A Study of Tensile Behavior on Drilling Induced Damage of Hybrid Composite

by

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

May 2011

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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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ABSTRACT

This report basically discusses the research on **a study of tensile behavior on drilling induced damage of hybrid composite**. The drilled holes may cause problems such as delamination, fiber pull out and interlaminar cracks of the holes. With loading condition, these problems may affect the performance of the final composite structure hence affect the mechanical properties of the mechanical parts. This study involves the fabrication 4mm with 55% FVF glass fiber and carbon fiber reinforced polyester. The test alongside with other mechanical test which includes the drilling operation is performed by using a 5mm HSS drill bit with 650 rpm, 1300 rpm, 1800 rpm, 2500 rpm spindle speed and 0.05 mm/rev, 0.10 mm/rev and 0.15 mm/rev feed rate. The damages within the hole region are assessed in terms of damage factor and the surface roughness. Tensile test is executed on the fabricated samples to determine the tensile properties of drilled and non-drilled samples. The tensile tests are performed using a Universal Testing Machine Amsler HA100. Delamination extension due to the tensile load, damage factor and surface roughness are gathered and compared for every sample. Furthermore, microstructure of the samples are analyzed after the tensile test and reported in this report. The findings of this project show that the maximum ultimate tensile strength of drilled sample is 296.975 MPa meanwhile for the non-drilled the ultimate tensile strength obtained is 372.200 MPa. The results show that the ultimate tensile strength for both drilled and non-drilled samples have 37.6% difference. The lowest feed rate which is 0.05 mm/rev and 1300 rpm which are the best option in drilling parameter which result in least damage of the samples and those parameters offer better surface around drilling region.

ACKNOWLEDGEMENT

Praise to Him the Almighty for giving me the strength and inspiration to complete this internship program successfully. Without His merciful blessings, this task could not be made possible.

Firstly, I am heartily thankful to AP. Dr Faiz Ahmad, my final year project supervisor whose vital encouragement, guidance and support from the preliminary to the concluding level enabled me to develop better understanding in research.

Secondly, I offer my regards and blessings to all of those who supported me in any respect during the completion of the project especially to Mr Azuan Maoinser, a PhD student, for the inspiration they extended and from whom I gained vast knowledge too. The project obviously would not be as smooth as it is without his understanding and great assistance.

Apart from that, I also would like to thank the technicians of the Mechanical Engineering Department that guide me along the completion of the project experiment. Their continuous support and help throughout the whole period of experiments are very much appreciated.

Not to be forgotten, I would like to deliver my utmost gratitude to my fellow colleagues and my family who have been giving me support and advice in order to make this project a great success. In short, unexceptional recognition is expressed to those who are not mentioned in this restricted space and have given heaps of support indirectly to me.

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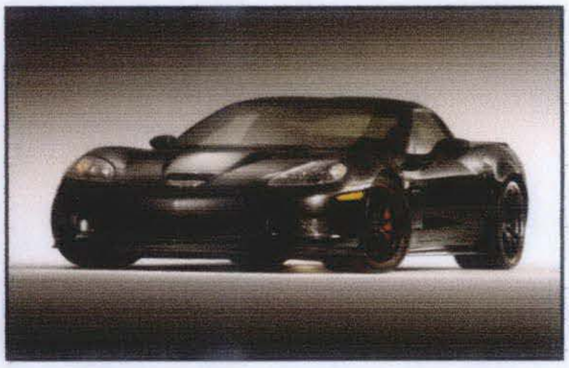
CHAPTER 1
INTRODUCTION

1.1 Background of Study

The term hybrid composites consist of two or more types of reinforcing fibers in one or more types of matrices in its construction. Due to their unique properties, the importance of hybrid composites being one of the most interesting groups of materials has increased. The advantages are related with their low weight, high strength, high stiffness and low fabrication cost. The development of these materials has been linked with the aerospace and aeronautical application and recent years have seen the spread of their use in many other industries like automotive, sport, railway and naval as illustrated in (Figures 1.1(a)-1.1(d)) and many others.

(a): The Airbus A380 has about 26 tons of hybrid composite in each aircraf



(b): Chevrolet Corvette Z06 has hybrid composite fibre bonnet

(c): Raleigh hybrid composite road bike

(d): Adam A700 all-composite personal jet

Figure 1.1(a) – 1.1(d): Examples of hybrid composites application in industries

Hybrid composites are usually produced to near final shape, however machining is often required, as it turns crucial to carry out the requirements concerning with tolerances or assembly needs. As the machining processes are important towards the production of holes for screws, rivets and bolts, drilling is one of the most frequently used in the industry. Machining operations in hybrid composites can be carried out with drilling machine (conventional or computer numerical control). However, due to the anisotropic nature of composites material, drilling may cause damage onto the fiber composites in the form of delamination, interlaminar cracks, fiber pull out and matrix burning around the hole that may ultimately cause variation in the residual strength of the component with drilled hole.

The tensile test in hybrid composites plays an important role in determining the mechanical properties of the drilled material as the drilling parameter might affect the reliability of the material. The strength of a material often is the primary concern. The strength of interest may be measured in terms of either the stress necessary to cause appreciable plastic deformation or the maximum stress that the material can withstand. When the drilled hybrid composites are subjected to the loads, the fracture tends to occur within the holes and defects will be appeared like the matrix cracking, debonding, delamination, void growth, and fiber breakage. Due to that case, the properties of the materials will be changing.

1.2 Problem Statement

Several researches have been done to study the effect of drilling parameters and tensile testing on the composites material, however the focus of this project is to investigate the mechanical properties of the glass and carbon fibers reinforced polyester with differ specification of the drilling parameters that may cause several damages like the fiber pull-out within the holes [1] despite the process related in the composite fabrication. These problems can affect the mechanical properties of the produced parts, hence, lower reliability. If the original strength is considered as the tensile strength after the composite being drilled, the final product from the material may lead to major catastrophe. Therefore it is a must for the determination of the tensile strength of the composite so that the new material can be developed and compared.

1.3 Objective and Scope of Study

As composite materials refer to a large variety of materials, a more specific selection of the type of materials has to be made. So, it was decided to study glass carbon fiber reinforced polyester. The aim of this research is to examine the machining and tensile properties of fabricated hybrid material and the scope of the research encompassed are:

- To fabricate 4 mm thickness with 55% fiber volume fraction (FVF) of hybrid composites material by the reinforced glass and carbon fiber with polyester as the continuous phase/matrix.
- To determine and measure the damage factor (ratio of original drill bit diameter of 5mm and delamination diameter) and surface roughness in micrometer of drilled holes on the fabricated hybrid composites material. (three (3) different feed rates 0.05 mm/rev, 0.1 mm/rev and 0.15 mm/rev at four (4) different cutting rpm of 650 rpm, 1300 rpm, 1800 rpm, and 2500 rpm)
- To execute tensile testing for the determination of the ultimate tensile strength of the drilled hybrid composites material.
- To perform microscopic the hybrid composites material structure by Scanning Electron Microscopy (SEM).
- Experimental result analysis

1.4 Relevancy of Project

The damage problems in normal fiber composites can be reduced with the use of hybrid composites which comes with improved mechanical properties. Obtaining the optimum drilling parameters (spindle speed and feed rate) can minimize the defects in hybrid composite as the material as the process of drilling this material is essential in a wide range of applications. Tensile test is important in order to determine the tensile properties of the hybrid composite as it will be a great problem if the mechanical strength of the material is to be taken at its original strength, the final product from the material.

1.5 Feasibility of the Project

The project will require the experimental works in fabricating the laminate of the hybrid fiber composite, the drilling of the laminate and the study of the effects and testing of the drilled hybrid fiber composite. This study is planned and scheduled to be done within 28 weeks and can be done within the allocated time given that everything goes as planned. All the objectives can be achieved if the procedures and methodology are followed closely.

1.6 Organization

On the first chapter stated about the background of the study and the project that being handle. Then the problems that contribute to the purpose of this project are stated as an overview of the matters that going to be solve. The objectives of this project are also listed down as a guideline to accomplish this personal project. Lastly, the scope and key assumption of this project are stated here to picture the goal of the project.

Chapter two is the literature review of this study and project that consist of introduction to drilling carbon fiber-reinforced composite material, effects of tensile test on hybrid composite material, influence of process parameters on spindle speed and feed rate for drilling process. It reviews about the relevant information to the study.

Chapter three is the methodology that appraises about the methods that been use in this project to accomplish the objectives and the scope of study. It contains the design of experiment, fabrication methods of laminates, the machining method, testing method and the equipment used in the experimental work.

Chapter four is the results obtain from the measurement and data analysis that have been done to the drilled hybrid composite material. All the graphs and tables shows the findings clearly and the finding is elaborated in the sentence form for better understanding.

Chapter five is the conclusion for this study that concludes all the achieved objectives and also stated the recommendation for improvement for further investigations of the same study in future.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

2.1.1 Employing the Use of Hybrid Composite

The term hybrid refers to a fabric that has more than one type of structural fiber in its construction. The initial concept was to optimize properties by using more than one type of fibers. For instance, the development of hybrid fiber which consists of glass fiber and carbon fiber reinforced polyester (HFRP) composite and hybrid fiber (consists of glass fiber and carbon fiber) reinforced epoxy (HFRE) composite have reduced the surface roughness (R_a) and damage factor (F_D) of the drilled holes [2].

The driving force is economic and the use of a small amount of carbon fiber, which is expensive, in a laminate composed mainly of a cheap fiber such as E-glass, is attractive [1]. Hybrid composites greatly expand the range of properties that can be achieved with advanced composites. The most common effect is to obtain a composite property, like tensile strength, whose value is higher than would be predicted from a simple application of the rule of mixtures. This effect is known as the 'hybrid effect'. The concept of hybrid composites has gone beyond the realm of conventional polymer composites.

One of the fundamentals for the occurrence of hybridization effect is that the two types of fibers differ in mechanical properties and the interfaces they form with the matrix are also not the same. Thus, with hybridization, it is possible to design a composite material system to better suit various requirements. In spite of the freedom of tailoring hybrid composites and gaining positive hybridization to meet design requirements, effect of such enhancements may be offset when one considers problems related to thick-section composites.

2.1.2 Drilling on Composite Material

Several studies have been done by many researchers and however the most relevant one is from Luís M. P. Durãola et al. (2005) in his studies of 'Machining Hybrid Composite' [1]. The hybrid composite mentioned in his report is the glass carbon fibers reinforced epoxy. The researcher performed the machining operation on the hybrid composite in which consist of the cutting mechanism, turning, milling, grinding and last but not least the drilling. Particularly, the researcher showed the machining related damage with regards to the manufacturing damages and machining defects such in the (Figure 2.1).

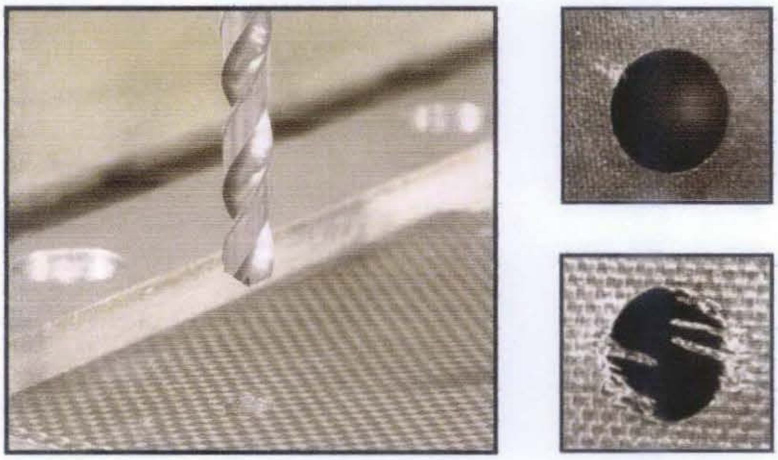


Figure 2.1: Drilling operation and the typical hole of the composite material [1]

Typically for the drilling operation, the researcher used different tool designs and selections. According to the researcher, for every drill used, it was necessary to look for a selection of parameters that minimize the thrust force during drilling. This effect has to be balanced with the need to avoid excessive heating during machining operation. As was already referred, excessive heating of the part can cause matrix degradation. For each pair drill type/ composite material, an optimization of drill speed and feed has to be carried out [5]. The first orientation for drilling parameters was based in suppliers' information, but other sources were considered. Not only that, many other authors also have studied the effect of machining parameters within the composite hole. Although those papers were already referred, a short reference is now recalled. Bongiorno et al. (1998) [6] said that low feed rates improve behavior under stress conditions. Chen et al.(1997) [7]

showed that cutting speed has a minor effect on thrust force and torque while feed rate has a strong influence on these forces. So, feed rate needs to be as low as possible, mainly at the last plies near the exit side of the plate, independently of the material considered. Caprino and Tagliaferri et al. (1995) [8] concluded that the type of damage in a composite material during drilling is strongly dependent on the feed rate. Tagliaferri et al. [9] state that the damage extent is strictly dependent on the feed rate adopted during drilling. Higher feeds lead to poorer quality.

The high requirement of high performance hybrid fiber composites are growing due to the flexibility in choice of polyester matrix [4] and fabrication techniques used in the hybrid fiber composites. According to [11-12], two types of reinforced fibers differ in mechanical properties, fiber/matrix interfaces, thermal expansion coefficient and thermal mismatch. In this study, machining and tensile properties need to be determined. As for drilling process on hybrid composites, it may affect the surface of the drilled holes and as well will cause damage or fiber pull-out within the holes. Moreover, thermal effects can be encountered on the matrix material caused by the heat generated during the drilling process. Drilling on hybrid composites can be operated using the conventional machinery available and cause surface damage around the drilled holes and consequently will result in loss of mechanical and tensile strength.

2.1.3 Tensile Testing on Composite Material

The mechanical testing of composite structures to obtain parameters such as strength and stiffness is a time consuming and often difficult process. It is, however, an essential process, and can be somewhat simplified by the testing of simple structures [13]. Tensile testing of composite include following main factors as primary concerns:

- Test equipment and test specimen
- Stress-strain curves and corresponding modulus
- Test methodology and data analysis

Processing variables such as layup accuracy, curing temperature and pressure can have a dramatic effect on the mechanical properties of composite materials [14]. Mechanical and process testing is necessary to understand the effect these variables have on the finished material or component:

- **Reliability**: For use in high performance applications in the aerospace, automotive and motorsport industries, material testing is required to prove the reliability and repeatability of component properties.
- **Damage Tolerance**: Testing is necessary that simulates real-life conditions such as tool drops, minor accidents and manufacturing imperfections.
- **Research and Development**: Testing is performed to investigate variables that will effect mechanical properties, damage tolerance, and provide data for finite element analysis.

Hybrid composites are susceptible to mechanical damages when they are subjected to efforts of tension which can lead to interlayer delamination. In any cases, the increase of the external load favors the propagation of delamination through the interlayer leading to the catastrophic failure of the component [7]. The tension and compression tests require only simple specimens, are easy to perform and give accurate and reliable measurements. According to [5], drilling parameters do not influence the tensile strength, however, bearing strength is shown to be affected by the drilling-induced damage in the form of micro-cracks.

Rectangular specimens are required for the composite material characterization, because the dog-bone type tends to split in the region where the width changes. The test ready laminates were subjected to tensile loads on a computer controlled Universal Testing Machine and the tests were performed at a constant crosshead speed of 1.27 mm/min. In this work the tensile strength is defined as the ultimate strength at which the complete fracture of the specimen occurs and the corresponding load is the critical load or the maximum load a material can with stand. For laminates, this definition corresponds to the last-ply failure [8]. The tests were closely monitored and conducted at room temperature and the effects of various parameters are as follows.

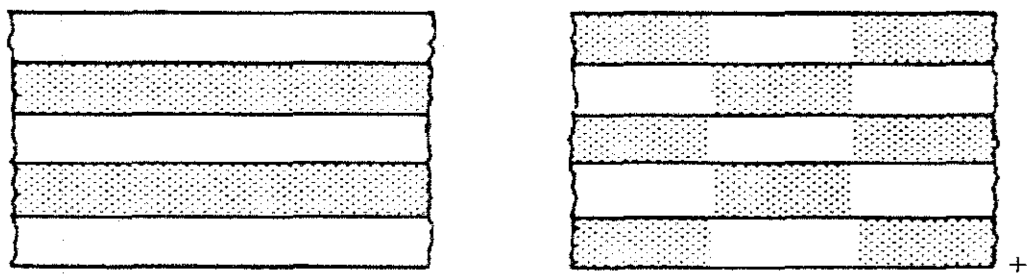
2.2 Theory and Fundamental

2.2.1 Types of Hybrid Composite

Since the use of high performance hybrid composites has been growing rapidly, one of the advantages of using composites is the flexibility in the choice and distribution of fiber reinforcements. In other words, it is basically how the reinforcement being laminated and arranged in order to produce a composite. According to M. M. Schwartz et al. [10], there are four basic types of hybrid composites which is illustrated in (Table 2.1):

Table 2.1: Types of hybrid composites description

Type of hybrid composite	Description
Type A - Interply hybrids	Consists of plies from two or more different unidirectional composites stacked in a specific sequence.
Type B - Intraply hybrids	Consisting in two or more different fibers mixed in the same ply.
Type C - Interply-intraply hybrids	Interply and intraply hybrids are stacked in a specific sequence.
Type D - Superhybrids	Resin-matrix composite plies stacked in a specific sequence.



a) Interply hybrid   b) Intraply hybrid

Figure 2.2: Definition on interply and intraply hybrids [9].

The first two types (A and B) as in the (Figure 2.2) of hybrids generally have the same matrix. Thermosetting and thermoplastic resins can be used as the continuous phase for hybrid composites. However in this project, thermosetting polyester will be used instead of epoxy. For this project, the author used the Type A of hybrid composites.

2.2.2 Laminates of Composite Material

From the several types of normally used composites, laminates are the ancient ones. Their main and more distinctive characteristic is the existence of layers that are easily detected in a simple naked eye observation. Laminates are a kind of material particularly attractive to engineers for its presentation in film or sheets makes design, production specification and control easier. When all the layers in a composite have their fibers oriented according to one direction only, laminate is designed as unidirectional. Different orientation can be defined for different layers, usually defined as an angle to a reference direction, named as 0°. In that case, it becomes necessary to have a symmetry plan in order to avoid coupling between bending and extension. Layers with angles of 90° and 45° to the reference direction are more usual, but other angles like 30° and 60° can also be found. Normally the reference direction (0°) is the direction of the main efforts that the part is expected to be subjected when in service. If the stacking sequence of the laminate has alternated layers with 0°, +45°, 90°, -45 ° orientations, the laminate is designed as quasi-isotropic. In that case, their properties are approximately identical in any direction considered in laminate plan. When the stacking sequence is another, the laminate is anisotropic, and so the reaction to a given strain depends and changes with its direction.

2.2.3 Matrices as the Continuous Phase

Matrices can be thermoplastic or thermosetting resins, minerals and metallic. Usual resins are polyesters, phenolic, melamine, silicone, polyurethane and epoxy. In this work, the author will concentrate in polyester matrix, whose matrix receives the general designation of resins. The main and most used thermosetting resins are unsaturated polyester and epoxy. Due to their low production cost, their diversity and good adaptability to simple construction processes, polyester resins are the most used. As advantages they present a good stiffness explained by their high modulus, good dimensional stability, good fibers and tissue wetting, easy to work, good chemical stability and resistance to hydrocarbons. Their disadvantages are the maximum service temperature under 120°C, sensitivity to cracks, high retraction, degradation under UV radiation and flammability.

2.2.4 Fiber Volume Fraction

The relative proportions of the matrix and reinforcing materials is a significant factor in the determination of the composites properties. The relative proportions can be given as the weight fractions are easier to obtain during fabrication. The volume fractions are used exclusively in the theoretical analysis of composites material. Thus, the volume fraction can be defined with the use of rule of mixture. Rule of mixture are indentified as:

$$V_m + V_f = V_c \qquad \text{...} (1)$$

The volume of the fiber can be expressed as;

$$v_f = \frac{\rho_m W_f}{\rho_f W_m + \rho_m W_f} \qquad \text{...} (2)$$

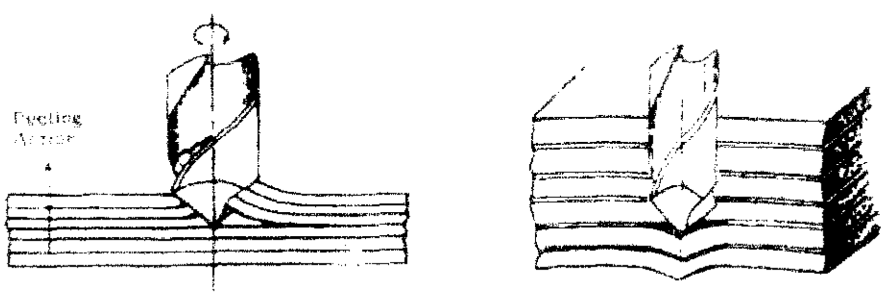
Rearranging equation (2) yields to;

$$W_m = \frac{\rho_m W_f - V_f \rho_m W_f}{\rho_f V_f} \qquad \text{...} (3)$$

2.3 Machining Damage

Composite parts manufacturing is a process in which fibers and resins are combined in a single product, using a certain fabrication technique. Some defects of the parts can be found after part manufacturing such as:

<u>Delamination</u>



Peel up delamination Push out delamination

Figure 2.3: Different forms of drilling induced damage

Therefore two types of delamination [3] in the hybrid composites material that can be identified instead of fiber torn-out or thermal degradation of the matrix [16] which are peel-up delamination and push-out delamination as shown in the (Figure 2.3). These types of delamination are yet to be encountered during the drilling process. Basically, delamination may be caused by interlmaniar stress concentration occurring in the neighborhood of the free edge or around loaded holes on the hybrid composite materials. The delamination is the indentation effect caused by the quasi stationary drill chisel edge, acting over the uncut plies of the laminate. These plies tend to be pushed away from the plate causing separation of two adjacent plies of the laminate. If the thrust force exerted by the drill exceeds the interlaminar fracture toughness of the plies, delamination will take place. The delamination can be referred as the push-out delamination. On top of that, the peel up delamination is a consequence of the drill entrance in the upper plies of the laminate. As the drill moves forward, it tends to pull the abraded material along the flute and cause the material spirals up. Normally, with the implementation of low feed rates in the drilling process may avoid this type of delamination.

Fibers pull out

In increasing longitudal tensile load, failure initiates by fiber breakage at their weakest sections. Breaking of fibers is totally a random process. Some cross section of the composite may become very weak to support the increasing load thus result in a complete rupture of the hybrid composite material. Moreover, the interfaces of broken fiber ends thus may contribute to the separation of the composite at a given cross section.

Debonding

The fibers may be separated from the matrix material due to cracks propagation through parallel to the fibers (debonding cracks). This happens due to breakage of the secondary bonds between the fibers and the matrix material. The cracking occurs when fibers are strong while the interfaces are weak. A debonding crack may spread at the fiber-matrix interface or in the adjacent matrix depending on their relative strengths. The more extensive debonding may cause a significant increase in the fracture energy.

2.4 Relevant Standard

The best standard to be referred to perform this project is as in Table 2.2:

Table 2.2: Referred Standards [17]

Code	Title
ASTM D3039/ D3039M-00	Tensile Properties of Polymer Matrix Composite Materials

For the preparation of the samples, ASTM D3039 is referred. The inception to design the hybrid composite is to determine the dimension of the sample. ASTM D3039 Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials has been referred to perform the design of the specimen. It covers test methods for a wide range of specimen dimensions as well as many different testing configurations. The ASTM D3039 stated that test at least five (5) specimens per test conditions unless valid results can be gained through the use of fewer specimens, such as in the case of a designed experiment. The parameter, requirement the recommendation from the ASTM D3039 can be viewed in the Appendix B.

CHAPTER 3
METHODOLOGY

3.1 Procedure Identification

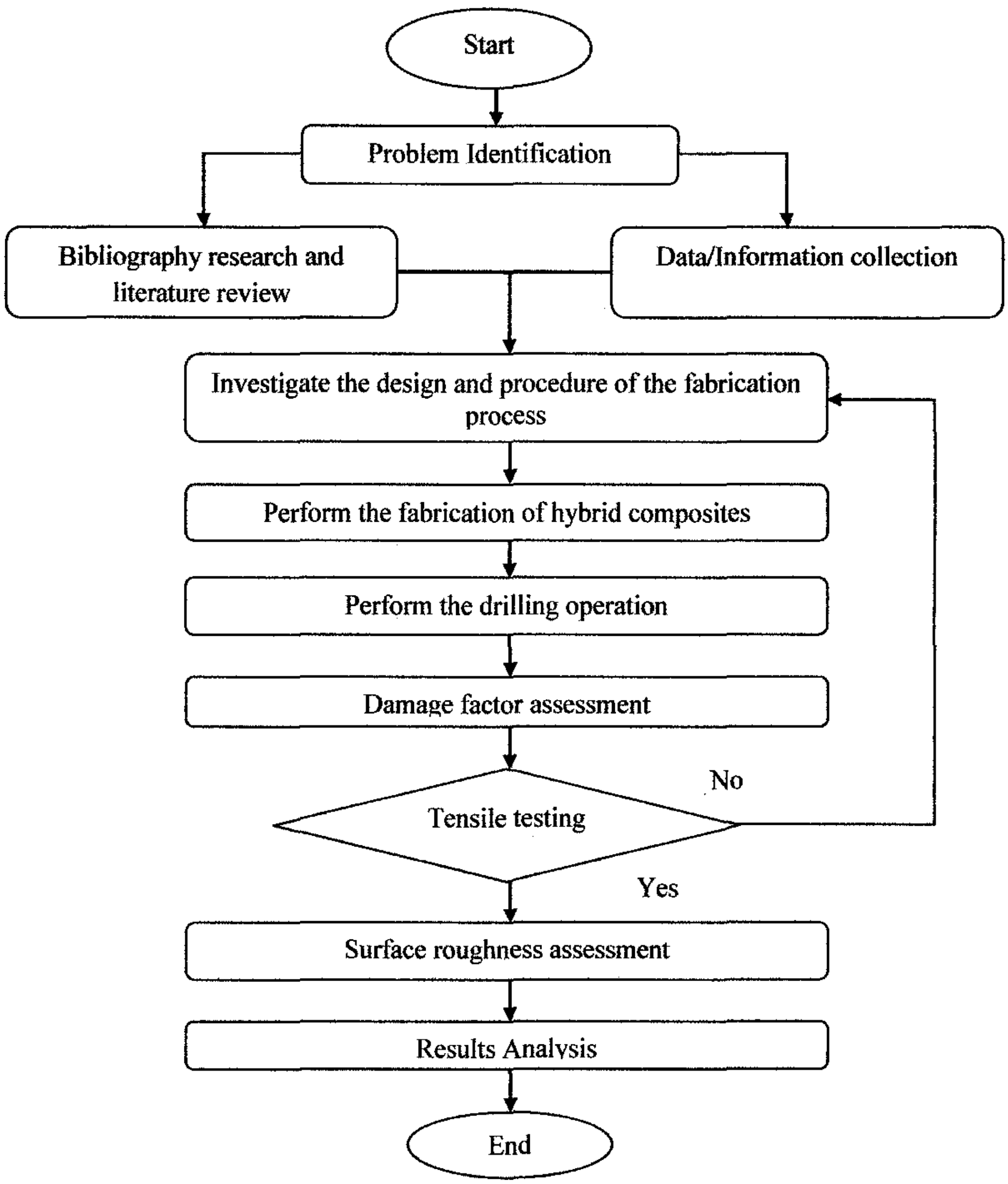
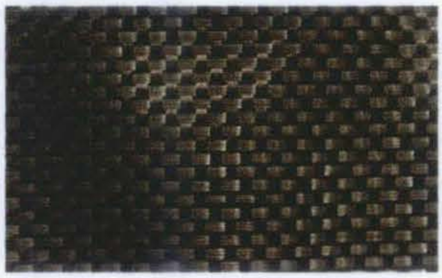


Figure 3.1: Process flow chart

3.2 Material Selection

The scope of this research work is the study of tensile behavior with drilling conditions for hybrid composite materials. The term composite stands for a wide range of different materials. Therefore a more accurate definition of the scope is needed. From the numerous composites available, the focus is given to the fibers reinforced polyester. This type of materials had seen their use widespread in recent years, as price goes down and reliability goes up.

(a)



(b)

Figure 3.2: (a) Woven roving laminate glass fiber, (b) Woven roving carbon fiber

3.2.1 Woven Roving Glass Fiber

The use of glass fiber is far more extensive, but less associated to high tech products. Glass fiber has lower than the carbon fiber. Their application include in the naval industries, domestic appliances, but also in sports and production cars. Glass fiber is formed when thin strands of silica based or other formulation glass is extruded into many fibers with small diameters suitable for textile processing [16]. The fibers provide most of the stiffness and strength and the matrix binds the fibers together thus providing load transfer between fibers and between the composite and the external loads and support [1].

3.2.2 Woven Roving Carbon Fiber

Carbon fibers are used in high technology sectors like aerospace and nuclear engineering, but also car racing and general engineering and transportation sector including several components like bearings, gears, cams, fan blades, automobile bodies, etc. Composites offer several advantages besides weight reduction, when used in airplanes, like durability and reduced maintenance. Its advantages and disadvantages are listed in the (Table 3.1)

Table 3.1: Characteristics of glass and carbon fibers

Fibers	Advantages	Disadvantages	Remarks
Glass	• Good tensile and compressive • Strength and stiffness • Good electrical properties • Low cost	• Poor impact resistance	Most commonly used
Carbon	• Highest specific stiffness of any fiber • Very high strength in tension and compression • High resistance to corrosion, creep and fatigue	• Impact strength is lower than glass • Brittle • Low break extension	Price is likely to decrease with increased production

3.2.3 Polyester Resin

Polyester resins are unsaturated resins formed by the reaction of dibasic organic acids and polyhydric alcohols.. Other industries also employ polyester resin thanks to its numerous beneficial properties. Polyester resins are, across the board, pale in color. This could be a pale gray color to a dull and diluted white. All polyester resins are thermosetting, that is, they are malleable until they are heated, at which time they permanently harden, even when exposed to the same heat a second time. Polyester resins are pretty resistant to both water and to UV rays. Furthermore due to the thermosetting nature of polyester resins, they can be fairly brittle because of their resistance to being bent or changed. When enough pressure is applied, they can crack or shatter. Polyester resins are generally viscous. In order to lessen their viscosity, styrene is added. However, styrene may create fumes that can endanger those who work with polyester resin in this project, the unsaturated polyester is mixed with the hardener. The hardener, is MEKP (Methyl Ethyl Ketone Peroxide) is added to begin the curing process. Hardeners for polyester resin often referred to as catalyst, come in small plastic tubes or bottles with graduated measurements marked on them. Hardeners are measured in drops or fractions of teaspoons for most lay-up. When polyester resin is cured it goes through a polymerization process. This process brings it from a liquid state to a solid state. The "polymerization" involved is the connecting of molecules in a grid pattern, which is permanent and results in the resin going from liquid to solid (hard). The MEKP hardener begins this process. Always consult the manufacturer's instructions for mixing the correct proportions of resin to hardener. Factors that will affect the hardening time and working time are temperature, thickness of the application, quantities of resin mixed per batch and humidity. The properties of the unsaturated polyester and hardener can be viewed in the Appendix A.

3.3 Experimental Procedure

3.3.1 Fabrication of Hybrid Composite

The hand lay-up technique [3] will be used to fabricate the desired hybrid composite material as it is the simplest and most commonly used method for the manufacture of prototypes and low volume production of fiber composite material parts. The composite part will have a nice smooth surface on one side and a very rough one on the other. The fibers are manually placed into a mould. The matrix is first need to be weighted in order to get the desired volume fraction by using the Equation (3). A matrix of thermosetting polyester is rolled onto the fibers using a hand roller. More layers can be added and, after drying, the composite part can be removed from the mould. Apart from that, this technique is easy to control fibers orientation and the process is very flexible as it can produce from very small, up to very large part of different kinds of geometry. However, the cycle time per part is very long, and only small series can be produced.

3.3.1.1 Mold Preparation

Generally, this is one of the most important functions in the molding cycle as if the mold is prepared in a correct form, the molding will be looked fine and the sample with the desired specifications of composites can be easily separated from the mold. Production mold preparation requires a thorough machine buffing and polishing of the mold. Pastes of silicon wax are applied for the purpose of mold release after the desired finish has been attained. In this particular study, the mold has been prepared by using the aluminum steel in line with the usage of cutting and folding technique. The final product of the mold is illustrated in (Figure 3.3) which having the area of 270mm x 185mm.

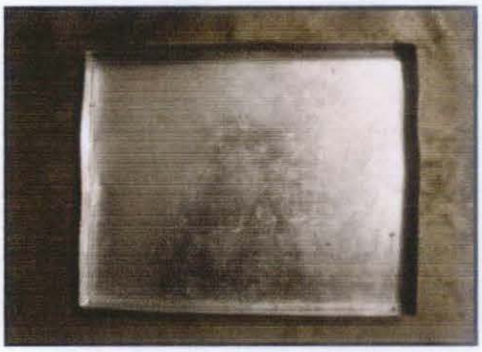


Figure 3.3: Prepared mold for sample fabrication

3.3.1.2 Hand Lay-Up Technique

This is the more simple process and maybe the first to be used in composites manufacturing. This is the more simple process and maybe the first to be used in composites manufacturing. This technique can also be called as contact lay-up, is an open-mold method of molding thermosetting resin in association with fibers. A chemical reaction initiated in the resin by a catalytic agent causes hardening to a finished part. Basically this type of technique is the best used in many industrial applications where production volume is low and other forms of production would be prohibitive because of costs and size requirements.

Required tools for hand lay-up technique:

1) Brush
2) Plastic bowl
3) Roller
4) Scissor
5) Mask
6) Glove
7) Electronic weighing scale

The procedure of the fabrication can be directed as below:

1. Wear proper goggles and glove and make sure other safety requirements are being followed
2. Release agent is applied on top of the mould surface to remove the impurities and for ease of removal
3. Weight the resin by using the electronic weighing machine (include the ratio)
4. Take ratio 5:1 of resin and hardener and mix them homogenously
5. The mixture is applied into the mould
6. The reinforced fibers are applied with accord to the design
7. Apply another layer of resin and continue the step until the desired layers and thickness are obtained
8. The fibers will be impregnated together with the resin and the excess air is removed with the help of roller
9. Laminates are left to cure under standard atmospheric conditions and leave it for about eight (8) hours to make it cure properly.

3.3.2 Drilling Operation

In order to perform the drilling process, one type of laminate is produced which glass and carbon fiber/polyester plate is fabricated from with a stacking sequence of [(0°/90°/0°/90°)]. Total numbers of 36 laminates are prepared to be drilled by using the XLMILL MTab-Denford CNC Milling Trainer as illustrated in (Figure 3.4). It is to ensure the samples are drilled at prefix feed rate and speed.

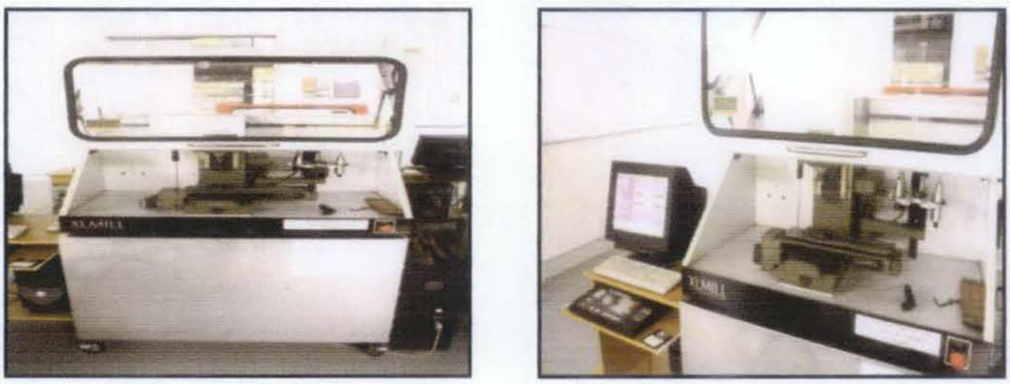


Figure 3.4: XMILL CNC Milling Machine

In the drilling process, CNC milling machine is used and jig as in (Figure 3.5) need to be located at bottom of the sample to support the sample and as well to eliminate delamination of the entrance and exit holes.

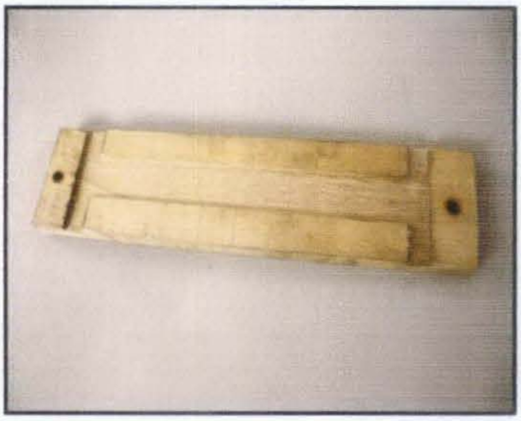


Figure 3.5: Jig to support and hold the sample together

The procedure of the drilling operation can be directed as below:

1. Perform the Start Up and Initialization procedure
2. Load the programme from the file
3. Adjust the coding according to the plan operation based on the technical drawing
4. Fix the samples with the backup plate on the worktable. Make sure the sample is fixed on the fixture.
5. Do the procedures for the offset of the operation
6. Run the program
7. Wait for the operation to finish
8. Inspect the finish hole quality, make sure the drill, drills thorough the sample and hit the back plate
9. For the other specimen, repeat the step 6 until the hole is drilled.
10. Close the CNC program
11. Perform shutdown procedure
12. House keeping

Health and safety precautions need to be taken into consideration as the chip of the hybrid composite will be splashed during the drilling process. Goggles must be worn at all times during the drilling operation. The process of drilling can be done such as in the (Figure 3.6) according to the coding as illustrated in (Figure 3.7).

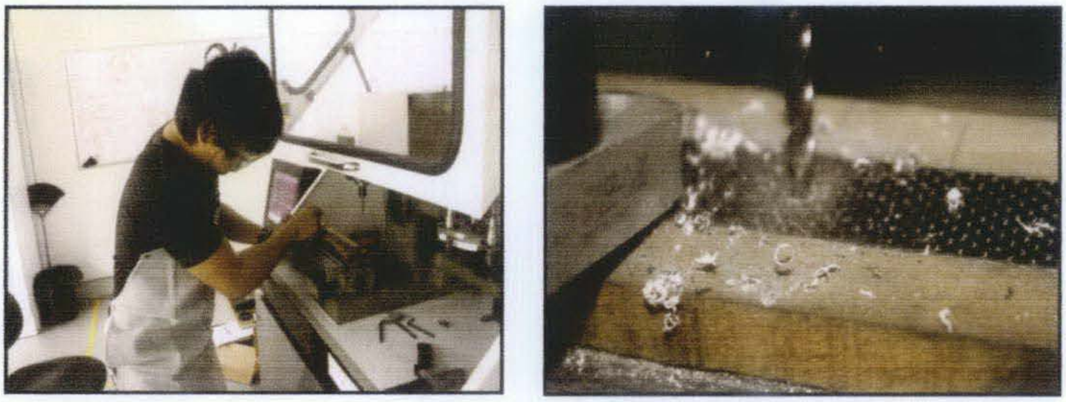


Figure 3.6: Executing the drilling process onto the samples

3.3.2.1 CNC Drilling Coding

```
Line 1                    Column 1

[BILLET X100 Y100 Z10 ;
[EDGEMOVE X-50 Y-50 ;
[TOOLDEF T2 D10 ;
G21 G94 ;
G91 G28 Z0 ;
G28 X0 Y0 ;
M06 T1 ;
M03 S1300 ;
G90 G0 X0 Y0 ;

N12 G0 X0 Y0 ;
N13 G0 Z10 ;
N15 X0 Y0 Z3 ;
N16 G81 X0 Y0 Z-5 R3. F62.5. ;
N17 G80 ;
N18 G0 X0 Y0 Z20. ;
N19 X0 Y0 Z50. ;
N20 G05 P0;
N21 G91 G28 Z0. M9 ;
N22 G28 X0. Y0. M05 ;
N24 G0 G28 X0. Y0. ;
N26 M30 ;
```

Figure 3.7: CNC code for drilling operation

Table 3.2: Drilling parameters and prepared samples

Thickness	4 mm											
Drill Bit Type	High Speed Steel + Coating											
Feed Rate (mm/rev)	0.05				0.10				0.15			
Sample	A	B	C	D	E	F	G	H	I	J	K	L
Speed (rpm)	650	1300	1800	2500	650	1300	1800	2500	650	1300	1800	2500

The drill bit used is the high speed steel with coating. The samples are drilled with three (3) different feed rates and four (4) spindle speeds such as shown in the (Table 3.2).

3.3 Damage Factor Assessment

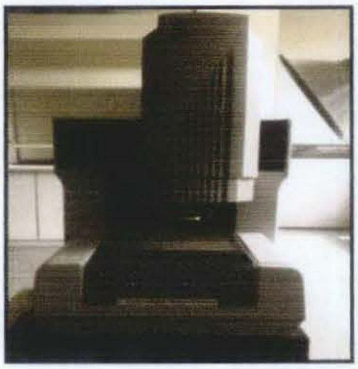


Figure 3.8: 3D Non- Contact Machine

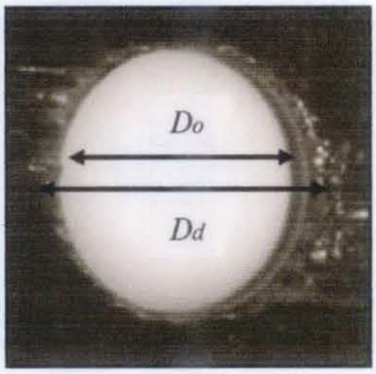


Figure 3.9: Damage factor assessment

Mitutoyo 3D Non- Contact Machine as illustrated in (Figure 3.8) consists of Quick Vision Apex® Series CNC video measuring systems which equipped with black and white or color cameras and offer illumination options of programmable ring lights with halogen ring-fiber or white/RGB LED. With 0.1 μm resolution, models are available with measuring ranges from 200 x 200 x 200 mm to 600 x 650 x 250 mm. Along with QVPAK® software, machines incorporate pattern focusing function and programmable power turret tube lens or programmable power zoom lens.

Chen et.al (1997) [17] proposed a comparing factor that enables the evaluation and analysis of delamination extent in composites, the Delamination Factor F_d, and it was defined such in the (Figure 3.9) as the quotient between the maximum delaminated diameter D_d and the hole nominal diameter D_o which can expressed as:

$$Damage\ Factor, F_D = \frac{D_d}{D_o} \quad \text{..} (4)$$

Damage factor proves to be closely related to the level of damage measured by a relative modulus decrease, which obviously occurs at the damage site. The measurement of the damage factor is basically the ratio of the original hole diameter and the diameter of the delamination of the hybrid composites material. In fact, the damage factor plays a significant role to obtain the best gap and length in order to proceed to make the other holes on a sample. By using the Mitutoyo 3D non contact machine, the delamination can clearly be observed. The diameter of the delamanition is calculated recorded.

3.4 Tensile Testing of Hybrid Composite

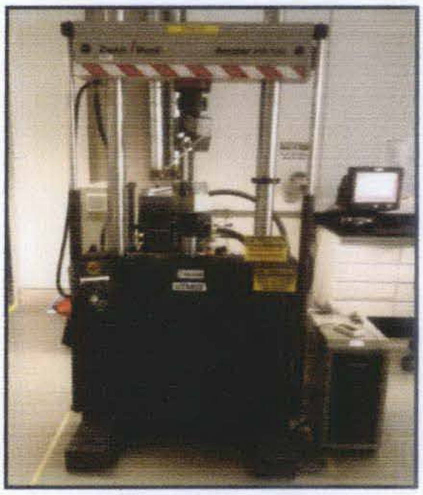


Figure 3.10: Universal Testing Machine

One of the most common machine stress-strain test performed is tension. The tensile test can be used to ascertain several mechanical properties that are important in any design. Universal Tensile Machine (UTM) as in (Figure 3.10) is normally used to conduct tensile stress-strain tests. A unidirectional force is applied to a specimen in the tensile test by means of moveable crosshead. The crosshead movement cab performed using screw or a hydraulic mechanism.

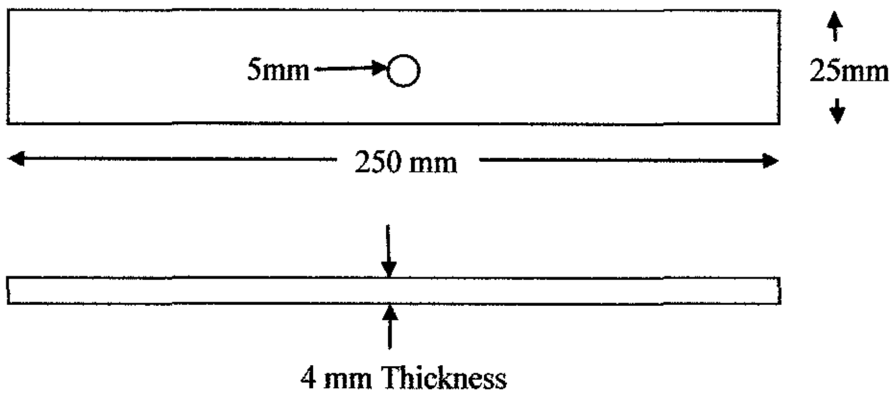


Figure 3.11: Tensile Sample geometry

A flat strip with a 4 mm thickness of hybrid composites having a constant rectangular cross section as shown in the (Figure 3.11) is mounted in the grips of mechanical testing machine and monotonically loaded in tension. The ultimate tensile strength can be determined from the maximum load carried before failure. Tensile testing is the most fundamental type of mechanical testing and applies a proof load to a sample past the yield point to failure. This method is intended to construct tensile property data for specified material, structural design and analysis. As per the ASTM for tensile testing of the hybrid composite material, the test specimens are balanced and symmetric laminates towards the test direction. The dog bone sample geometry is not be used since ASTM D3039 standard is chosen.

3.4.1 Test Procedure

The identity of each sample should be verified and pertinent identification should be accurately recorded for the test records and report. The dimensions needed to calculate the cross sectional area of the reduced sections should be measured and recorded. These measurements should be repeated for every specimen. The load-indicator zero and the plot-load-axis zero, if applicable, should be set before the specimen is placed in the grips. Zeroes should never be reset after the sample is in place.

3.4.1.1 Sample Insertion

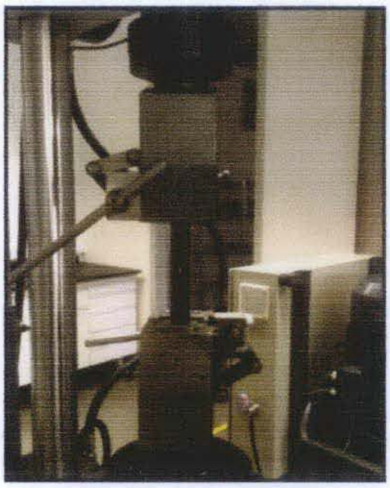


Figure 3.12: Clamped samples into machine grips

First and foremost, the sample must be marked accordingly. As recommended in the standard, the sample can be marked 5cm for each end before inserting in the grips of the testing machine. The alignment of the sample must be taken care to align the long axis of the test direction. Tighten the grips, recording the pressure used on pressure controllable (hydraulic or pneumatic) grips. By clamping the specimen as in (Figure 3.12) to force it to be straight, internal forced will be induced in the specimen. Thus, the results of the testing will be affected seriously.

3.4.1.2 Speed of Testing

The strain rate within 1 to 10min is selected to produce failure. If the ultimate strain of the material cannot be reasonably estimated, initial trials should be conducted using standard speed until the ultimate strain of the material and the compliance of the system are known, and the strain rate can be adjusted. The suggested standard speeds are:

- Strain- Controlled Test: 0.01 min^{-1} (standard strain rate)
- Constant Head Speed Test: 2mm/min (standard head displacement rate)

3.4.2 Stress Strain Curves

A tensile test involves mounting the sample in a machine, such as those described in the previous section, and subjecting it to tension. The tensile force is recorded as a function of the increase in gage length. (Figure 3.13) shows a typical curve for a ductile material. Such plots of tensile force versus tensile elongation would be of little value if they were not normalized with respect to specimen dimensions.

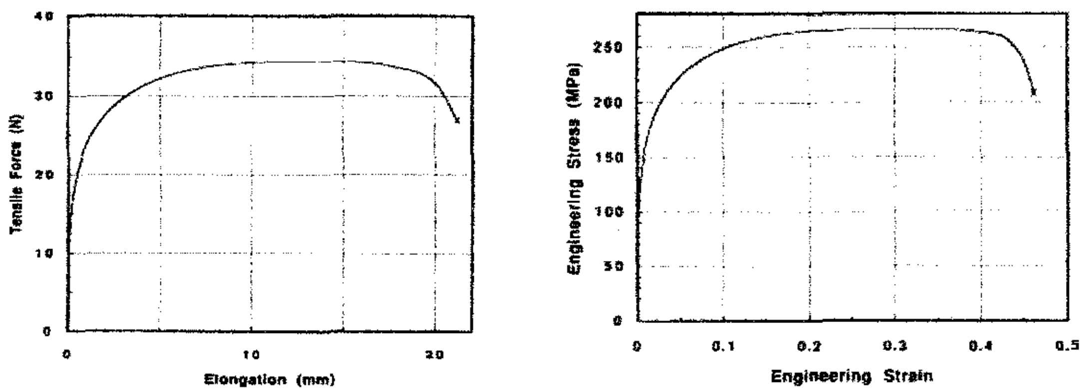


Figure 3.13: Typical stress strain curves

After data recording, the ultimate tensile strength has to be determined and report the result three significant figures.

Tensile stress/ Tensile strength can be calculated as:

$$\sigma_{UT} = \frac{F_{max}}{A} \quad \text{.........} \quad (5)$$

Engineering strain or nominal strain is defined as:

$$\varepsilon = \frac{\Delta L}{L} \quad \text{.........} \quad (6)$$

Elastic Modulus is calculated as:

$$E = \frac{\sigma}{\varepsilon} \quad \text{.........} \quad (7)$$

3.5 Surface Roughness Assessment

Figure 3.14: Mitutoyo Surface Tester Profilometer

Mitutoyo Surftest SV-3000 system software supports RS-232C for bi-directional communications between its own PC, and the PLCs of automated material handling systems. As the performed the drilling operation, the stylus device of the profilometer as in (Figure 3.14) which is a measuring instrument used to measure a surface's profile, will be inserted through the hole in order to quantify its roughness of holes across the depth [3]. Basically it is to study the effects of surface roughness of part produced form different machining processes, to establish relationship between material and machining on a specific component and to measure quality of surface after drilling processes have been done.

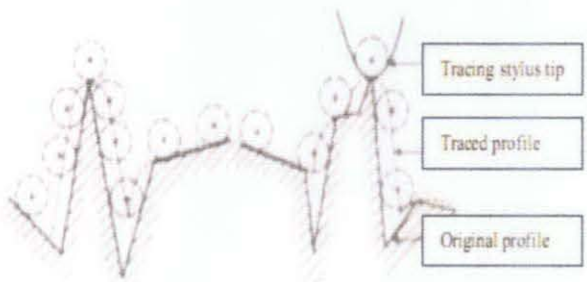


Figure 3.15: Path of stylus in surface roughness measurement

Roughness refers to the finely spaces surface irregularities. It results from machining operations in the case of machined surfaces. Roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small the surface is smooth. Roughness is typically considered to be the high frequency, short wavelength component of a measured surface. The most commonly used instruments feature a diamond stylus which travel along a straight line over the surface (Figure 3.15). The distance that the stylus travels is called the cutoff. It generally ranges from 0.08 mm to 25 mm; 0.8 mm is typical for most applications.

3.6 Microscopic Analysis

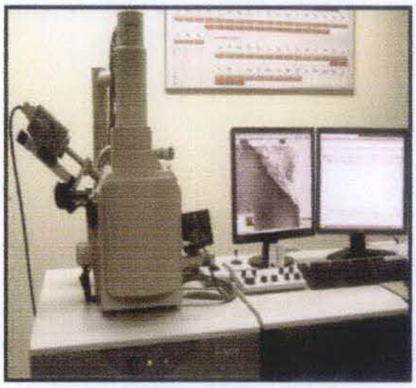


Figure 3.16: Scanning Electron Microscope

In order to analyze microstructure of any material specimen Scanning Electron Microscope as in (Figure 3.16) is used. The principle of SEM images and composition analysis are based on the reflected rays after an electron hits a specimen's surface target. If the surface of the specimen is an insulating material, it may require further preparation such as 'gold coating' before placed in the SEM. SEM has the capability to produce micrograph (microstructure images) and composition analysis results (weight-%) concurrently from the same material's specimen.

3.7 Gantt Chart

Activities/Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
Project work continues: Sample Fabrication Continuation	■	■	■					Mid Semester Break							
Perform Drilling Operation: 1. Jig preparation 2. CNC programming			■	■											
Project work continues: Damage factor assessment					■	■									
Progress Report Preparation							■								
Submission of Progress Report									△						
Perform Tensile Testing									■	■					
Surface Roughness assessment									■	■					
Analysis by using SEM											■				
Result gathering											■	■			
Poster Exhibition												△			
Submission of Dissertation final draft															△
Oral presentation															△
Submission of Dissertation (hard bound)									After Final Examination						

Figure 3.17: FYP II Gantt chart

△ - Milestone

■ Completed Activities

Figure 3.17 shows the Gantt chart summary that will need to be referred as the milestone for the intended final year project (FYP II) throughout the 14 weeks. This planned Gantt chart is significant and possible to be followed in order to discipline the author in making the project as a success. Firstly, as planned during FYP I after choosing the particular topic, the author should collect all the relevant data with regards to the design, fabrication and analysis on the hybrid composites material. The author has fabricated the total of 36 samples all together. Jig preparation is needed to perform the drilling operation. After the drilling operation in week 4, damage factor has been measured by using the Mitutoyo 3D Non- Contact Machine. Tensile testing is done in week 8 until week 9. After all samples have been tested, the samples are needed to assess again in term of surface roughness by using the available profilometer and lastly the study of microstructure by using SEM. All of the results can be viewed in chapter 4 in the week 11, author needs to submit the poster and finally after the analysis, the author has to prepare for the submission of interim report, draft of dissertation and lastly the oral presentation. The three (3) copies of hardbound final dissertation are submitted after the final examination.

CHAPTER 4
RESULT AND DISCUSSION

4.1 Sample Thickness

Based on the recommendations in (Table B-2) in Appendix B, the recommended thickness of a tensile specimen is 2mm. The author has made the alterations to the thickness based on the (Table B-1) in which it stated that thickness is not fixed and can be altered as needed and required to the test. The decision thickness is 4 mm. 4 mm thickness of hybrid composites is selected in order to have different plies and sequence of laminates. In order to measure the single layer thickness of the fibers, caliper is used. The mat should be folded to several layers so the precise readings can be obtained as can be viewed in (Table 4.1).

Table 4.1: Thickness of woven mat based on materials

No of Layers	Thickness, mm	
	Carbon fiber	**Glass fiber**
8 layer	1.52	1.36
1 layer	0.19	0.17

The acquired thickness from both materials can now be used to determine layers required to fabricate the sample to the required thicknesses, which is 4 mm. Therefore the 4 mm thickness will required 16 layers of combined carbon fiber and glass fiber altogether, respectively.

4.2 Rules of Mixture (Mass Calculation)

Generally, fiber volume fraction is used to obtain the weight of the matrix used to fabricate the desired composite. In this study, 45% matrix volume fraction of polyester resin and 55% of fibers volume fraction is used. The weight of polyester can be obtained as;

Calculation of unsaturated polyester mass 4.0 mm thickness samples

$V_m = 0.45$ $V_f = 0.55$

v_c = 27cm x 18.5cm x 0.40cm (as per ASTM sample geometry)

$v_c = 199.8\ cm^3$

$v_m = V_m v_c$

$= (0.45)(199.8 cm^3)$

$= 89.91 cm^3$

$\rho = m/v$

$m_m = (1.2 g/cm^3)(89.91 cm^3)$

= **107.892g (required mass of polyester for one mold)**

This is the amount of polyester resin used to fabricate the samples and 10% of MEKP is mixed homogenously with the resin in order to cure the samples. Total of 6 layers carbon fiber and 10 layers of glass fiber to get 20% FVF of carbon fiber and 35% of FVF of glass fiber.

4.3 Fabricated Samples

The author has completed the final design of the samples. Hybrids have unique features that can be used to meet design requirements in a more cost-effective way than advanced or conventional composites [3]. Type A hybrid composite which is made of intermingling fibers of different types in a common polyester will lead to a better properties of the particular composites. As an illustration, the inexpensive E-glass fibers may be utilized to mingle with the relatively costly carbon/graphite. The relatively costly carbon/graphite fiber is chosen due to its low density, high specific strength and as well as the high specific modulus. Glass fiber is the major composition in this fabrication work. Fabrication of hybrid composite which consist of carbon fiber and glass fiber produced a better mechanical properties with low cost as compared to carbon fiber composite and glass fiber composite respectively. Basically, for the fabrication of hybrid composite material, as illustrated in figure two types of fibers which are the glass fiber and carbon fiber (both are woven type) will be used. The hybrid composites are fabricated in 4 mm thickness and 55% FVF as illustrated in the (Figure 4.1). The arrangement of carbon fiber at the middle of the laminate is to reduce the delamination occurred during drilling process. Furthermore, as shown in the (Table 4.2) is the stacking sequence of the samples which is $0^\circ/90^\circ$ orientation.

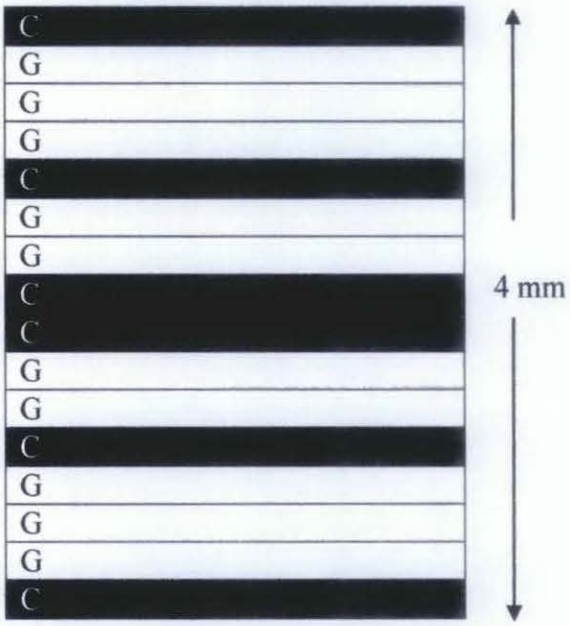


Figure 4.1: Initial design for the hybrid composite

Table 4.2: Stacking Sequence of samples

Composite	Stacking Sequence
Carbon/Glass/Polyester $C/G_3/C/G_2/C_2/G_2/C/G_3/C)$	$[(0^\circ/90^\circ)/\ (0^\circ/90^\circ)/\ (0^\circ/90^\circ)/\ (0^\circ/90^\circ)/\ (0^\circ/90^\circ)/\ (0^\circ/90^\circ)/\ (0^\circ/90^\circ)/\ (0^\circ/90^\circ)/\ (0^\circ/90^\circ)/\ (0^\circ/90^\circ)/\ (0^\circ/90^\circ)/\ (0^\circ/90^\circ)/\ (0^\circ/90^\circ)/\ (0^\circ/90^\circ)/\ (0^\circ/90^\circ)/\ (0^\circ/90^\circ)/$

Based on (Figure 4.2), a short conclusion is drawn here where in the project, even number of fiber plies are used and arranged in opposite direction with refer to the symmetric line in order to avoid coupling happen in the composite plate [20]. The symmetric orientation of glass fiber and carbon fiber within the hybrid composite has avoided the plate from bending in one direction in which it will reduce the mechanical properties of the hybrid composite [20].

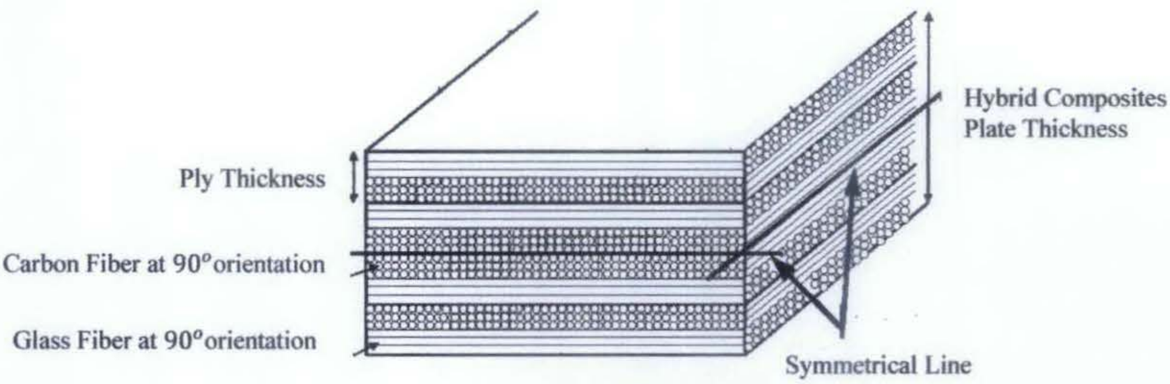


Figure 4.2: Cross-section of symmetrical hybrid composite.

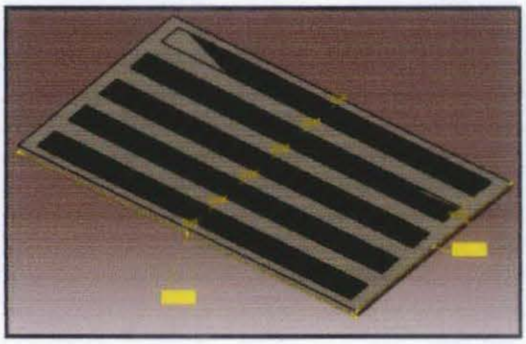


Figure: 4.3: Dimension of design

Figure 4.4: Final product of 4 mm samples

Previously, as can be seen from the (Figure 4.3), tolerance between samples in the mold must be taken in consideration. The purpose of the allowance is to avoid from delamination to occur when cutting process takes place. The tolerance of 1 cm per sample will be used in the designing process. The fabrication is done such way to avoid damage on the samples during cutting process.

After all the specimens were cut by using abrasive cutter, the author managed to get the final product of samples as illustrated in the (Figure 4.4). The amount of samples that have been fabricated is 36 samples. Each of the samples has been labeled in order to differentiate each of them before proceeding with other experimental work.

4.4 Drilling Result

4.4.1 Drilling Parameters

Drilling of this composite material, irrespective of the application area, can be considered a critical operation owing to their tendency to delaminate when subjected to mechanical stresses. Among the defects caused by drilling, delamination appears to be the most critical. All of the samples being drilled with 5 mm high speed steel drill bit. Three (3) different feed rates and four (4) different spindle speeds are used in the drilling process.

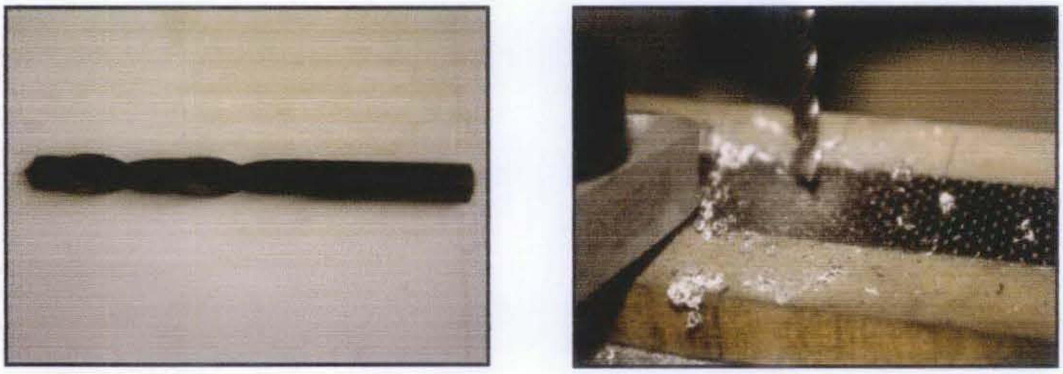


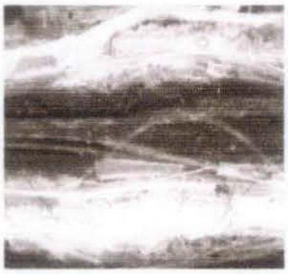
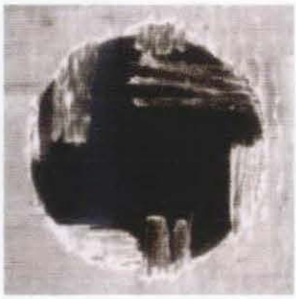
Figure 4.5: Type of drill bit used

Table 4.3: Drilling Parameters of samples

Thickness	4 mm											
Drill Bit Type	High Speed Steel + Coating											
Feed Rate (mm/rev)	0.05				0.10				0.15			
Sample	A	B	C	D	E	F	G	H	I	J	K	L
Speed (rpm)	650	1300	1800	2500	650	1300	1800	2500	650	1300	1800	2500

4.4.2 Quality Issues of Drilled Hole

As the material develops it gets more difficult to machine as the increasing demand on cutting tool functions and tool performance and high demands on hole and edge quality. In fact the main indicator is the hole quality. However, the quality is not easily assessed as there is no chip to look at and damage (delamination) cannot visible by naked eyes. After the author performed the drilling operation, the drilled samples are observed with three different means which are by using optical microscope, 3D Non Contact Machine and SEM. The 36 of samples that are drilled were examined under optical microscopic and 3D Non Contact Machine. Observations showed that the structures were suffered from drilling process. The main types of structural damage generated during drilling of polymeric matrix composites are delamination, splintering, matrix cratering and thermal damage.

Delamination	**Splintering**
 (a)  (b) Figure 4.6: Separation of the bottom layers due to the thrust of the drill	 (a)  (b) Figure 4.7: Residual fibers in the interior of the hole due to poor cutting action

4.5 Result of Damage Factor

Generally delamination is the damage which is normally occurred after drilling composite materials. Delamination can be seen around the circular area of the hole. Therefore by using the Mitutoyo 3D Non-Contact Machine, the diameter of the delamination can be determined. As in the (Table 4.4), the damage factor has been calculated by dividing the delamination diameter with the original drill bit diameter. Next, the images of the delamination have been captured by using the same machine as the evident of the result.

Table 4.4: Calculated Damage Factor, F_D

Sample	Feed rate (mm/rev)	Drill Bit Diameter, D_o (mm)	Delamination Diameter, D_d (mm)	Damage Factor, F_D
A	0.05	5	6.1065	1.2213
B	0.05	5	6.0078	1.2016
C	0.05	5	6.0158	1.2032
D	0.05	5	6.0226	1.2045
E	0.10	5	6.2136	1.2333
F	0.10	5	6.0841	1.2168
G	0.10	5	6.0369	1.2074
H	0.10	5	6.1179	1.2236
I	0.15	5	6.2248	1.2450
J	0.15	5	6.1072	1.2214
K	0.15	5	6.1180	1.2236
L	0.15	5	6.1941	1.2388

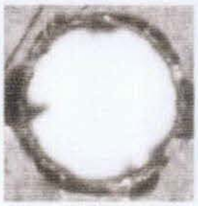
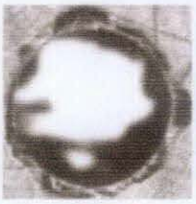
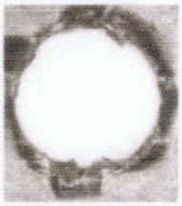
Thickness	Sample A	Sample B	Sample C	Sample D
4mm	 F_D= 1.2213	 F_D= 1.2016	 F_D=1.2032	 F_D=1.2045
	Sample E	Sample F	Sample G	Sample H
	 F_D=1.2333	 F_D=1.2168	 F_D= 1.2074	 F_D=1.2236
	Sample I	Sample J	Sample K	Sample L
	 F_D=1.2450	 F_D=1.2214	 F_D= 1.2236	 F_D= 1.2388

Figure 4.8: Delamination images of samples

(Figure 4.8) shows the delamination images captured by the Mitutoyo 3D Non Contact Machine. It is clearly shows that the delamination formed on the samples after drilling process. As can be seen in (Table 4.4), as the feed rate and spindle speed increases, the larger the delamination can be observed. The larger diameter of delamination, the larger the damage factor is. Based on the result, a damage factor versus graph has been plotted showing the significant of the damage factor upon the different drilling parameters. It verifies that higher feed rate gives higher value of damage factor and too low of spindle speed conduce to high damage factor for those feed rates.

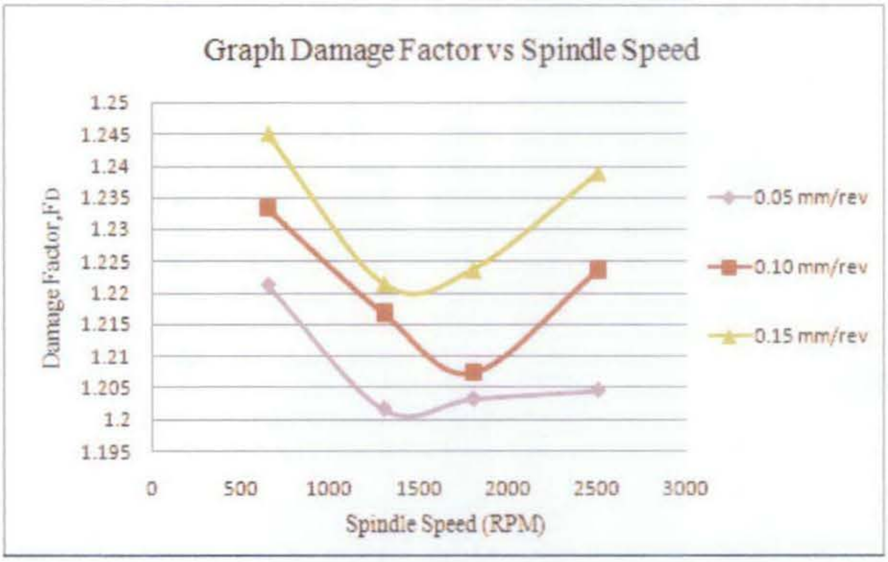


Figure 4.9: Damage factor, F_D results for different speeds and feed rate

In general, these results are adequate to identify an optimum domain of parameters combining low feed rates with low cutting speeds. Higher cutting speeds increase the risk of thermal damage as it causes the softening of the matrix material. A consequence of that phenomenon can be a loss of mechanical strength of the uncut plies of the laminate, leading to extended delamination. 1300 rpm spindle speed produces low F_D. The best result identified among other sample, for a 5 mm diameter tool, is **sample B** with lowest damage factor (1.2016) due to the lower value of feed rate applied during drilling process.

The best results for delamination, were always found when a low feed rate was used. Regarding the experimental set used in this work, it is not surprising to observe that a feed of 0.05 mm/rev has resulted as the best option as in (Figure 4.9). However, it must be remembered that a low feed rate also increases the heating of the hole machined walls during machining. In some cases, the possibility of matrix softening should be taken into account. In that case, thermograph techniques should be used in order to evaluate this risk. The use of CNC machines, enabling a variable feed rate strategy is a good option to consider when drilling laminate plates.

As the conclusion, delamination can be reduced if proper cutting parameters are selected. Considering the parameters used in this work, the best set was a spindle speed of 1300 rpm and feed rate of 0.05 mm/rev .However, low spindle speed might cause severe delamination on the hybrid composites samples.

4.6 Recommendation to Reduce Damage on Top of the Drilled Hole

Increasing feed rate and cutting speed will increase the productivity of production, however, poor hole quality will be produced resulted from this activity. Poor hole quality required for works which is expensive and time consumed. Hence, these problems can be solved by [18];

Table 4.5: Solution to delamination and splintering problem

Problem	Solution
Delamination	• Reduce feed rate • Consider a change in geometry
Splintering	• Consider a more positive geometry • Increase speed • Increase feed rate

4.7 Result of Tensile Test

The data presented in this topic is to compare the failure mode of drilled and non-drilled samples. As shown in the (Figure 4.10), the typical failures of samples are reported. Most of the samples experience similar brittle breaking. The drilled and non-drilled samples are successfully fractured at the center of the samples.

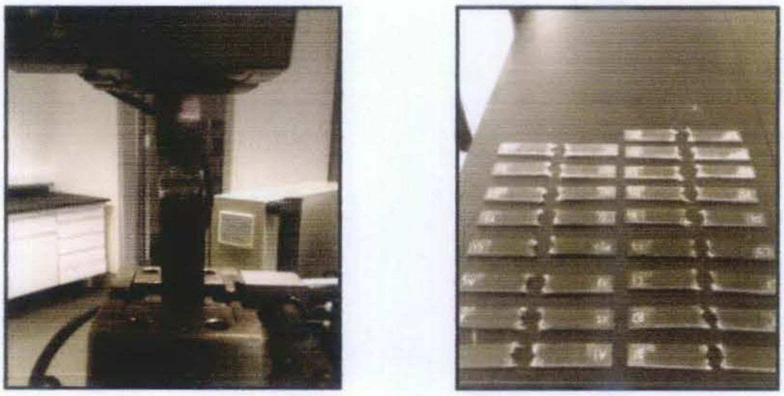
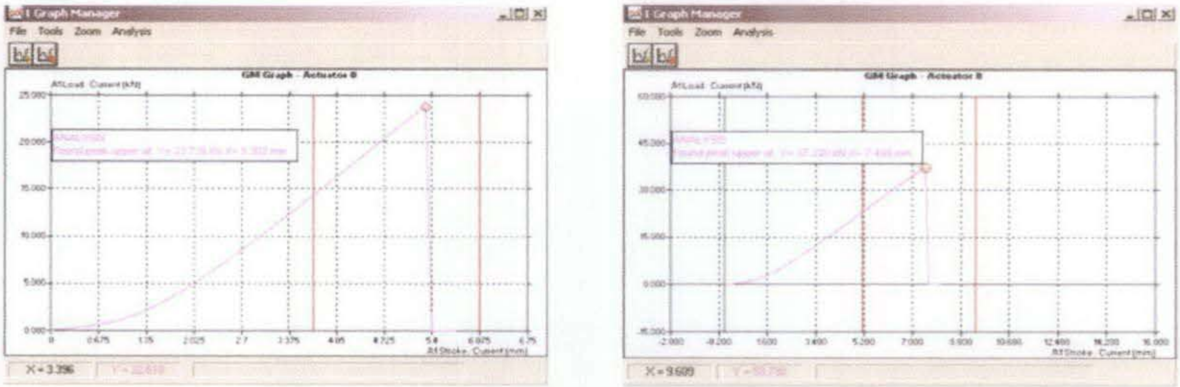


Figure 4.10: Fractured samples after tensile test

Figure 4.11(a-b) illustrates the tensile graphical behavior of the samples. The maximum loads before fracture for drilled samples are within the range of 22kN to 23kN, while for the non-drilled samples, the maximum loads are in the range of 35kN to 37kN. It can be clearly observed from graphs that drilled samples required smaller load as compared to the non-drilled samples. It is because the drilled samples have higher stress concentration at the center which can be easily failed when stress is applied in the longitudinal direction. The fibers are considered to be totally brittle and the matrix phase to be reasonably ductile [13].

At the initial stage, both fibers and matrix deform elastically which normally this portion of the curve is linear. Typically for this type of composite, the matrix yields and deform plastically while fibers continue to stretch elastically, in as much as the tensile strength of the fibers is significantly higher than the yield strength of the matrix. This process constitutes stage 2 which plastic deformation starts to occur. This stage is ordinarily linear, but of diminished slope relative to stage 1 (elastic deformation). In this case, the fibers will fail before the matrix. Once the fibers have fractured, most of the load that was borne by the fibers is now transferred to the matrix.



(a) (b)

Figure 4.11: (a) Tensile result for (a) drilled samples and (b) non-drilled samples

Table 4.6: Determined tensile properties for drilled samples

Sample	Load (kN)	Tensile Strength (MPa)	Stroke (mm)	Tensile Strain	Elastic Modulus (GPa)
A	22.545	281.813	5.225	0.0209	13.483
B	23.199	289.988	5.228	0.0209	13.875
C	23.059	288.238	5.315	0.0213	13.532
D	23.195	289.938	5.318	0.0213	13.612
E	22.174	277.175	5.131	0.0205	13.521
F	23.758	296.975	5.368	0.0215	13.813
G	22.228	277.850	5.130	0.0205	13.554
H	23.342	291.775	5.318	0.0213	13.698
I	23.736	296.700	5.302	0.0212	14.000
J	22.656	283.200	5.266	0.0211	13.422
K	23.153	289.413	5.201	0.0208	13.914
L	22.562	282.025	5.268	0.0211	13.366

Table 4.7: Determined tensile properties for non-drilled samples

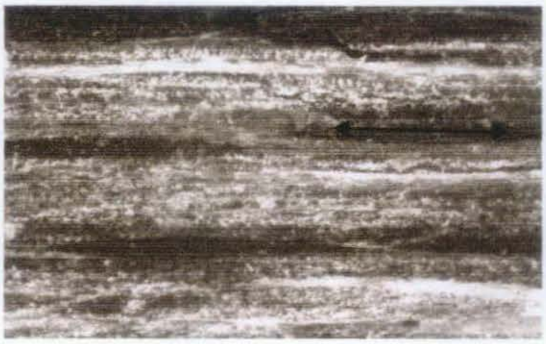
Sample	Load (kN)	Tensile Strength (MPa)	Stroke (mm)	Tensile Strain	Elastic Modulus (GPa)
P	36.545	365.450	7.365	0.0295	12.388
Q	37.220	372.200	7.495	0.0300	12.406
R	36.059	360.590	7.318	0.0293	12.307
S	35.895	358.950	7.147	0.0286	12.551
T	37.174	371.740	7.495	0.0300	12.391

In increasing longitudinal tensile load, failure initiates by fiber breakage at their weakest sections. Breaking of fibers is totally a random process. Some cross section of the composite may become very weak to support the increasing load thus result in a complete rupture of the hybrid composite material. Moreover, the interfaces of broken fiber ends thus may contribute to the separation of the composite at a given cross section. Based from (Table 4.6-4.7), it specifies the properties gained for every samples after the tensile test. Only the load (kN) and stroke (mm) which the displacement data can be obtained from the software. The ultimate tensile stress, tensile strain, elastic modulus can be achieved by substituting the load and elongation values into Equation (7) as in chapter 3.

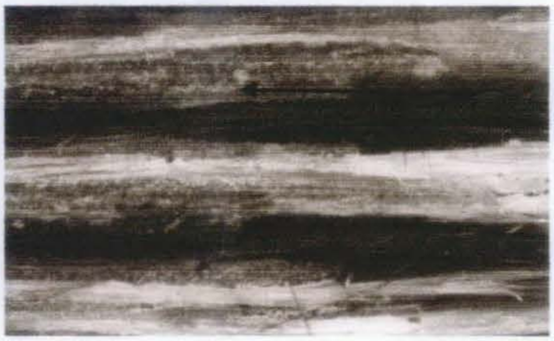
As expected, the drilling effect of composite material having it lost its mechanical strength due to higher stress concentration at the middle of the samples. Drilled hole at the centre of the samples have reduced the ability of the fiber and matrix to sustain the higher stress concentration applied at the middle of the samples. Having feed rate of 0.05 mm/rev, 0.10 mm/rev and 0.15 mm/rev did not show significant difference in the tensile strength of the samples. This is clearly shown that the drilling parameter did not influence the strength of the drilled composite as the range of the ultimate tensile strength is in the range between 277MPa to 296Mpa. The results show that the ultimate tensile strength for both drilled and non-drilled samples have 37.6% difference. The reduction of ultimate tensile strength suggests that there is a drill size and geometry effect on the samples, However, there are no significant difference in how the drilling parameters affecting the tensile strength of the samples. If higher and large feed rates for example 2 mm/rev are used in drilling process of the hybrid composites, it will cause higher damage or delamination within the hole and strength of the composite will decrease to a specified value.

As in the conclusion, when hybrid are stressed in tension, failure is usually non-catastrophic in which it does not occur suddenly. The carbon fibers are the first to fail, at which time the load is transferred to the glass fibers. Upon failure of the glass fibers, the matrix phase must sustain the applied load. Eventual hybrid composite failure concurs with that of the matrix phase.

4.8 Delamination Analysis after Tensile Testing

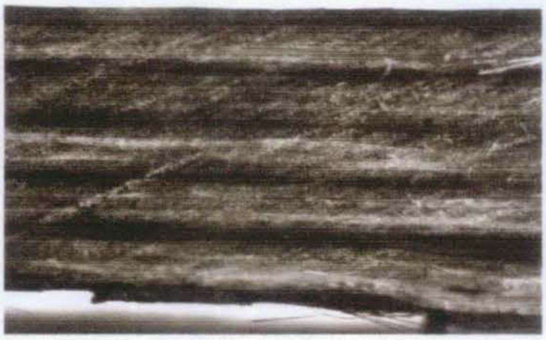


(a)

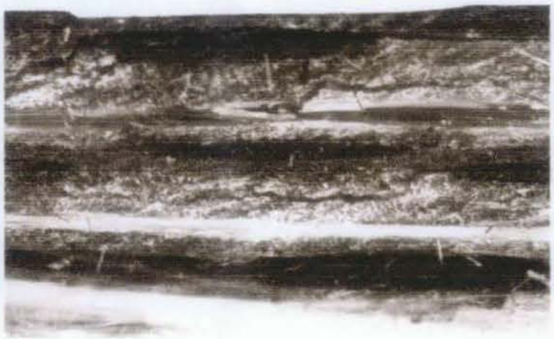


(b)

Figure 4.12(a-b) basically is the side view of sample B. Crack propagating along the 0°/90° interface can be seen from Figure 4.12(a). The propagation of the crack is the interlaminar crack. Figure 4.12(b) shows the start of the delamination. The length measured for sample B is 12.447 mm. Thus, 0.05 mm/rev feed rate result in lower delamination compared to 0.1 mm/rev and 0.15 mm/rev.



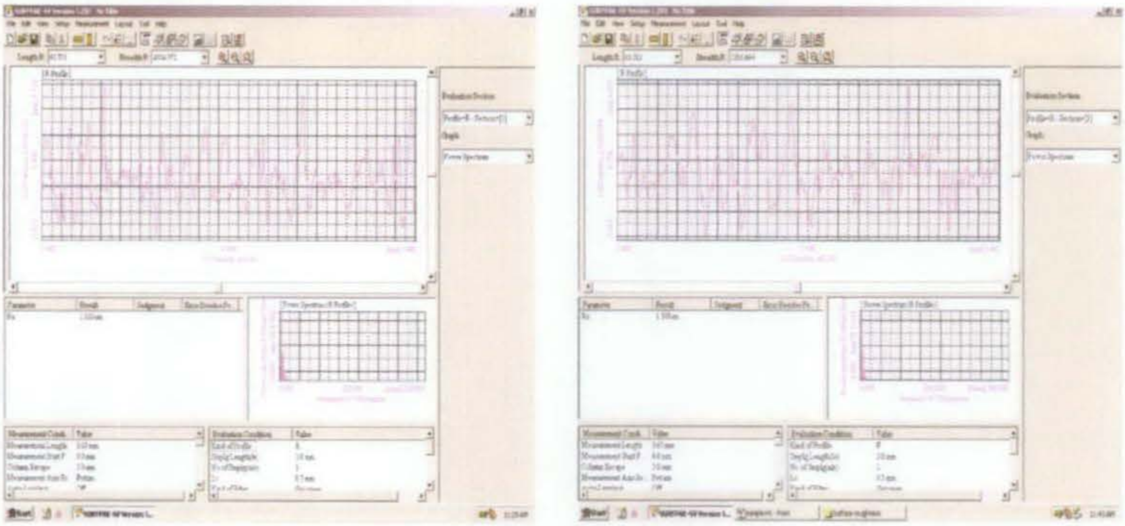
(a)



(b)

Figure 4.13(a-b) is the side view of sample J. Greater delamination can be observed from Figure 4.13(b). The delamination measure is 16.87 mm. The sample of 0.15 mm/rev feed rate experience larger damage factor and after the tensile test it also shows the tendency for a longer delamination. Variation in drilling parameters during drilling might not affect the tensile strength, but it shows that the damage for higher feed rate is worse than the lower feed rate.

4.9 Result of Surface Roughness



(a) (b)

Figure 4.14: Surface roughness result for (a) sample B and (b) sample F

Table 4.8: Result of surface roughness

Thickness	4 mm											
Drill Bit Type	High Speed Steel + Coating											
Feed Rate (mm/rev)	0.05				0.10				0.15			
Sample	A	B	C	D	E	F	G	H	I	J	K	L
peed (rpm)	650	1300	1800	2500	650	1300	1800	2500	650	1300	1800	2500
Surface oughness,R_a (μm)	1.249	1.390	1.477	1.624	1.355	1.638	1.821	1.910	1.563	1.883	2.240	2.490

Surface roughness (R_a) is the measure of the texture of the surface at the drilled hole wall. Internal surface roughness measurement measures the internal surface of the drilled holes as delamination occurred. The evolution of surface roughness is closely observed with increasing feed rates and spindle speed. It can be inferred that the value of Ra are increased with increasing feed rate as shown in (Table 4.8).

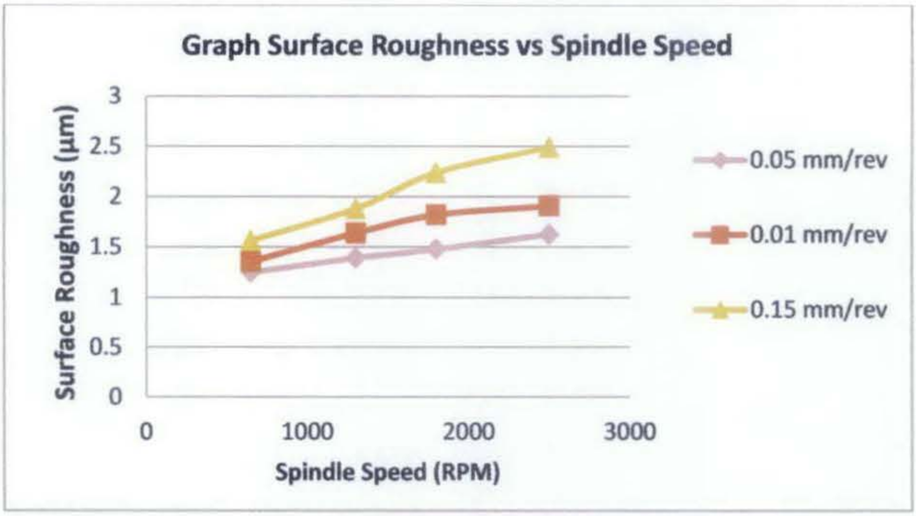


Figure 4.15: Graph surface roughness vs spindle speed

As illustrated from (Figure 4.15), it specified the result of the surface roughness, R_a. It was determined by using the profilometer with different feed rate and spindle speed. The experiment is repeated three times for each sample and average results were calculated Based from data obtained, the finest surface roughness is sample A with lowest feed rate of 0.05 mm/rev and 650 rpm of spindle speed, meanwhile the sample L which is giving the higher surface roughness which is 0.15 mm/rev feed rate and 2500 rpm of spindle speed. The result shows that the sample of 0.05 mm/rev feed rate gives lower value of surface roughness which indicates the sample having smoother surface. Surface roughness is the first symptom that can be quantified to predict the damage or delamination length for the particular sample. Samples with low value of surface roughness will produce the results of lesser damage [1].

4.10 Result from Scanning Electron Microscope

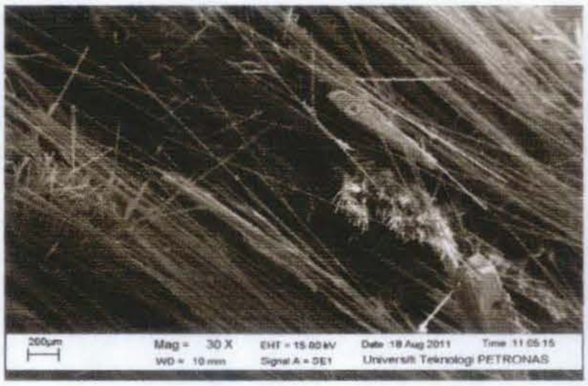


Figure 4.16(a)

Figure 4.16(b)

Figure 4.16(a) shows the fractured fibers experienced the longitudinal tensile load of sample L. The image is taken with 30X magnification at the tip of the broken sample (middle). It verifies that the fibers being laminated in term $0^{o}/90^{o}$ stacking sequence.

Figure 4.16(b) shows the single glass fiber with higher magnification image. As understood, the glass fiber sustains the load after the failure of carbon fiber. The fibers being pulled out due to the weak crossing point to polyester resin.

Figure 4.16(c)

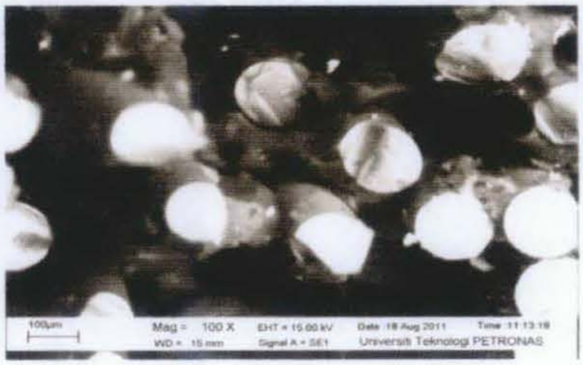


Figure 4.16(d)

As illustrated in Figure 4.16(c), hybrid composite are anisotropic, when these are stressed in tension, failure is usually non catastrophic. The failure of carbon fiber at the earlier stage has transferred the load to the glass fiber. Then, the matrix phase has to sustain the applied load upon failure of the glass fiber. It also shows hackle formation in the matrix phase exhibiting matrix damage

Figure 4.16(d) micrograph shows the pull out of the glass fibers in the recessed areas due to weak interface between the glass fiber and the matrix.

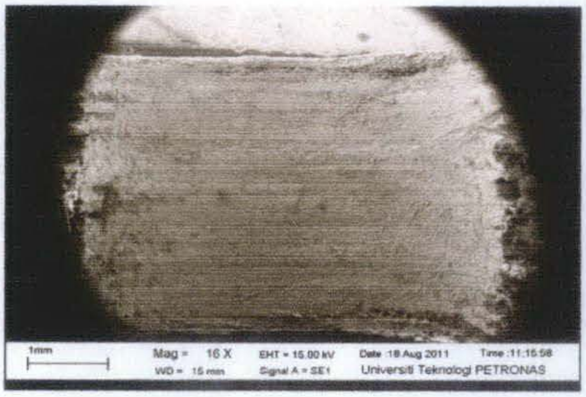


Figure: 4.17(a)

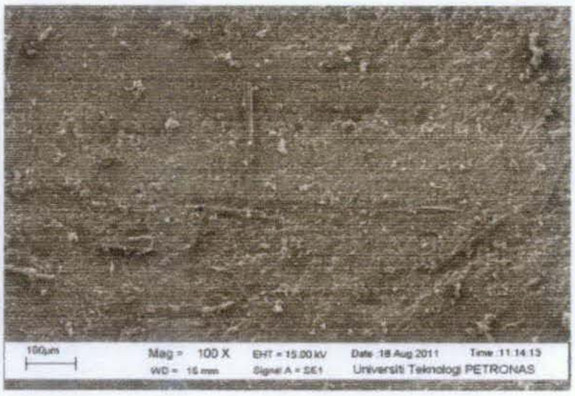


Figure:4.17(b)

Figure 4.17(a-d) are the images of sample A. It is captured at the middle surface of the drilled hole. As can be seen, the surface is smooth and no damages observed. 0.05 mm/rev gives best result in order to have relatively smooth surface.

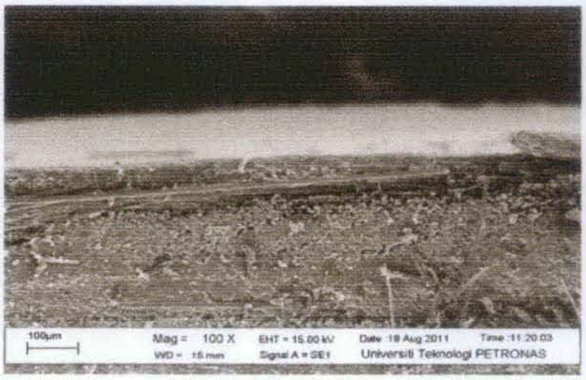


Figure:4.17(c)

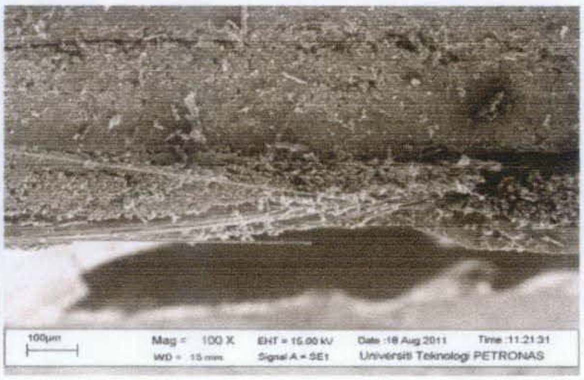


Figure: 4.17(d)

Figure 4.17(a) is the image at the entrance of the hole. It is illustrated to have slight fiber peel up delamination due to the pulling action in the drilling process.

Figure 4.17(d) is the image taken at the exit of the hole. Fiber push out delamination can be observed because of thrust force exerted by the drill exceeds the interlaminar fracture toughness of the plies. However for sample with 0.05 mm/rev the damage is not really obvious and catastrophic.

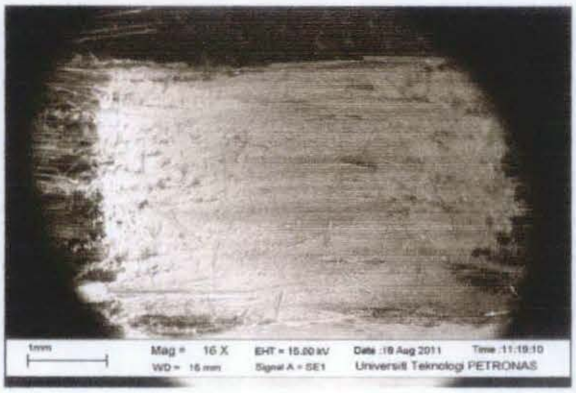


Figure:4.18(a)

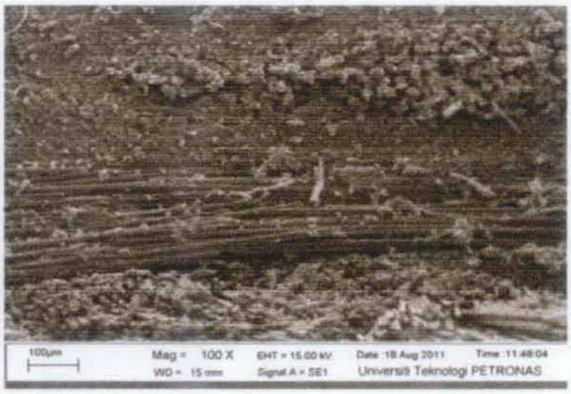


Figure:4.18(b)

Figure 4.18(a-d) are the images of sample E. It is taken at the middle surface of the drilled hole. The damage can be clearly observed with 100X magnification. Figure 4.18(b) shows the recessed pockets as fiber bundle pullouts in the broken cross section of sample with fiber orientation of $0^{o}/90^{o}$. It also shows a delamination crack front propagating along the $0^{o}/90^{o}$ interface. 0.1 mm/rev feed rate of drilling process gives slight damage to the samples

.

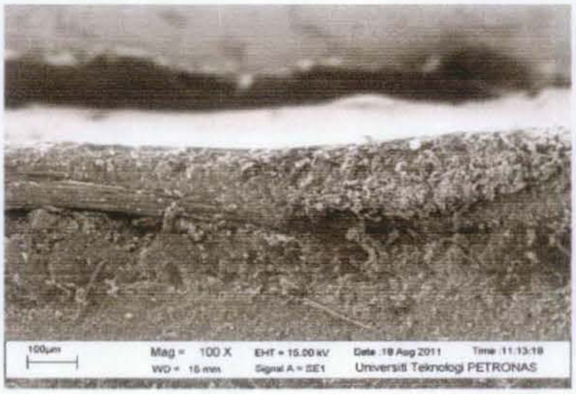


Figure:14.8(c)

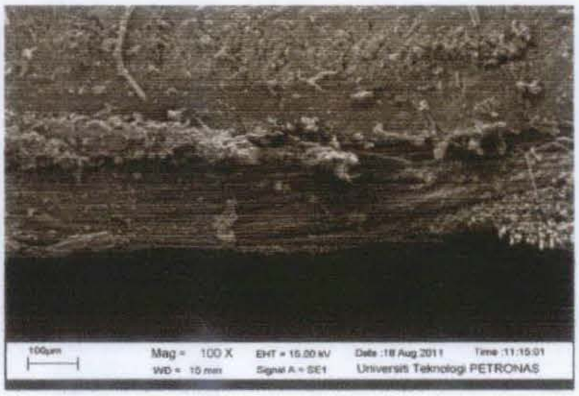


Figure:14.8(d)

Figure 4.18(c) is the image at the entrance of the hole. It is illustrated to have slight fiber peel up delamination due to the pulling action in the drilling process.

Figure 4.18(d) is the image taken at the exit of the hole. Severe fiber push out delamination can be observed because of thrust force exerted by the drill exceeds the interlaminar fracture toughness of the plies. However for sample with 0.10 mm/rev the damage is not really obvious and catastrophic as compared to 0.15 mm/rev feed rate.

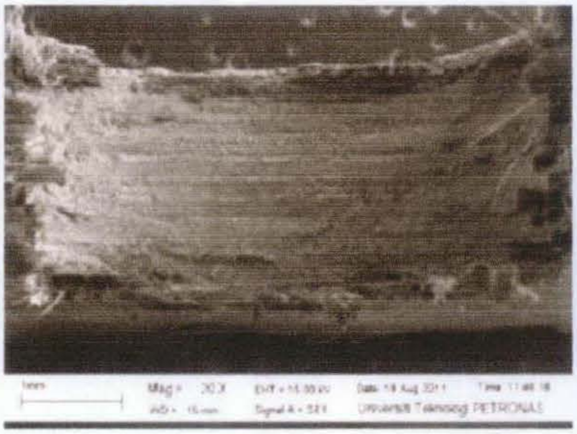


Figure: 4.19(a)

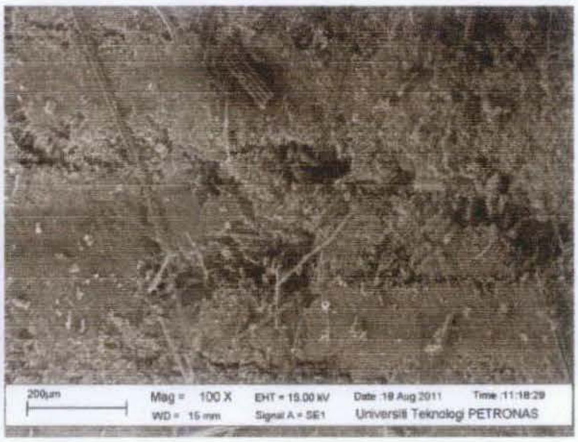


Figure: 4.19(b)

Figure 4.19(a-d) are the images of sample L. Figure 4.19(a-b) is the middle surface of the drilled hole. It interprets that 0.1 mm/rev feed rate results in rougher surface of the sample. Cracks also can be observed. The damage may begin with the formation of striations/microscopic cracks. Therefore, higher feed rate such as 0.15 mm/rev will greatly affect the surface of the drilled hole.

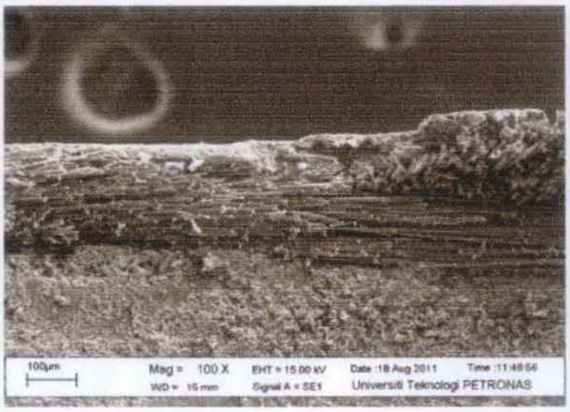


Figure: 4.19(c)

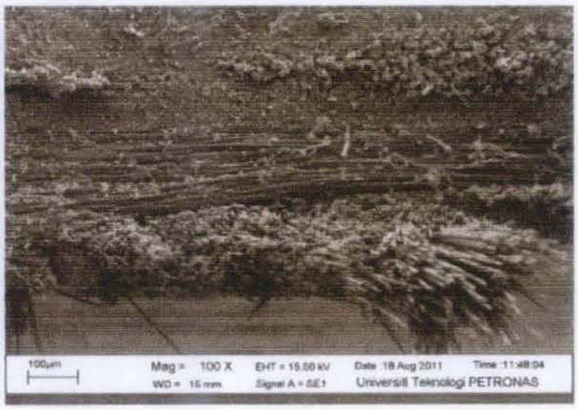


Figure: 4.19(d)

Figure 4.19(c) is the image at the entrance of the hole. It shows the sample experiences great fiber peel up delamination due to the pulling action in the drilling process.

Figure 4.19(d) is the image taken at the exit of the hole. Sever fiber push out delamination can be observed. Sample with 0.15 mm/rev experience great damage in term of drilling damage assessment.

CHAPTER 5

CONCLUSION & RECOMMENDATION

This project consists of five main processes, which are the design, fabrication, drilling, testing and finally the analysis. Total of 36 samples have been fabricated. The size, dimension of each sample and testing method has been referred from ASTM D3039. From the research that have been done so far, it seems that using the fiber volume fraction equation is the most important step for determining the properties of the desired hybrid composite. After the fabrication work has been done, the drilling operation took place with specified parameters in order to obtain the surface roughness and damage factor. Delamination problem can be solved by reducing the feed rate in the drilling operation and consider the change in drill bit geometry of the hybrid composites. Residual fibers in the interior of the hole can be reduced by increasing the cutting speed and feed rate. Tensile testing has been executed according to the ASTM. The ultimate tensile strength of drilled sample is 296.975 MPa while for the non-drilled the tensile strength obtained is 372.200 MPa. The results show that the ultimate tensile strength for both drilled and non-drilled samples have 37.6% difference. The reduction of ultimate tensile strength suggests there is a size and geometry effect (orientation of the laminates) of the samples. As in the conclusion the 0.05 mm/rev feed rate and 1300 rpm which are the best option in drilling parameter which resulted in minimun damage of the samples and those parameters offers smoother surface around drilling region

For further research activity it is highly recommended that to measure the tensile properties for different type of hybrid composites material such as flax fibers bio composite with various ply thickness, laminates stacking sequence of laminates. It also recommended that to continue this experiment with dog-bone type of sample in order to validate the experimental results.

REFERENCES

[1] Luis M. P. Duraola, D.J (2005). Machining of Hybrid Composites, PhD. Thesis, Department of Mechanical Engineering and Industrial Management,Faculty of Engineering, University of Porto.

[2] M.A. Maoinser, and F. Ahmad, "Drilling behavior of fiber composite and hybrid fiber composite at different drilling parameters," MSc Thesis, 2010.

[3] Faiz Ahmad, M.A Maoinse, P.S.M Megat-Yusoff and Farah, Drilling Holes in Hybrid Fiber, *Conference on Engineering and Technology Education*,02-05 August,2010.

[4] Farah 'Aaeni Sabrina Ahmad, Effect of Drilling Parameters on Hybrid Fiber Composite, Mechanical Engineering Universiti Teknologi PETRONAS, December 2009.

[5] I.Singh N Bhatnagar "Damage in unidirectional glass fiber "reinforced plastic (UD-GFRP) composite laminates 877–882,2006;

[6] Bongiorno, A., Capello, E., Copani, G., Tagliaferri, V. "Drilled hole damage and residual fatigue behaviour of GFRP", ECCM-8, Naples, Italy Vol. II, pp. 525-532, June 1998;

[7] Chen, W. C., "Some experimental investigations in the drilling of carbon fibre-reinforced plastic (CFRP) composite laminates", Int. J. of Machine Tools and Manufacture, 37, pp. 1097-1108, 1997;

[8] Caprino, G., Tagliaferri, V., "Damage development in drilling glass fiber reinforced plastics", Int. J. of Machine Tools and Manufacture, 35, pp. 817-829, 1995;

[9] Tagliaferri, V., Caprino, G., Ditterlizzi, A. "Effect of drilling parameters on the finish and mechanical properties of GFRP composites", Int. J. of Machine Tools and Manufacture, 30, pp. 77-84, 1990;

[10] Schwartz, M. M., "Composite Materials Handbook", McGraw Hill, 1988;

[11] S. Arula, L. V. S.K Malhotra, R.Krishnamurthy (2006). "The effect of vibratory drilling on hole quality in polymeric composites. International Journal of Machine Tool & Manufacture, 46, 252-259.

[12] Luis M. P. Duraola, D.J (2006). Drilling of carbon fibre reinforced laminates- A Copmparative Analysis of Five Different Drills on Thrust Force, Roughness and Delamination" J. Materials Science Forum (Vol.636-637). PP.206-213.

[13] Harding J, WelshLM. A tensile testing technique for fibre reinforced composites at impact rates of strain. J Mater Sci 1983;18:1810–26.

[14] Hsiao HM, Daniel I M. Strain rate behavior of composite materials. Composites PartB 1998; 29B:521– 33.

[15] Chou, P. C. and Miller, H. in ASTM STP 744, American Society for Testing and Materials, Philadelphia, PA, 1981, pp.114-I28.

[16] Delale, B. L. (2007). Hybrid Carbon-Glass Fiber/ Toughened Epoxy Thick Composite Joints Subject to Drop-Weight and Ballistics Impacts. U.S Army Research Office (ARO), Report No. A383284.

[17] ASTM D 3039/ D 3039M-00, American Society for Testing and Materials, Philadelphia, PA, 19428-2959, United States.

[18] SANDVICK Coromant, Machining carbon fiber materials user's guide, Composite solution

[19] Pui W. J (2009) Flax Fiber Bio Composite, Internship Report, DRIVE Laboratory of ISAT, France.

[20] H. Ashiran (2009) Design of fatigue machine, Internship Report, DRIVE Laboratory of ISAT, France.

APPENDICES

Appendix A: Table of Properties

Table A-1: Properties of E-glass and Carbon Fibers

Properties	Unit	E-Glass	Carbon
Density, ρ	g/cm^3	2.6	1750
Modulus of elasticity, E	GP_a	74	230
Shear modulus, G	GP_a	30	50
Poisson ratio, v	-	0.25	0.3
Tensile strength, σ_u	MP_a	2500	3200
Elongation, δ	-	3.5	1.3
Coefficient of thermal expansion, α	K^{-1}	0.5 x 10^{-5}	0.02 x 10^{-5}
Thermal conductivity, K	W/mK	1	200
Maximum operating temperature, T_{max}	°C	700	>1500

Table A-2: Provisional Specifications of unsaturated Polyester used

Provisional Specifications	
Appearance	Hazy; pinkish
Non-Volatile, %	54.5 ± 1.5
Viscosity @ 25°C, cps	300-450
Thixotropic Index	1.05 minimum
Geltime @ 25 °C, minute- 1% MEKP	25-35

Table A-3: Typical properties of Unsaturated Polyester Resin used

Typical Properties	
Specific Gravity	1.12
Acid Value, mg KOH/g	32
Volumetric Shrinkage, %	8

Table A-4: Typical properties of MEKP

Specifications	
Peroxide Content	50%
Active Oxygen Content	10%
Colour and State	Colourless liquid
Specific gravity @ 25°C	1.016
Viscosity @ 25°C	16cps
Flash point	65-104 °C
Solubility	Immiscible in water but soluble in most organic solvents

Appendix B: Sample Geometry (ASTM D3039)

Table B-1: Specimen Geometry Requirements

Parameter	Requirement
Coupon Requirements:	
Shape	Constant rectangular cross-section
Minimum length	Gripping + 2 times width + gage length
Specimen width	As needed
Specimen width tolerance	±1% of width
Specimen thickness	As needed
Specimen thickness tolerance	±4% of thickness
Specimen flatness	Flat with light finger pressure
Tab Requirements (if used):	
Tab material	As needed
Fiber orientation	As needed
Lab thickness	As needed
Lab thickness variation between tabs	±1% tab thickness
Tab bevel angle	5 to 90°, inclusive
Tab step at bevel to specimen	Feathered without damaging specimen

Table B-2: Specimen Geometry Recommendations

Fiber orientation	**Width, mm**	**Overall length, mm**	**Thickness, mm**	**Tab length, mm**	**Tab thickness, mm**	**Tab bevel angle, °**
0° unidirectional	15	250	1.0	26	1.5	7 or 90
90° unidirectional	25	175	2.0	25	1.5	90
Balanced and symmetric	**25**	**250**	**2.5**	**Emery cloth**	-	-
Random-continuous	25	250	2.5		-	-

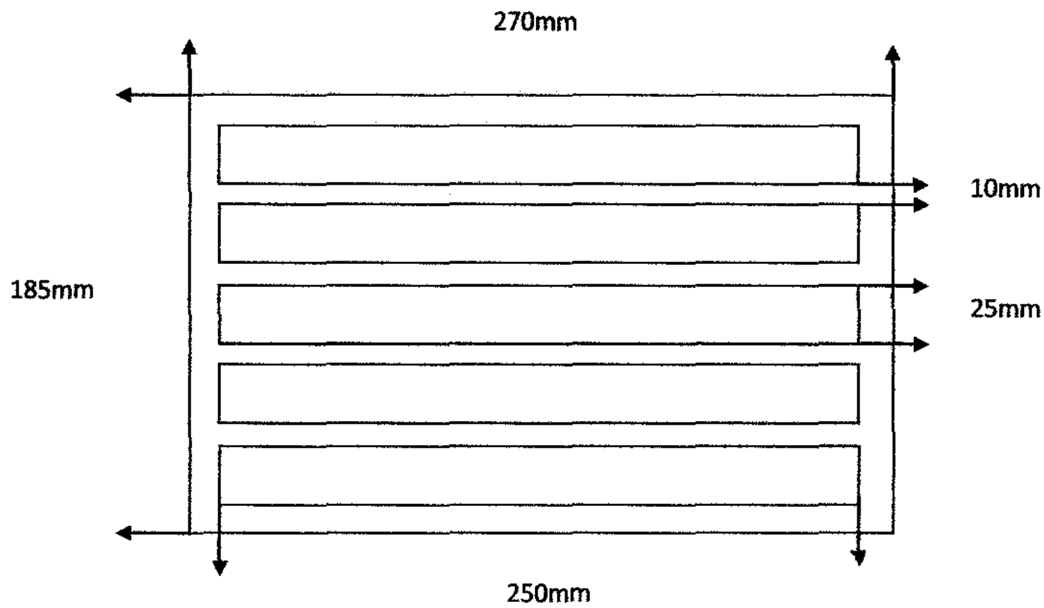
APPENDIX C

C-1 FYP I Gantt Chart

Activities/ Week	1	2	3	4	5	6	7	Mid Semester Break	8	9	10	11	12	13	14	15
Selection of project topic and Submission of proposal																
Research on selected topic			△													
Preparation and submission of Preliminary report																
Study on the method of assessment																
Preparation the procedure of the testing																
Hybrid composite sample designing																
Submission of progress report									△							
Seminar									△							
Fabricate the sample for testing operation																
Plan and design the CNC code for drilling operation																
Submission of interim report final draft															△	
Oral presentation																△

△ Milestone ■ Completed Activities

C-2 Total Length of Carbon Fiber Used



1 sample = 25mm x 250mm

1 mould consist of 5 samples including allowance

For 4mm thickness

270mm x 185mm x 6 layers (carbon) = 300mm^2 = 0.3m^2

0.3 x 8 mould = 2.4 m^2

1.5 m^2 the author obtained 40 samples for 4mm thickness and out of 40 samples, 4 are the extra samples.

Total area of carbon used is = 2.1 m^2

Area= L x W

L = 2.1m^2 / 1m = 2.1 m ⟶ TOTAL LENGTH USED