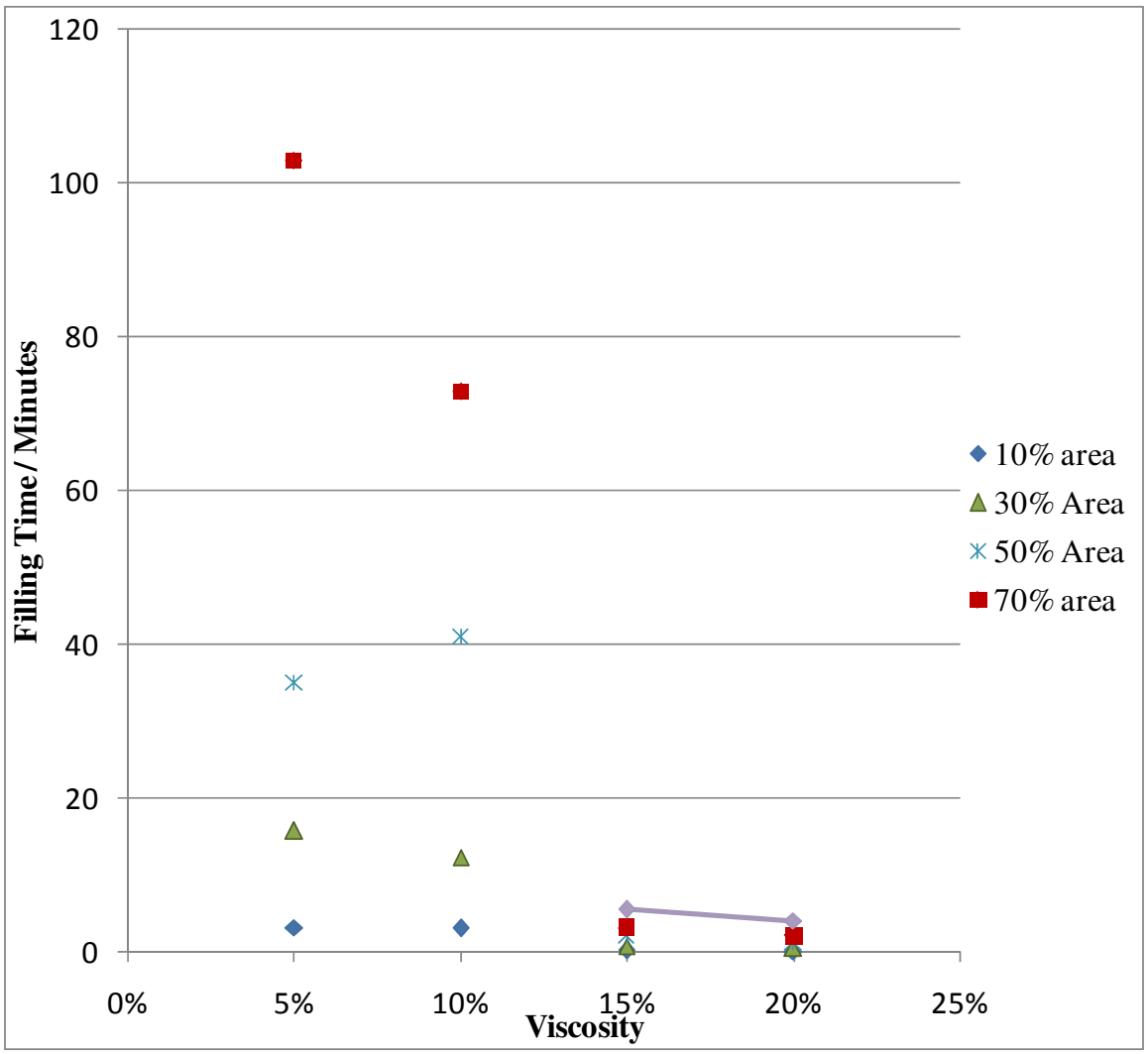

Figure 10: Filling time versus viscosity.

Note that the lines indicate the percentage of area infused during the infusion process.

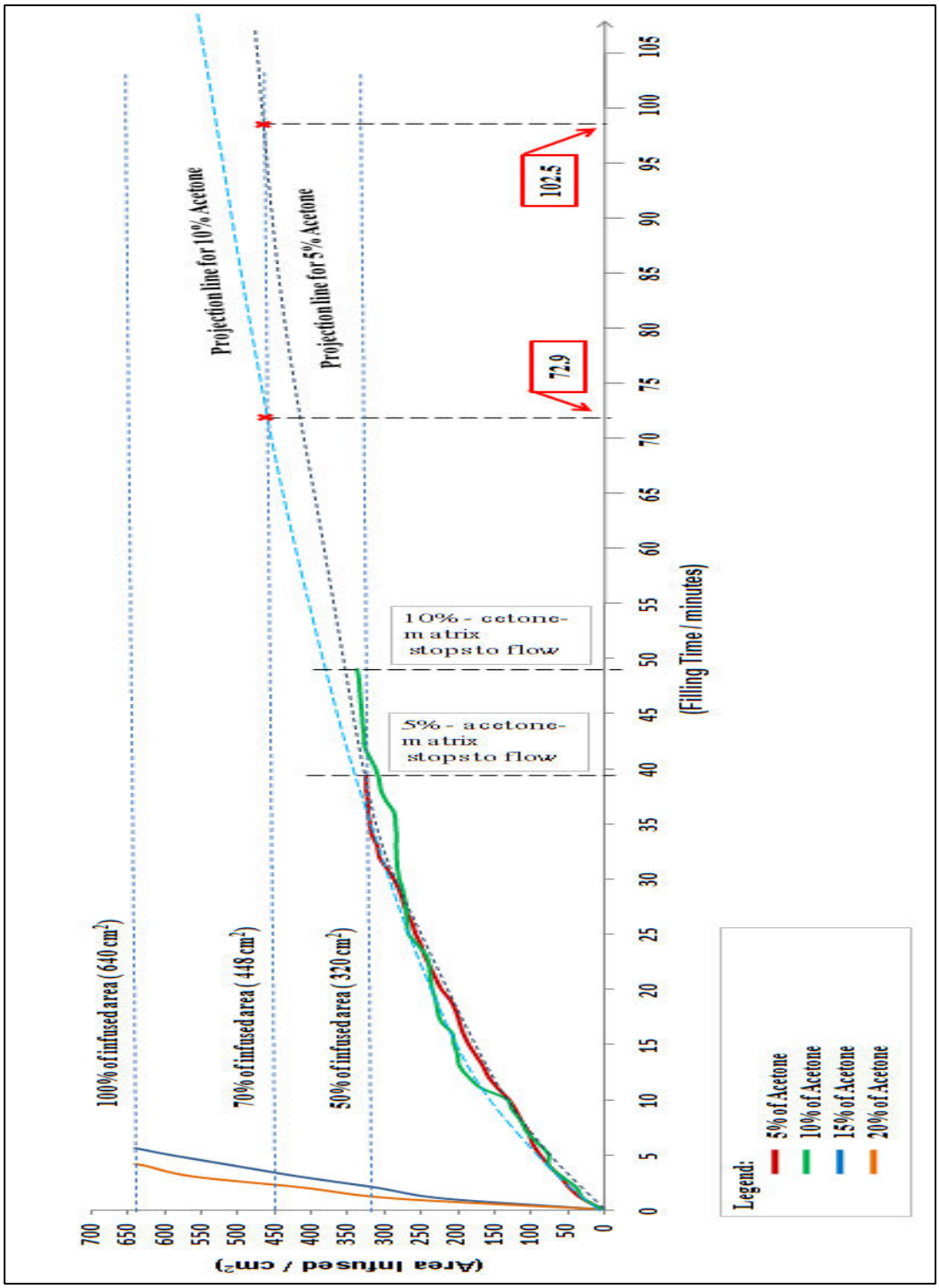

Figure 11: Area infused versus filling time. The lines for 5% and 10% are projected until 70% of total infusion area.

Based on the data shown in Table 5, adding acetone to the epoxy resin has lowered the viscosity. By plotting the filling time versus viscosity, result as in Figure 10 is obtained. Observing the lines, there is only small difference of filling time between 15% acetone and 20% acetone. The difference by average is about 1.0 minute. However, lowering the viscosity of resin by adding 15% and 20% of acetone give a huge variance between the filling times.

Also, the matrix that contains 5% of acetone resulted in incomplete infusion and took about 39 minutes just to complete 51% of total sample area. The same thing happened to the sample that used 10% of acetone-matrix which took 49 minutes before stop to infuse. The red line does project the filing time for both 5% and 10% of acetone matrix to complete 70% out of 640 cm^2 sample area.

Besides, 100% of infusion only successful by the use of low viscous matrix (in this case by adding 15% or 20% acetone). If the 100% (green) line to be projected for both 5% and 10% of acetone, it should gives very long projection line, as been shown in Figure 11.

Therefore, if someone would like to do the infusion (in case of using the same epoxy), then he need to consider the time taken to complete the infusion. Clearly, the usage of 15% and 20% of acetone could benefits in term of time.

4.3 Mechanical Testing Outcomes

The graphs obtained from the tensile machine are in form of load versus displacement (stroke).

4.3.1 Load versus Displacement Curves

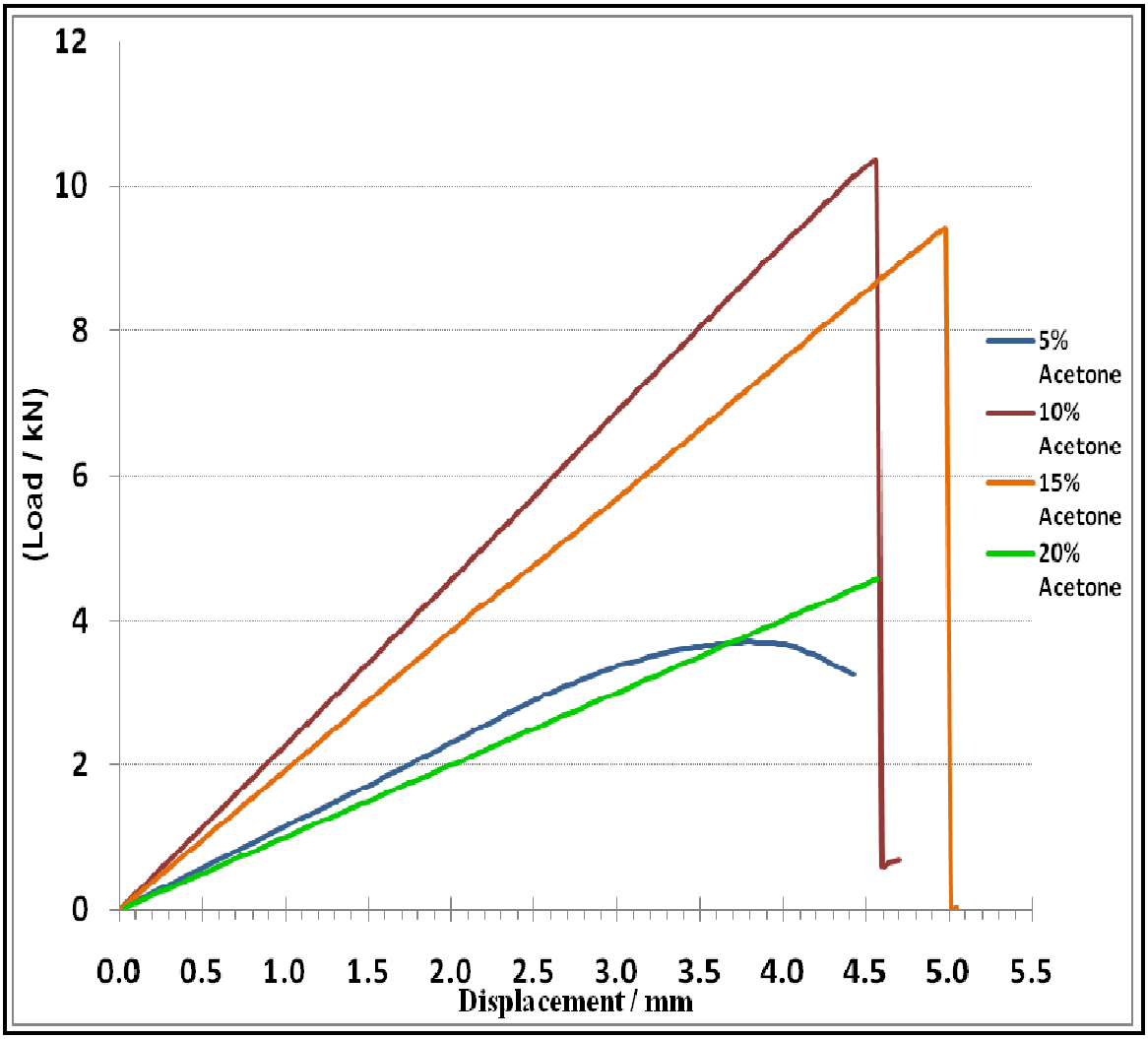

Figure 12: Load versus displacement graphs obtained from mechanical testing.

4.3.2 Stress versus Stroke

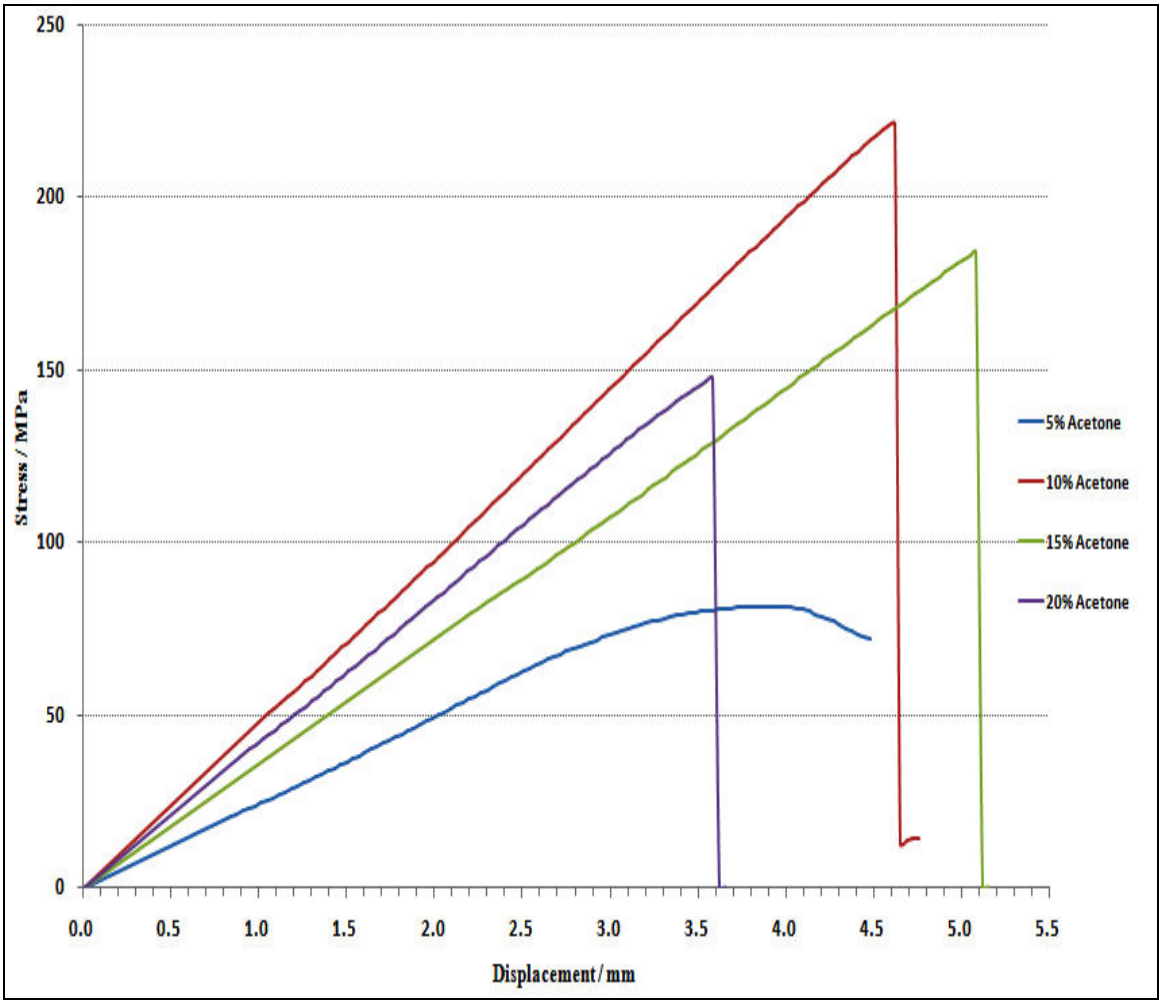

Figure 13: Stress versus strain curve from the composite specimens.

From graphs in Figure 12, we could obtain stiffness of the composite samples. The stiffness of each specimen is as shown in Table 6 below:

From the curves in Figure 12, stiffness for each samples can be obtained as shown in Table 6.

Table 6: The stiffness obtained from the composite samples.

Samples (% of Acetone Added)	Stiffness (kN/mm)
5% of acetone	1.17
10% of acetone	2.329
15% of acetone	1.875
20% of acetone	1

The stiffness is increasing as the viscosity decrease. However, the value is insignificant for Sample 1(5% acetone) as the sample failed during the testing. Comparing the stiffness values for Sample 2 to 4, the variances are acceptably small.

From Figure 13, the maximum stress indicates the tensile strength of the samples. The maximum strength for 20% acetone sample is 147.6 MPa, followed by 15%-acetone sample 184 MPa, and 221.4 MPa and 81.7 MPa for both 10% and 5% -acetone samples.

Need to mention that stress-strain graph can not be presented here because no strain gauge was used during the testing. Besides, the strain value could not be simply derived from displacement (stroke) values since they do not directly represent the elongation of the sample alone and the displacement values may be affected by the movement of the grips.

4.4 Discussions

4.4.1 Filling Time

Filling time for the lower viscosity of acetone is higher compared to more viscous matrix. The explanation behind, is that at lower viscosity the resistance for the matrix to flow is lesser. Since the matrix needs to flow through the spaces between the fibers strands, the fluid stick to the strands by cohesive force. According to Darcy's Law, the flow of matrix the flow flux of matrix is affected by viscosity, pressure change, and the length (size) of the porous medium (in this case is fiber layers).Thus, the change in resistance effects the change in filling time as well. Higher resistance means longer filling time.

Then, in composite manufacturing technique such as resin infusion, time is very important. Faster infusion can save cost and energy. Besides, shorter infusion time could helps in better infusion activity without worrying of sudden leakage and gelling of matrix.

4.4.2 Effect of Viscosity to the Mechanical Properties

Adding acetone to the matrix effectively change the strength of the composites produced. Lowering the viscosity of matrix by mixing it with acetone seems to weaken the strength of the material parts. Referring to stress-stroke graph, sample with lower percentage of acetone (more viscous) ruptures at higher stress point. However, the situation is contradicted with the result of specimen with 5% of acetone. The curve is varies with other curves. From the analysis, the specimen with 5% of acetone is soft and easy to bend. It is believed that the problem caused by improper curing of resin after the infusion process which weakens the bond between the matrix and the fibers. Besides, it is suspected that the problem might occur because of trapped bubbles in the specimen.

Besides that, it is essential to figure the mode of failures (Figure 14 and 15) for the specimen parts. Most of the mechanical testing resulted in failure at the grip points. The failures might caused by several factors such as tab material, tab alignment, grip type, specimens positioning, and initial cracks at the specimen body.

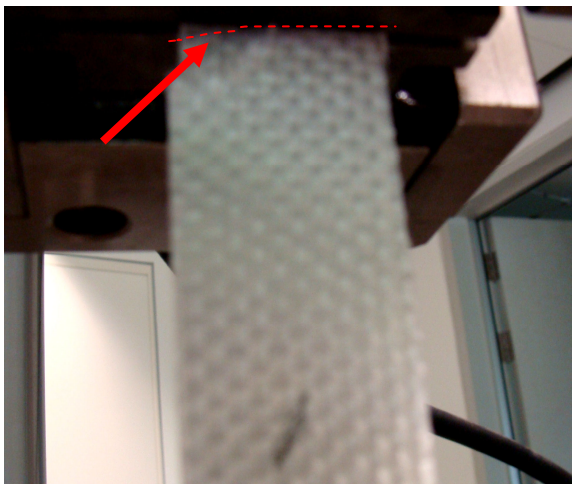

Figure 14: LAT, tensile test failure mode (Lateral, At-grip, Top)

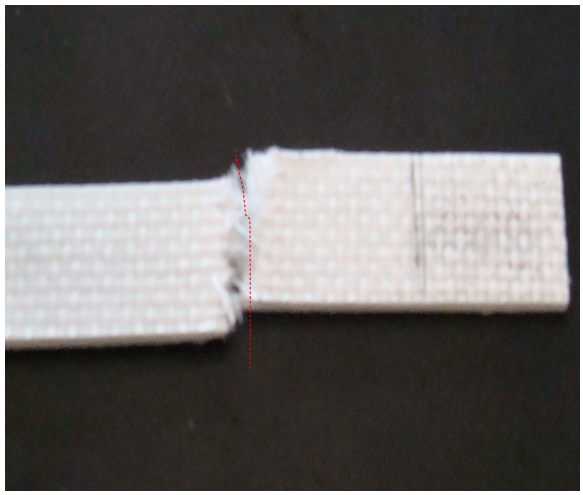

Figure 15: LGM (Lateral, Gage, Middle) type of failure mode.

4.4.3 Acetone in Resin Infusion Process

During the experiment, acetone has helped to improve the quality of degassing. Since it is volatile, thus it helps to stimulate the trapped bubbles to escape, hence improving the quality of matrix. However, the samples with higher content of acetone have more voids contents compared to lower one. This may due to improper degassing which leads to entering of gas into the resin. Besides, when the samples exposed to ambient air (to cure), they showed porosity. This was believed that the acetone that bond with resin was vaporized, leaving an empty space at the surface of samples. Thus the usage of acetone, even it helps in improving the quality of matrix, but it still potentially defect the sample after the infusion done.

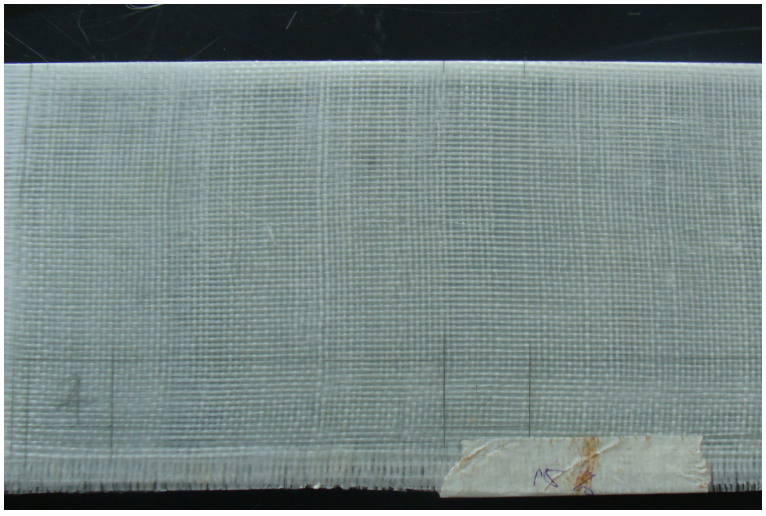

Figure 16: Coarse surface on 15% acetone sample resulted from acetone vaporization.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATION

Based on the results obtained, the objectives are achieved. The change in viscosity of resin, significantly affect the mechanical properties of the glass fiber composites as well as the filling time. Acetone is good to be used as solvent, but it still needs better research to study the effect of acetone to the chemical properties of resin and quality of infusion.

With adding the acetone within 10% to 15% - lower the viscosity of resin - it could give acceptable mechanical strength to the composite materials with lower usage of resin and save the processing time too. However, if quality is the main criteria to achieved, the need of using high viscosity resin should be considered.

5.1 Recommendations

There are so many factors that affect the efficiency of the process. However, a better infusion process could be realized by the use of better quality of equipments. The use of finer glass fibers, net, vacuum bag, and degassing chamber could increase the efficiency of the resin infusion process.Acetone is acceptably used as a resin solvent. However, the use of other dispersion aid such as rubber modifiers, engineering thermoplastics, and silica might improves the mechanical properties of the composite while reducing the amount of resin usage.

In order to maintain a good infusion progress, the system must be completely sealed. In this case, vacuum integrity becomes a great concern. To achieve stable vacuum integrity, all the weak points must be monitored. Most of the leakage happened around the inlet and outlet lines, and between the plate and vacuum bag. The use of high quality of sealant tape might help in best sealing.Finally, it is good to say that resin infusion technique has a bright future to be developed further within this university. It could become a laboratory subject to the Material students, or promoted to be commercialized. With the expanding prospect of composites in this country, UTP should look forward to be a leading research center for composite manufacturing (including resin infusion technique).

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APPENDICES

Appendix I:Gantt Chart for FYP I and FYP II

PROJECT GANTT CHART FOR FYP 1																
No.	**Activities \ Weeks**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**		**10**	**11**	**12**	**13**	**14**
1	*Propose project title*			Closure of UTP- H1N1							Mid semester break					
2	*Special meeting with supervisor and team members*															
3	*Collecting information from journals, research papers, etc*															
4	*Submission of Progress Report 1*															
5	*Practice on how to do vacuum infusion*															
6	*Purchase the necessary tool kits*															
7	*Set up the infusion aparatus*															
8	*Submission of Progress Report 2*															
9	*Seminar (compulsory)*															
10	*Submission of interim report final draft*															
11	*Oral presentation*											study weeks				

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

Appendix II: Load versus Stroke Curves from Universal Testing Machine

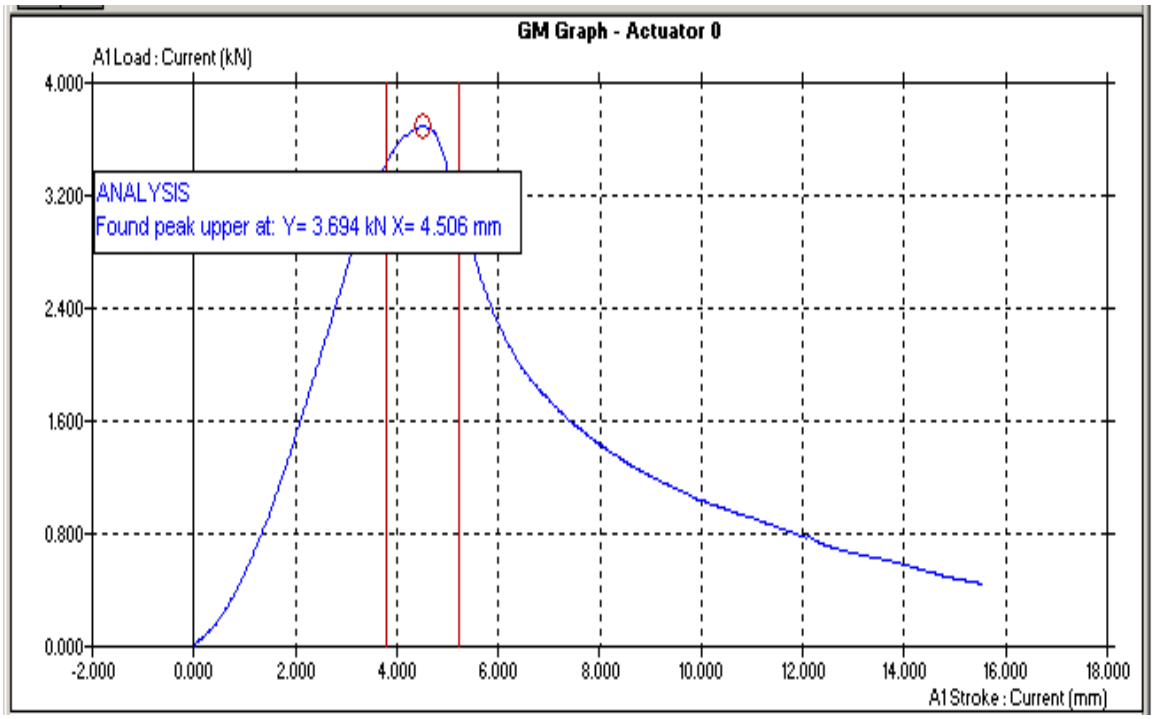


Figure: Load versus stroke curve for composite which contain 5% of acetone.

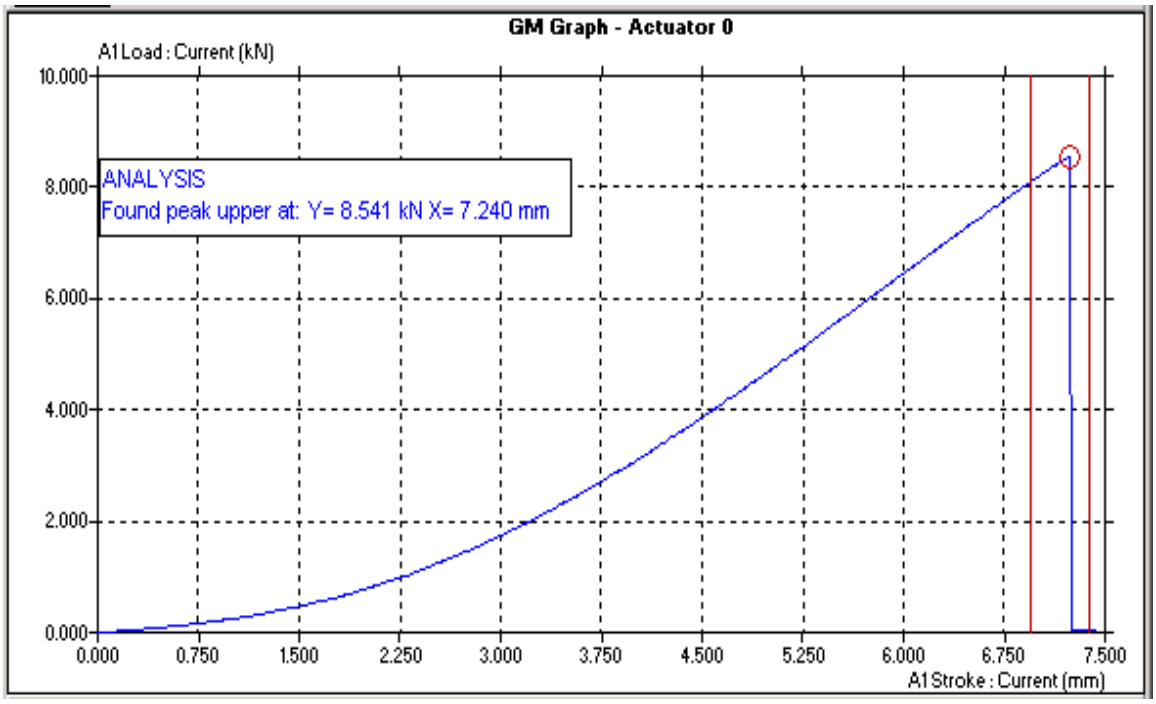


Figure: Load versus stroke curve for composite which contain 10% of acetone.

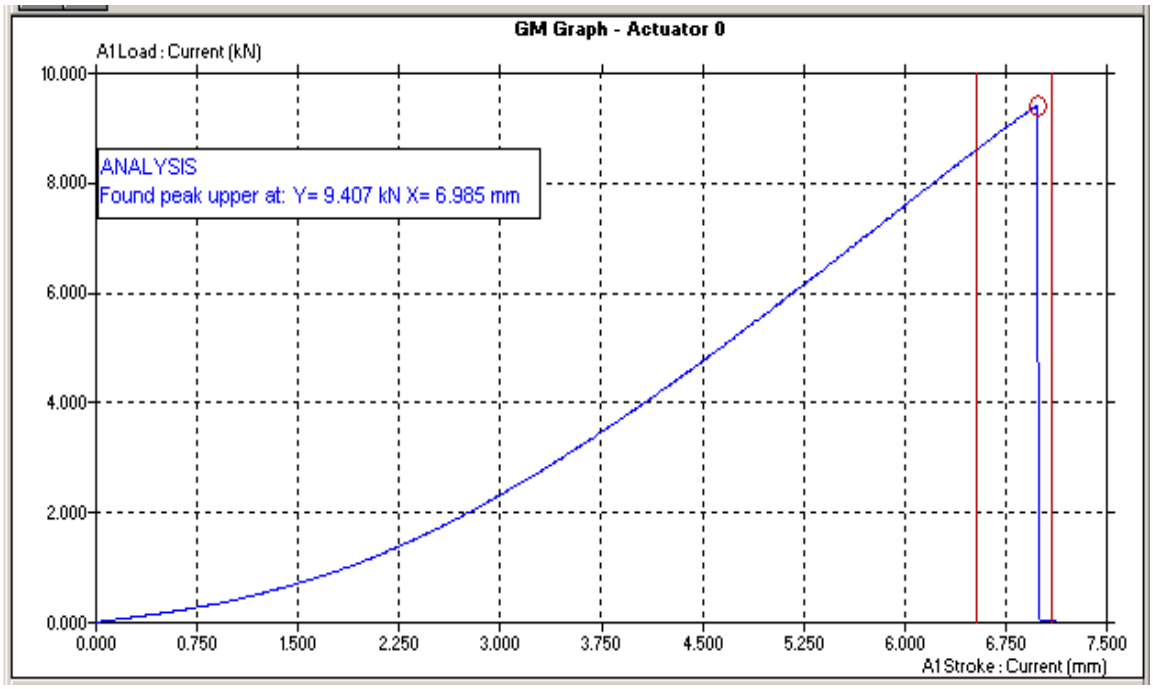


Figure: Load versus stroke curve for composite which contain 15% of acetone.

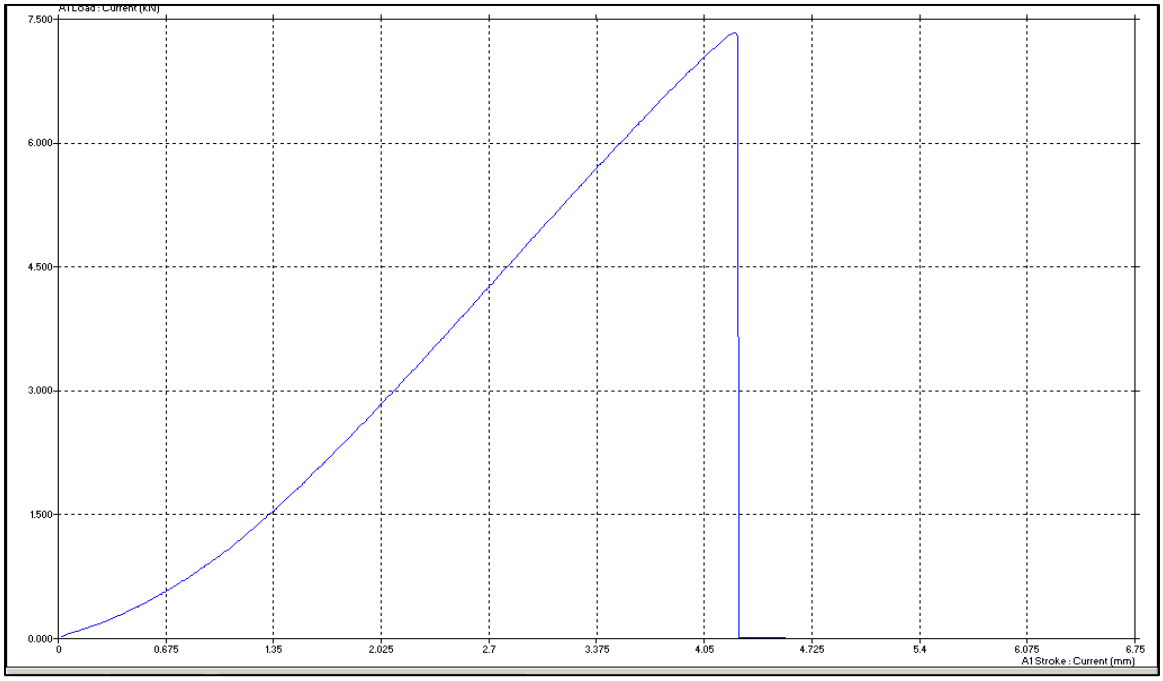


Figure: Load versus stroke curve for composite which contain 20% of acetone.

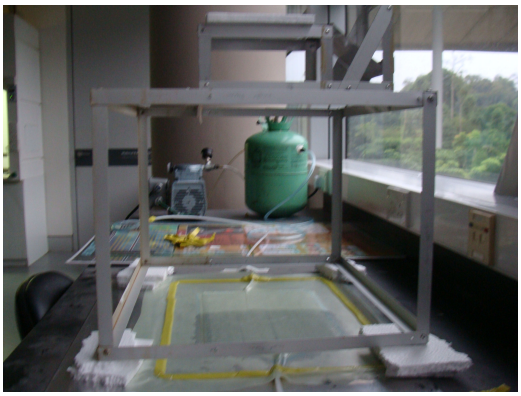
Appendix III: Measured Area for Filling Time

20%		15%		10%		5%	
MIN	AREA(cm2)	MIN	AREA(cm2)	MIN	AREA(cm2)	MIN	AREA(cm2)
0	0	0	0	0	0	0	0
1	286	1	220	1	27.5	1	30
2	413	2	312.5	2	37.5	2	47.5
3	562	3	417.5	3	57.5	3	60
4	628.5	4	507.5	4	75	4	75
4.13	640	5	596.5	5	75.5	5	87.5
		5.57	640	6	90	6	97.5
				7	105	7	102.5
				8	112.5	8	112.5
				9	125	9	120
				10	132.5	10	130
				11	167.5	11	145
				12	185	12	157.5
				13	197.5	13	165
				14	200	14	175
				15	205	15	185
				16	207.5	16	192.5
				17	222.5	17	197.5
				18	227.5	18	202.5
				19	230	19	210
				20	235	20	222.5
				32	283.5	32	307.5
				33	284	33	310
				34	283.5	34	317.5
				35	285	35	320
				36	287	36	322.5
				37	297.5	37	323
				38	305	38	325
				39	307.5	39	325
				40	312.5	39.28	325
				41	320.5		
				42	327.5		
				43	328		
				44	330		
				45	331		
				46	332.5		
				47	334		
				48	335		
				49	337.5		

Skipped

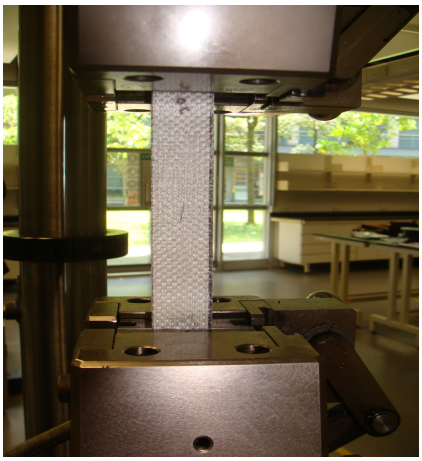
Appendix IV: Activities

(1). Preparation for resin viscosity



(2). Infusion set-up system

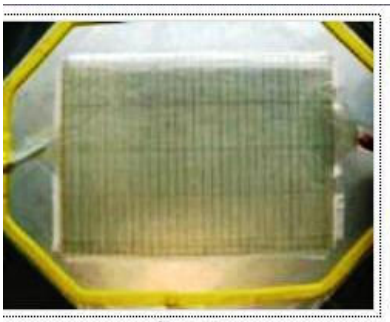
(3). Cutting the samples using diamond cutter



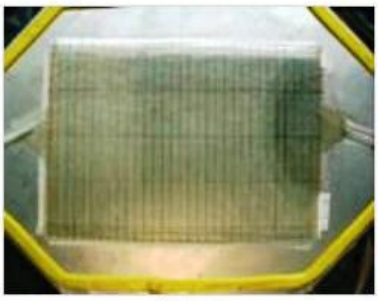
(3) Tensile testing

Appendix V: Filling Time for Composite Samples

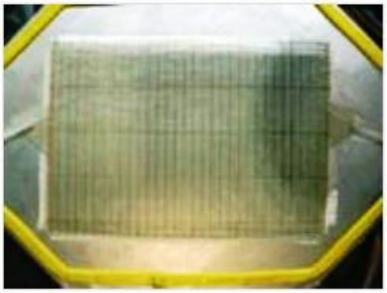
(A). 5% Acetone-Matrix



* min 1



* min 5

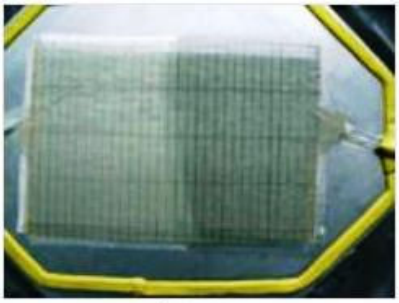


* min 10

* min 15

* min 25

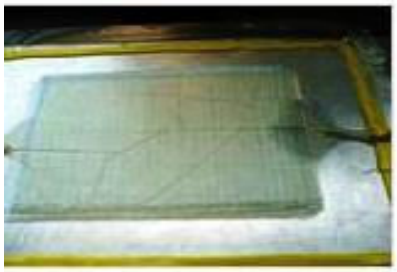
* min 30



* min 35

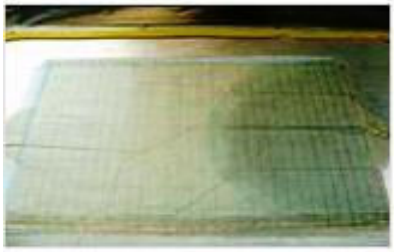
* min 39

(B). 10% Acetone-Matrix

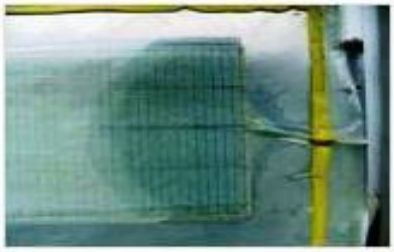


* min 1

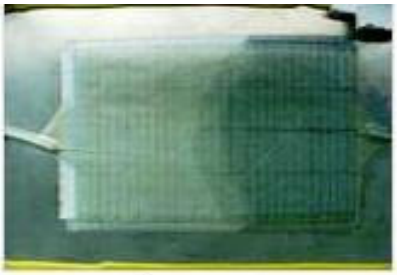
* min 10



* min 20



* min 30



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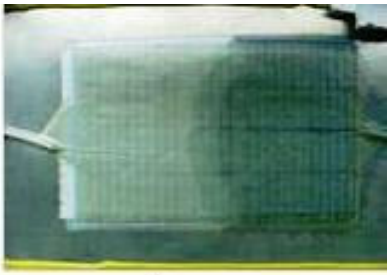
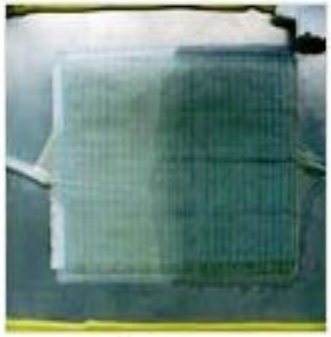


* min 50

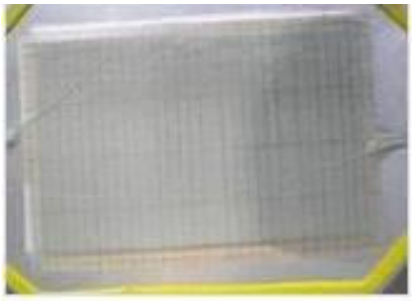
* min 60



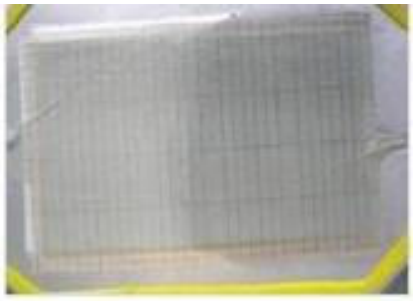
* min 70

* min 79.5_end_gel time_no...

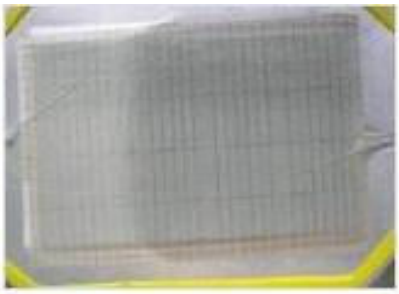
(C). 15%Acetone-Matrix



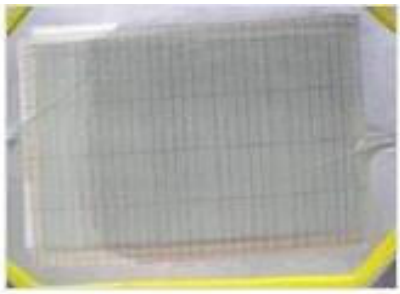
min 1



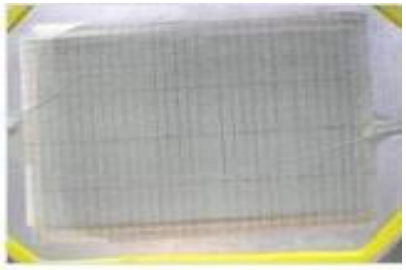
min 2



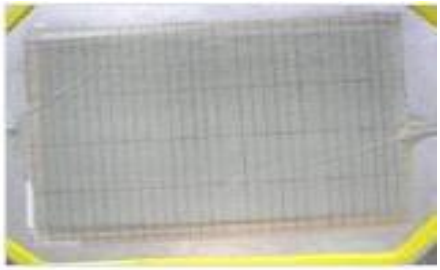
min 3



min 4

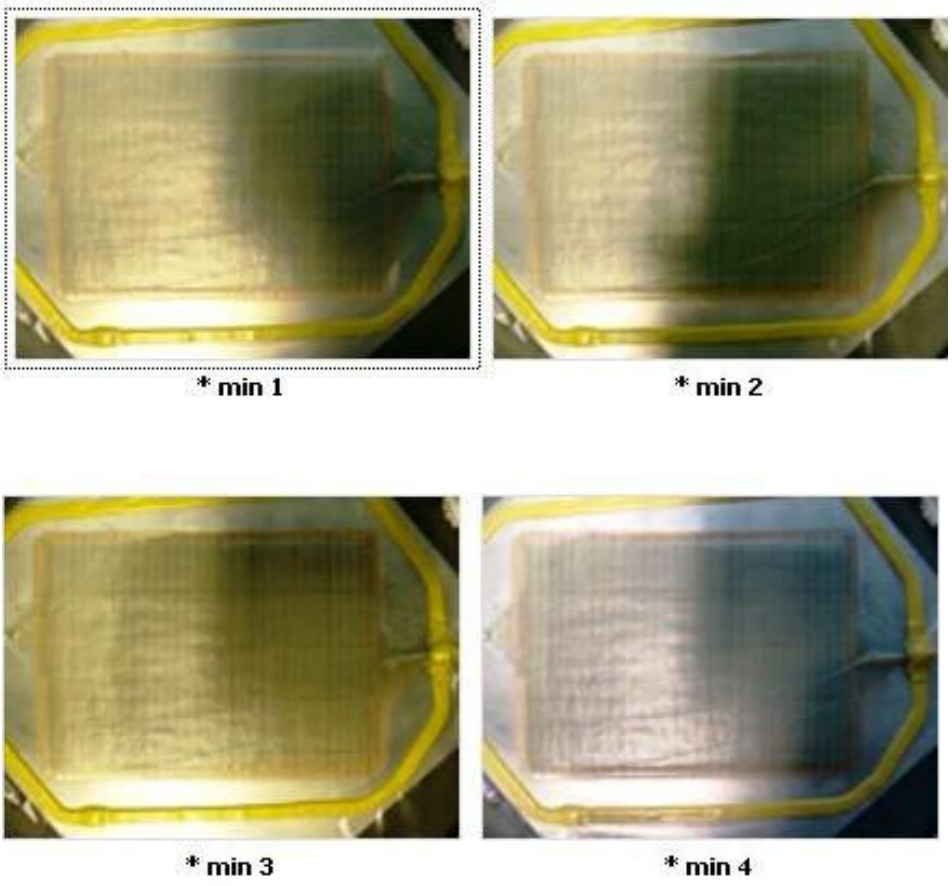


min 5



min 5.57_full

(D). 20% Acetone-Matrix



* min 1 * min 2

* min 3 * min 4

Appendix VI: Mechanical Testing Results

5%		10%		15%		20%	
Stress (Mpa)	**Strain ε (x10-2)**	**Stress (Mpa)**	**Strain ε (x10-2)**	**Stress (Mpa)**	**Strain ε (x10-2)**	**Stress (Mpa)**	**Strain ε (x10-2)**
0.022	0.001	0.021	0.000	0.020	-0.001	0.725	0.019
0.022	0.001	0.021	0.000	0.000	-0.001	1.209	0
5.797	0.355	3.788	0.452	2.505	0.207	20.124	0
6.240	0.374	4.023	0.471	2.739	0.228	21.091	0.596
6.704	0.395	4.237	0.491	2.994	0.248	22.179	0.617
7.191	0.414	4.473	0.511	3.209	0.268	23.247	0.635
7.700	0.435	4.729	0.532	3.463	0.287	24.314	0.655
8.209	0.454	4.986	0.550	3.698	0.307	25.463	0.676
8.740	0.474	5.243	0.570	3.972	0.327	26.631	0.695
9.315	0.494	5.521	0.590	4.227	0.346	27.799	0.715
9.824	0.513	5.778	0.609	4.520	0.366	29.008	0.735
10.399	0.533	6.099	0.630	4.794	0.386	30.156	0.755
10.975	0.552	6.399	0.649	5.087	0.405	31.365	0.774
11.572	0.572	6.698	0.668	5.361	0.425	32.574	0.794
12.147	0.593	7.041	0.688	5.674	0.445	33.943	0.815
12.701	0.611	7.362	0.708	5.988	0.465	35.192	0.835
13.342	0.631	7.726	0.728	6.301	0.485	36.462	0.855
14.006	0.651	8.068	0.748	6.633	0.505	37.731	0.875
14.714	0.672	8.432	0.768	6.946	0.524	39.000	0.894
15.378	0.693	8.774	0.787	7.279	0.544	40.329	0.914
16.042	0.712	9.159	0.806	7.631	0.564	41.719	0.934
16.639	0.731	9.566	0.827	8.023	0.585	43.129	0.955
17.369	0.751	9.951	0.846	8.394	0.605	44.519	0.976
18.033	0.771	10.358	0.866	8.805	0.625	45.869	0.995
18.675	0.790	10.764	0.885	9.197	0.645	47.199	1.015
19.383	0.810	11.150	0.905	9.607	0.665	48.588	1.035
20.069	0.830	11.578	0.925	10.018	0.684	50.059	1.057
20.799	0.851	11.984	0.944	10.449	0.704	51.469	1.077
21.529	0.871	12.412	0.964	10.899	0.724	52.799	1.096
22.303	0.890	12.840	0.983	11.329	0.744	54.269	1.117
23.078	0.910	13.290	1.003	11.740	0.764	55.659	1.135
23.874	0.930	13.782	1.023	12.171	0.783	57.049	1.155
24.671	0.949	14.274	1.043	12.621	0.803	58.540	1.175
25.490	0.970	14.788	1.062	13.090	0.823	59.930	1.195
26.242	0.989	15.301	1.081	13.560	0.844	61.380	1.215

Skipped

27.083	1.008	15.836	1.102	14.088	0.864	62.790	1.235
27.924	1.028	16.371	1.122	14.578	0.883	64.341	1.257
28.764	1.048	16.928	1.141	15.086	0.903	65.872	1.277
29.605	1.067	17.463	1.161	15.595	0.922	67.383	1.298
30.490	1.088	18.040	1.180	16.143	0.942	68.934	1.319
31.331	1.107	18.640	1.199	16.671	0.962	70.506	1.340
32.216	1.127	19.239	1.220	17.239	0.982	72.077	1.361
33.101	1.146	19.817	1.240	17.747	1.001	73.648	1.382
34.008	1.168	20.373	1.259	18.276	1.021	75.139	1.402
34.871	1.187	20.951	1.279	18.824	1.041	76.569	1.421
35.734	1.207	21.507	1.299	19.391	1.061	78.100	1.442
36.597	1.227	22.128	1.319	20.017	1.080	79.651	1.462
37.504	1.247	22.813	1.338	20.683	1.100	81.202	1.483
38.411	1.267	23.519	1.358	21.348	1.120	82.673	1.502
39.319	1.287	24.204	1.377	21.974	1.140	84.184	1.522
40.226	1.307	24.931	1.398	22.639	1.159	85.735	1.543
41.111	1.327	25.659	1.417	23.305	1.179	87.226	1.562
42.018	1.347	26.365	1.436	23.970	1.199	88.696	1.582
42.925	1.367	27.093	1.456	24.674	1.219	90.267	1.602
43.810	1.386	27.842	1.476	25.379	1.239	91.738	1.622
44.717	1.407	28.569	1.495	26.083	1.258	93.249	1.642
45.603	1.426	29.361	1.515	26.846	1.279	94.679	1.661
46.465	1.446	30.089	1.534	27.531	1.298	96.210	1.682
47.351	1.466	30.881	1.555	28.275	1.317	97.721	1.701
48.324	1.487	31.630	1.574	29.038	1.338	99.312	1.722
49.209	1.506	32.400	1.594	29.781	1.357	100.783	1.741
50.138	1.526	33.170	1.613	30.544	1.377	102.233	1.761
51.068	1.546	34.005	1.634	31.347	1.398	103.744	1.781
51.975	1.566	34.840	1.653	32.129	1.417	105.275	1.802
52.882	1.586	35.696	1.672	32.932	1.437	106.705	1.821
53.811	1.605	36.530	1.692	33.773	1.457	108.196	1.841
		179.934	4.067	174.617	3.841		
		181.025	4.087	175.850	3.860		
		182.074	4.107	177.102	3.881		
		68.888	4.138	178.296	3.900		
		0.749	4.146	179.490	3.920		
		0.685	4.166	180.683	3.940		
		0.663	4.187	181.896	3.960		
				183.012	3.980		
				183.931	3.999		

Skipped

Appendix VII: Filling Time with Respect to Area Infused

		Viscosity				
Area infused (%)	**Area Infused (cm^2)**	5%	10%	15%	20%	
10	64	3.25	3.1	0.25	0.2	**Filling Time (min)**
20	128	9.6	9.4	0.52	0.42	
30	192	15.8	12.3	0.83	0.62	
40	256	24.8	24.2	1.32	0.83	
50	320	35	41	2.07	1.2	
60	384	70.8	53	2.7	1.75	
70	448	102.9	72.9	3.3	2.23	
80	512	-	-	4.05	2.62	
90	576	-	-	4.75	3.14	
100	640	-	-	5.57	4.13	