The Study of Tensile Failure on Thin Plate Hybrid Composites with Drilled Hole

by

Muhammad Hatta b Mohd Junaidi

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

May 2011

UniversitiTeknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak DarulRidzuan

CERTIFICATION OF APPROVAL

The Study of Tensile Failure on Thin Plate Hybrid Composites with Drilled Holes

by

Muhammad Hatta b Mohd Junaidi

A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

Approved by,

____

(Dr. Faiz Ahmad)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

MAY 2011

CERTIFICATION OF ORIGINALITY

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

MUHAMMAD HATTA B MOHD JUNAIDI

ABSTRACT

This report basically presents the research that had been done on the topic "**The Study of Tensile Failure on Thin Plate Hybrid Composites with Drilled Holes**". This study involves using had lay up technique on fabrication of 2.0mm thickness plate samples of 55% volume fraction of woven cloth carbon fiber and woven cloth glass fiber of orientation of 0/90/0/90 in polyester matrix. Using a 5mm HSS drill bit, the samples are drilled using CNC drilling machine with feed rate of 0.05mm/rev and 0.15mm/rev, and spindle speed of 690, 790, 1250, 1340, 2500, and 2700 RPM. The damage extension due to the drilling are observed and measured using 3D Non Contact machine and the damage factor are carried out to analyze the effect drilling parameters to the samples. Surface roughness of the feed rate is measured using Profilometer for alternative to measure the drilling effect. Tensile test using UTM 100kN machine is used to acquire the tensile properties of each of the sample along with the undrilled ones. Analysis including using Scanning Electron Microscopic for microscopic view for the surface of the drilled area, delamination extension due to the tensile force, damage factor of drilled area and surface roughness are compiled together and compared to investigate the relation of each of the data to the tensile properties.

Keywords: Glass fiber, carbon fiber, polyester, hand lay-up, 5mm HSS drill bit, CNC drilling, damage factor, surface roughness, tensile properties.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank and praise God for His guidance and blessings throughout the entire course of my Final Year Project.

In second place, I wish to express my gratitude to Dr. Faiz Ahmad, for his limitless guidance and continuous support throughout completing my Final Year Project as partial fulfillment of the requirement for the Bachelor of Engineering (Hons) of Mechanical Engineering.

I also thank to my colleague Zainol Ariffin b Zainal Alam for Mechanical Engineering course for his guidance, availability and for revising this study.

A special gratitude to M.A Maoinse for the assistance and knowledge given in fabrication technique and test performed.

Many figures had provided immeasurable amount of guidance, ideas, assistance, support and advice. Without help from these people, this Final Year Project may not be that meaningful and successful. My appreciation to UTP mechanical technologist for the guidance in the test performed.

My acknowledgement also would be incomplete without giving credit to Universiti Teknologi PETRONAS, especially Mechanical Engineering Department which has equipped students with essential skills for self-learning.

Finally, I would like to thank my family. They have been a wonderful source of encouragement and joy to me and also not to forget the fellow colleague. Their help and motivational support was a tremendous gift to me. May God bless all of only HE; the Almighty could repay all my debts to them.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Hybrid fiber composite referring to the word *hybrid* which means "combines" is the combination of two or more reinforcing fibers to become a new unique material. Hybrid fiber composites are attractive for application to provide synergy effect in achieving properties such as tensile strength stiffness, reduced weight or cost, and improved fatigue or impact resistance [1]. Although composites components are produced to near-net shape, machining is often needed, as it turns out necessary to fulfill requirements related with tolerances or assembly needs. Among the several machining processes, drilling is one of the most frequently used for the production of holes for screws, rivets and bolts. Machining operations in composites can be carried out in conventional machinery normally used to metallic parts. However, it is necessary to bear in mind the need to adapt the processes and/or tooling. When composites parts are subjected to drilling operations, the defects that are likely to appear differ from metallic parts, making evaluation of hole quality more difficult. Besides process related problems in composites fabrication, drilling can cause several defects like, delamination, intralaminar cracks, fiber pull out and thermal damage. Besides, with regards to the difference in thermal expansion coefficients of fibers and resin, thermal mismatch is already a concern in thin hybrid composites [4].These problems can affect the mechanical properties of the produced parts, hence, lower reliability [3]. Tensile test in the drilled hybrid composites is one of the ways to measure the new reliability of the material. Due to the case of lower reliability, tensile test plays an important role to determine the new mechanical properties of the drilled material, as the rough surface and damage factor will affect the mechanical properties.

1.2 Problem Statement

Drilling is a frequently practiced machining process in industry due to the need for component assembly in mechanical pieces and structures. Drilling can be carried out using conventional machinery, however, this operation can cause several damages in the laminates such as region around the hole and delaminating is the most serious problems as it causes a loss of mechanical and fatigue strength [1]. This will also contribute to the differences in properties of the tensile properties before and after the drilling process. If the mechanical strength of the material is to be taken at its original strength, the final product from the material may lead to major catastrophe. Hence the flexibility of the choice in resin matrix and reinforcements, UTP is yet to study the material of glass and carbon fiber reinforced polyester under the terms of drilling and tensile testing where the focus of the study is more to determining the relation of drilling parameters, the surface roughness and the damage factor to the tensile strength of glass and carbon fiber reinforced polyester.

1.3 Objective and Scope of Study

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:

- Fabrication of 55% fiber volume of combined glass and carbon fiber in polyester matrix.
- Measuring the damage factor and surface roughness of drilled holes on the fabricated hybrid composites material.
- Execution of tensile testing for the determination of the failure modes and tensile behaviour of the drilled hybrid composites material.
- Performing microscopic the hybrid composites material structure with the utilization of Scanning Electron Microscopy (SEM).

CHAPTER 2
LITERATURE REVIEW

2.1 Drilling

Among the machining processes the main focus was on drilling. Several informal conversations with some engineers in industrial areas that work with reinforced plastics highlighted the evidence that turning is not very desirable in these materials, as the final appearance is never pleasant or extra operations are needed, making the product more expensive. On the other side, drilling is a widely used technique as it is always needed to assemble components in more complex structures. It can also be reminded that, in the aircraft industry, about 60% of part rejections come from drilling-associated delamination [1]. There is a long way to follow until reach compatible performance that is standard in metallic construction.Drilling is a frequently practiced machining process in industry due to the need for component assembly in mechanical pieces and structures. Drilling of composite materials is significantly affected by damage tendency of these materials under action of cutting forces (thrust force and torque) [3-4]. Drilling may affect the surface of the drilled holes and cause damage of fiber pull-out within the hole having detrimental effects on structural application. The heat generated during drilling may have thermal effects on the matrix material. On top of that, drilling can cause several damages in the laminates of the region around the drilled hole and delaminating is the most serious problems as it causes a loss of mechanical and fatigue strength [1].

Drilling is a complex process which is characterized by the existence of extrusion and cut mechanisms. The first one is caused by the drill chisel edge that has null or very small linear speed and the second mechanism is by the existence of rotating cutting lips at a certain speed [2]. This study will investigate the relation of drilling parameters, which are the feed rate, the drill bit diameter and the damage factor caused by drilling process, and the tensile failure of the composite itself. The surface roughness due to drilling process in the study will also be investigated utilizing a Profilometer.

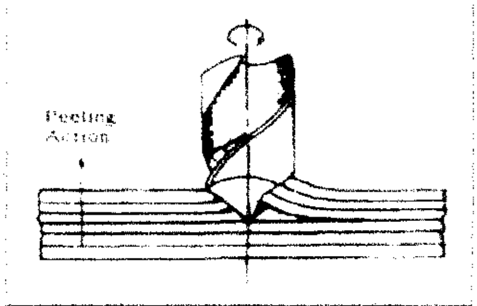


Figure 2.1: Peel Up Delamination.

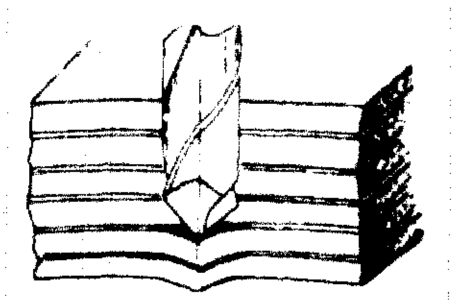


Figure 2.2: Push Out Delamination.

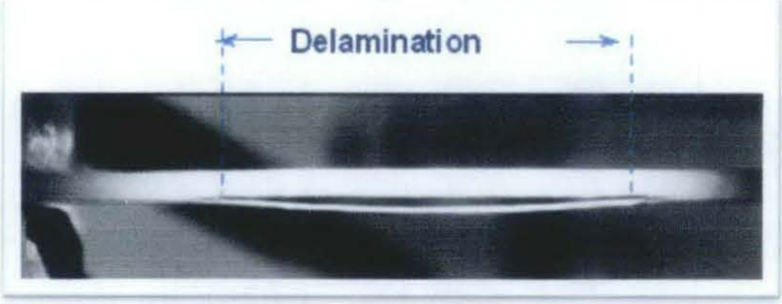


Figure 2.1: Delamination.

2.2 Drilling of Glass/Epoxy Materials

Tagliaferri et al. [9] carried out drilling tests on a glass/epoxy panel obtained from prepreg in a quasi-isotropic stacking sequence, high speed steel (HSS) drills, without backing or cutting fluid. By analyzing the variation of cutting speed and feed, they concluded that, if feed remains constant, damage reduction is accomplished by an increase in cutting speed, and if speed remains constant, lower feeds show better results in terms of damage reduction. They also said that the tensile strength of a GFRP containing a hole is not dependent on damage extent and that bearing strength only correlates with damage extent when this damage is quite large. Finally, they suggested that an optimal ratio between speed and feed seems to exist for maximum bearing strength, adopting lower drilling speeds.

Bongiorno et al. [10] drilled several glass/epoxy plates in different process conditions, generating different kinds and levels of damage, using HSS drills with 5 mm diameter. Plates were subjected to fatigue bearing tests. Results showed that the presence of defects like intralaminar cracks along the hole section deeply affects fatigue behaviour as these cracks propagate quickly into the material, while delamination played a minor role. To avoid these types of cracks a low feed should be adopted. They also verified that the presence of a support plate reduces push-out delamination only, but does not affect internal hole damage.

2.3 Drilling of Carbon/Epoxy Materials

Persson et al. [11] studied the effect of hole machining defects on strength and fatigue life of carbon/epoxy composite laminates. For that purpose they have compared two traditional machining methods using a PCD (synthetic polycrystalline diamond) drill, a Dagger drill and the orbital drilling method. This is a patented method by NOVATOR®, developed by Zackrisson, Persson and Bäcklund at the Department of Aeronautics of Kungl Tekniska Högskolan (KTH) in Sweden.

The hole generation method is shown in figure 2.8. The hole is machined both axially and radially by rotating the cutting tool about its own axis as well as eccentrically about a principal axis while feeding through the laminate.

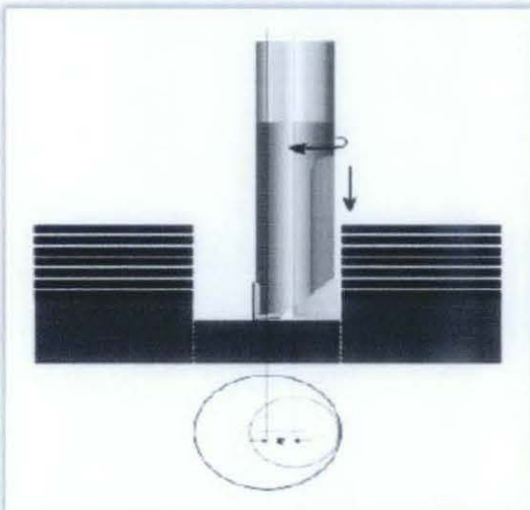


Figure 2.2: Hole generation using NOVATOR orbital drilling method. Source: NOVATOR AB.

Some advantages of this method are referred by the authors in [11] when compared to traditional hole machining methods. First is the elimination of a stationary tool centre, thus reducing axial force. Second is the reduction of the risk of tool clogging, as the tool diameter is smaller than hole diameter. For this reason the cutting edges are only partially and intermittently in contact with hole surface, allowing efficient removal of cut material and efficient cooling of tool and hole surface. Third advantage is the possibility of using one tool diameter to machine holes of several diameters and fourth is the precision of the hole that is determined by tool positioning and not by tool precision itself, reducing tool costs.

Quasi-isotropic carbon/epoxy plates were drilled using the three methods and the following conclusions were drawn. Radiographs showed no damage around orbital drilled specimens, damage extended to nearly a quarter of hole radius in Dagger drilled specimens and almost equal to hole radius in PCD drilled specimens. Static testing of pin load specimens gives the highest values for orbital drilled specimens with a reduction of 2 to 3% for Dagger specimens and about 11% for PCD specimens.

Fatigue testing results yielded 8 to 10% lower strengths for PCD and Dagger than orbital drilled specimens. Dagger drill, although giving fair results, has some disadvantages, in the authors' opinion. Due to its long and sharp tip it is less suitable in situations with limited space on the exit side of the laminate. Other disadvantages are related with the inability to remove chips and the relatively short tool life, around 70 holes.

2.4 Thermal Damage

Thermal damage is a consequence of friction between part and tool cutting edge, causing localised heating, which has more importance in composites cutting as cooling fluids are not recommended for these materials. An abnormally high temperature of the hole can cause local damage to the matrix, like burning or even melting, if the temperature reaches or exceeds the glass transition temperature (Tg). Low feeds increase the possibility of high temperature generation. Sometimes even fibers can be thermally affected. In a research by Caprino and Tagliaferi [84], with the aim to clarify the interactions between damage and cutting parameters, several microscopic observations showed no thermal damage in the matrix, for all feeds used from 0.0057 to 2.63 mm/rev. The authors reported a strong influence of feed in delamination, being low feeds better to reduce this damage.

If carbon reinforced composites are considered, thermal damages become more serious, due to the low thermal conductivity of carbon fibers. As some fibers are bent instead of being cut, they tend to return to the initial position, causing tightening around the drill and increasing friction. This increase in friction is responsible for added heating of the part and temperatures can reach glass transition temperature of the resin and cause matrix damage. In some cases, matrix material can stick to the drill, interrupting the drilling process and damaging the tool as well [48].

2.5 Tensile Test of drilled Carbon/Epoxy Material

Park et al. [12] applied the helical-feed method to avoid fuzzing and delamination. Tool used for the drilling experiments was a core drill made of cast iron with bonded diamond in two shapes, straight and rounded. The latter showed the best results as no delamination was observed around drilled holes. A tungsten carbide drill was used for results comparison and it was found that drilling quality degraded and fuzzing observed as the number of drilled holes increased due to the wear of cutting edge. The use of helical-feed allows the drilling operation to be completed efficiently without any limitation of drilling depth. Tensile tests performed on specimens drilled in different conditions did not show dependency of drilling methods on test results.

CHAPTER 3
METHODOLOGY

3.1 Procedure Identification

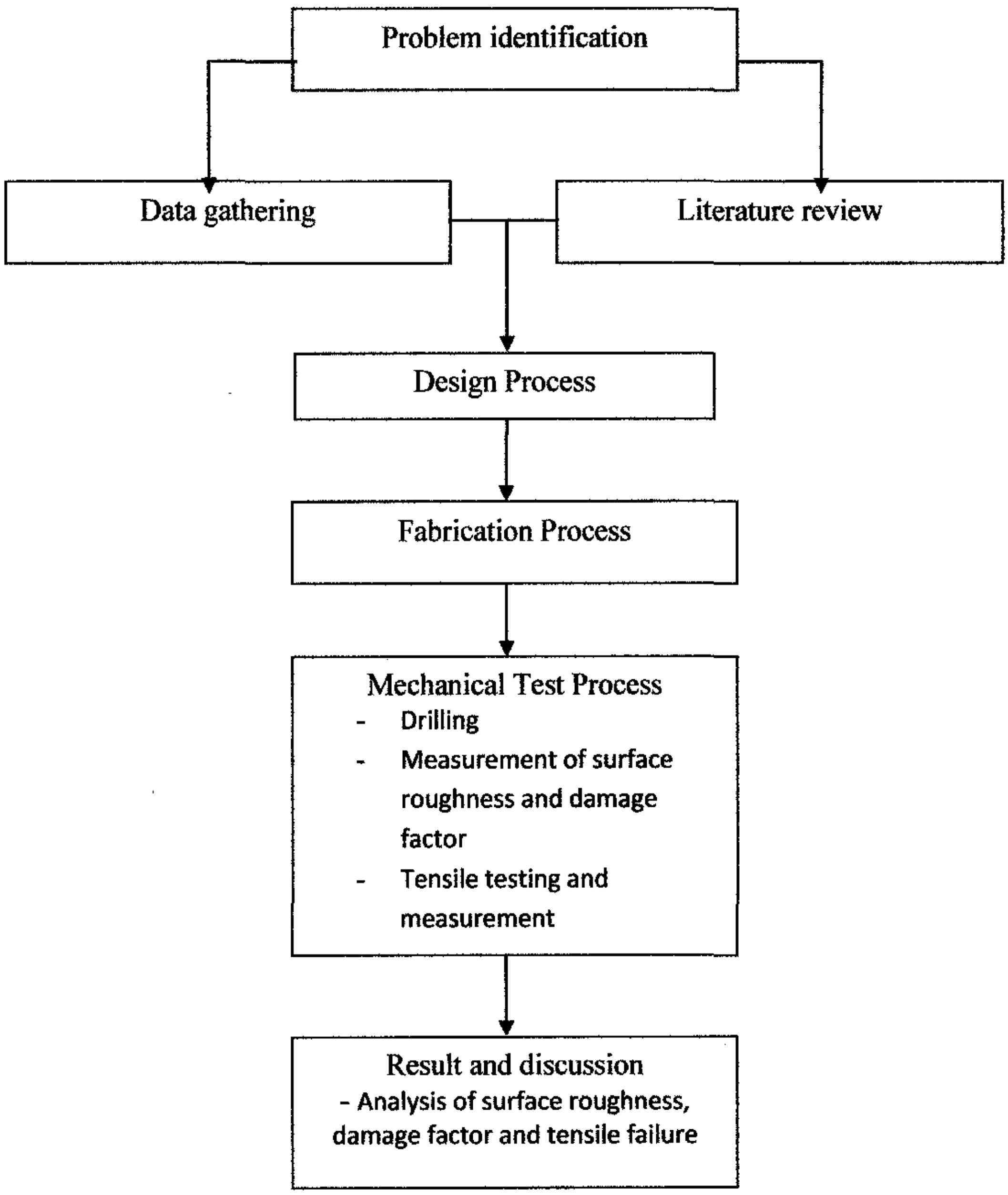


Figure 3.1: Process flow chart.

3.2 Design Process

There are four basic types of hybrid composites; Type A is made of intermingling fibers of different types in a common matrix (intermingled or intraply); Type B is formed by laminating layers with fibers of different type (interlaminated or interply); Type C is in form of fiber skins with fiber core; and Type D is constructed by fiber skins with a non-fiber core. Hybrid composites with two types of fibers are most useful and cost effective. In the Type A hybrid composite incorporating both glass and carbon fibers into a single matrix, one would lead to a better properties. For instance, the inexpensive E-glass fibers may ne used to mingle with the relatively costly carbon/graphite.

Hybrids have unique features that can be used to meet design requirements in a more cost-effective way than advanced or conventional composites. Some of those advantages are the balanced strength and stiffness, balanced thermal distortion, reduced weight and/or cost, improved fatigue resistance, reduced notch sensitivity, improved fracture toughness and impact resistance [2]. In practice, hybrid composites with two types of fibers are most useful and cost-effective depends on the desired types of fibers being used. 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. The utilization of fiber glass and carbon/graphite fibers is referred as a good combination as price and the mechanical properties can be balanced according to the desired laminates. Basically, for the fabrication of hybrid composite material, two types of fibers which are the woven glass and carbon will be used. The hybrid composites will be fabricated as planned with thickness of 2.0mm of 55% of combined volume of fibers as illustrated in the figure. Carbon fibers are will be arranged in the middle of the laminate for the purpose of delamination reduction.

Physical Properties	**Metric**
Density	0.601 - 2.00 g/cc
Viscosity	110 - 180000 cP
Linear Mold Shrinkage	0.00100 - 0.00500 cm/cm
Chemical Properties	**Metric**
Styrene Content	23.0 - 44.0 %
Mechanical Properties	**Metric**
Hardness, Barcol	37.0 - 68.0
Tensile Strength, Ultimate	10.0 - 123 MPa
Elongation at Break	0.500 - 120 %
Modulus of Elasticity	1.00 - 10.6 GPa
Flexural Modulus	0.359 - 9.93 GPa
Flexural Yield Strength	76.0 - 216 MPa
Izod Impact, Notched	0.641 - 5.34 J/cm
Thermal Properties	**Metric**
Deflection Temperature at 0.46 MPa (66 psi)	50.0 - 227 °C
Deflection Temperature at 1.8 MPa (264 psi)	46.7 - 260 °C
Shrinkage	1.00 %

Figure 3.2: Properties of Polyester.

Table 3.1: Properties of glass fiber and carbon fiber.

Properties	Unit	Glass Fiber (E)	Carbon Fiber
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}	℃	700	>1500

This combination of carbon and glass fibers is referred as a good mix, as price and mechanical properties can be balanced according to the designer needs. For instance, since the mechanical properties of glass and carbon fibers and the interfacial properties of a glass-fiber-reinforced-polymer and a carbon fiber reinforced polymer differ greatly, the hybridization effect would very likely exist for their hybrid composites.

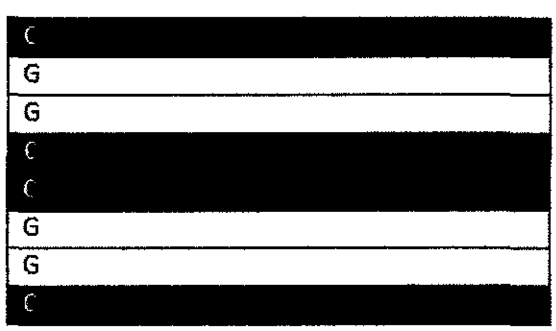


Figure 3.3: Symmetrical Design of Hybrid Composite of 8 Layers.

3.3 Fabrication Process

The weight of the matrix will be measured first to get the desired fiber volume fraction by calculation of fiber volume fraction.

3.3.1 Hand Lay Up Technique

The hand lay up technique is the oldest, simplest, and most commonly used method for the manufacture of both small and large reinforced products. A flat surface, a cavity (male) or a positive (male) – shaped mold, made from wood, metal, plastics, reinforced plastics, or a combination of these materials may be used. Fiber reinforcements and resin are palced manually against the mold surface. Thickness is controlled by the layers of materials placed against the mold.

This technique, also called contact lay-up, is an open-mold method of molding thermosetting resins (usually glass-fiber mat, fabric, or woven roving). A chemical reaction initiated in the resin by a catalytic agent causes hardening to a finished part. Hand lay up technique are best used in applications where production volume is low and other forms of production would be prohibitive because of costs or size requirements. Typical applications include boat and boat hulls, radomes, ducts, pools, tanks, furniture, and corrugated and flat sheets.

3.3.2 Hand Lay Up Technique Process:

1) *Mold preparation* - This is one of the most important functions in the separate cycle. If it is done well, the molding will look good and separate from the mold easily. Production mold preparation requires a thorough machine buffing and polishing of the mold. After the desired finish has been attained, several coats (usually three of four) of paste wax are applied for the purpose of mold release.

   Many different release systems are available such as wax, polyvinyl alcohol (PVA), fluorocarbons, silicones, release papers and release films, and liquid internal releases. The choice of release agent depends on the type of surface to be molded, the degree of luster desired in the finished will be required.

2) *Gel Coating* - When good surface appearance is desired, the first step in the open-mold processes is the application of a specially formulated resin layer called the gel coat. It is normally a polyester, mineral-filled, pigmented, nonreinforced layer or coating. It is applied first to the mold and this becomes the outer surface of the laminate when complete. This produces a decorative, protective, glossy, coloured surface that requires little or no subsequent finishing. The gel coating may be painted on, air-atomized with gravity or pressure feeding, or sprayed by an airless sprayer.

3) *Hand Lay-up* - After properly preparing the mold and gel coating it, the next step in the molding process is material preparation. In hand lay-up, the fiberglass is applied in the form of chopped strand mat, cloth, or woven roving. Premeasured resin and catalyst (hardener) are then thoroughly mixed together. The resin mixture can be applied to the glass either outside of or on the mold. To ensure complete air removal and wet-out, serrated rollers are used to compact the material against the mold to remove any entrapped air. The resin-catalyst mixture can be deposited on the glass via a spray gun, which automatically

meters and combines the ingredients. The first layer of reinforcement is usually a thin randomly oriented fiber mat designed to reinforce the resin rich surface of the moldings and improve surface finish. Such a reinforcement, called *surfacing mat* or *veil*, and made with a weight of about 30g/cm^2, may also be made from a chemically resistant type of glass if corrosion resistance s required. Extra care must be given to this surfacing mat to ensure that no air bubbles are left between the glass and the gel coat.

3.3.3 Hand Lay-up Specific Procedures

1) Wear proper PPE which are glove and mask. Make sure that other safety requirement is being followed.
2) A release agent is applied on top of the mold surface to remove impurities and for ease of removal.
3) Measure the weight of epoxy and polyester according to the calculated weight (include the ratio)
4) Liquid resin is applied to the mold.
5) Apply reinforcement on top of the resin.
6) Put another layer of resin on top.
7) Repeat step (5) and (6) until the desired layer is acquired.
8) Impregnate the fiber using roller.
9) Cure the mixture in the oven with 60°C for 5 hours.

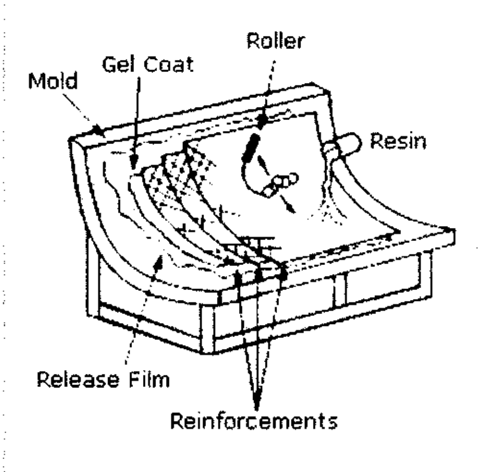


Figure 3.4: Hand Lay-up Technique.

3.4 Sample Designing

ASTM D3039 Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials is referred to design the hybrid fiber composite in order to determine the dimension of the samples.. The ASTM 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. Table 3.2 and table 3.3 refer to ASTM D3039 for the parameters and dimensions of the samples. This study utilizes clothes of woven type fibers of orientation of 0/90/0/90, which specified as balanced and symmetric fiber orientation in table 3.3.

Table 3.2: Tensile Specimen Geometry Requirements [ASTM D3039]

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 3.3: Tensile Specimen Geometry Recommendations [ASTM D3039]

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**	-	-
Random-continuous	25	250	2.5	**cloth**	-	-

Five (5) specimens is needed per sample group. The tolerance between specimens in the mold must be taken in consideration to avoid delamination of samples during cutting process. The tolerance of 1 cm per sample is used in the designing process. The dimension of the mold obtained is 185 mm x 270 mm x 2 0mm as shown in figure 3.5.

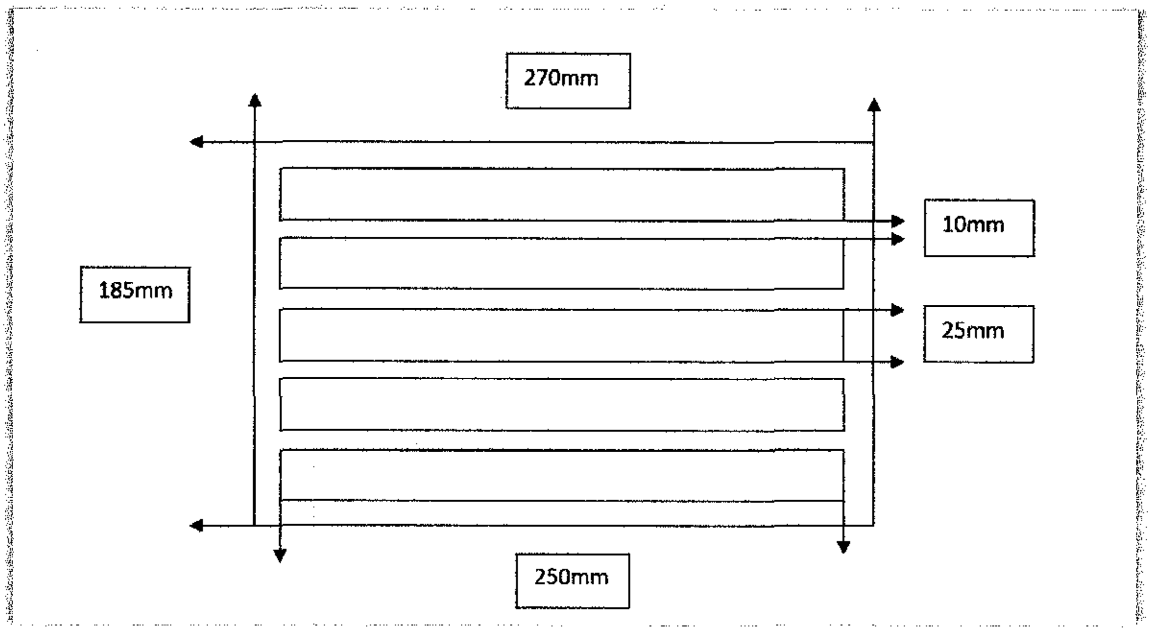


Figure 3.5: Design of Dimension of Composite.

3.5 Thickness

According to the recommendations in table 3.2 and table 3.3, the recommended thickness of a tensile testing specimen is 2.5 mm. However, it is not necessary to provide the recommended thickness as the thickness can always be altered to adapt with the study. In this experiment, 2.0 mm thickness of hybrid fiber composite is selected to comply with the purpose of the study of thin plate. Table 3.4 shows the thicknesses of glass fiber and carbon fiber measured using caliper.

Table 3.4: Thickness of Woven Mat based on Materials.

	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 are 2.0 mm. For the thickness of 2.0 mm with taking into account of matrix thickness on each layer, the required layers will be 8 layers and of combined carbon fiber and glass fiber altogether, respectively. 4 layers of glass fiber and 4 layers of carbon fiber are in a symmetrical arrangement; otherwise the sample will tend to bend in one direction when it hardens.

3.6 Fiber Volume Fraction

Fiber volume fraction is used to obtain the weight of the matrix used to fabricated the desired composite. In this study which using 45% of polyester as matrix and 55% of fibers, the weight of polyester is obtain through;

<u>Calculation for 2.0 mm thickness</u>

$V_{m}= 0.45$ $\quad$ $V_{f} = 0.55$

v_{c} (according to ASTM recommended dimension)

$= 27\ cm \times 18.5\ cm \times 0.20\ cm$

$v_{c} = 99.9\ cm^3$

$v_{m} = V_{m}\, v_{c}$

$=(0.45)(99.9\ cm^3)$

$=44.955\ cm^3$

$\rho = m/v$

$m_m = (1.2\ g/cm^3)(44.955\ cm^3)$

$= 53.946\ g$

3.7 Mold Preparation

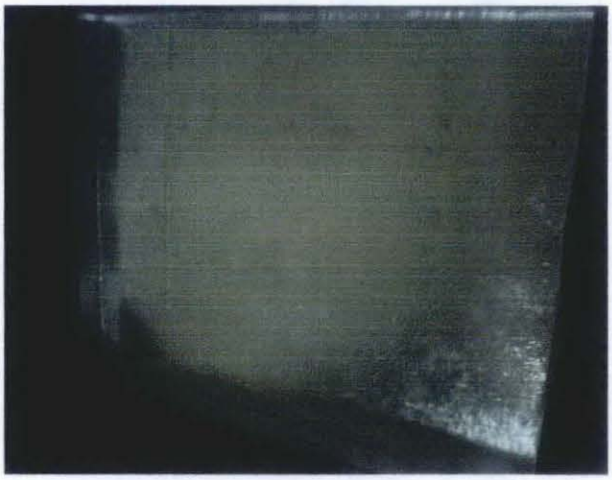


Figure 3.6: Mold for Hand Lay Up Technique.

Fabrication using the Hand Lay Up technique requires mold to perform. The mold is made of aluminum foil with thickness less than 1.5 mm. The foil is shaped in rectangular with the dimensions of 185 mm x 270 mm x 20 mm.

3.8 Fabrication of sample

Given all the information the author has gathered, the fabrication can now be preceded. The layer design of 2.0 mm is illustrated in the figure 3.7. Utilizing the required tools, the composite is fabricated using Hand Lay Up technique. The composite is left for curing in the temperature room for about eight (8) hours. Then, the cured composite will undergo cutting process. The cut sample then will be transferred to abrasive cutter for better surface finish and dimension tolerance of the sample.

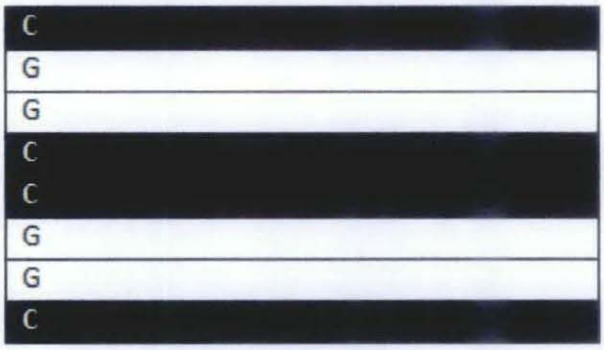


Figure 3.7:Design of layer for Thickness 2.0 mm.

Required tools for Hand Lay Up technique:

1) Brush
2) Plastic bowl
3) Plastic spoon
4) Scissor
5) Mask
6) Glove
7) Electronic weight scaler

Figure 3.8: Finished Fabrication of Samples 2.0 mm.

3.9 Drilling process

Total of fourteen (14) groups of samples are prepared for the experiment. Sample groups for feed rate of 0.05 mm/rev are group A, B, C, D, E, F while group G, H, I, J, K, L are for feed rate of 0.15 mm/rev. Group sample O represents the undrilled samples of thickness 2.0 mm used as control experiments for comparison among the results.

Table 3.5: List of Group Sample and its Specifications.

Sample thickness	2.0 mm (Group Sample O is not drilled)											
Feed Rate (mm/rev)	0.05						0.15					
Spindle Speed (RPM)	690	790	1250	1340	2500	2700	690	790	1250	1340	2500	2700
Group Sample	A	B	C	D	E	F	G	H	I	J	K	L

Figure 3.9: Drill Bit used during Process; HSS Twist Type Drill Bit.

3.10 CNC Drilling

CNC drilling process is a computerized drilling that ensures the samples are drilled at prefix feedrate and speed. Conventional drilling is not advisable because the feedrate of drilling cannot be determined. Rapid drilling cycle time per sample can be ensured by using a Jig that acts as a mould to the sample. Jig is a mould that holds a sample when drilling process is being implemented upon the sample. The material used to manufacture the Jig is wood. For every sample that need to be drilled, rezeroing process of CNC machine will be executed which will cost a lot of time but by using a Jig, it can save the drilling cycle time because rezeroing process of CNC machine will only be executed once at the Jig.

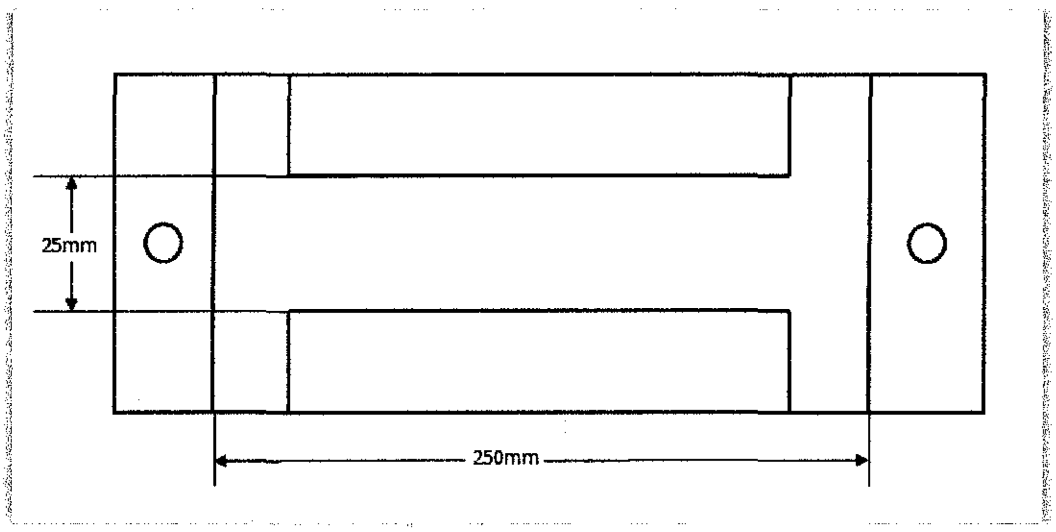


Figure 3.10: Design of Jig.

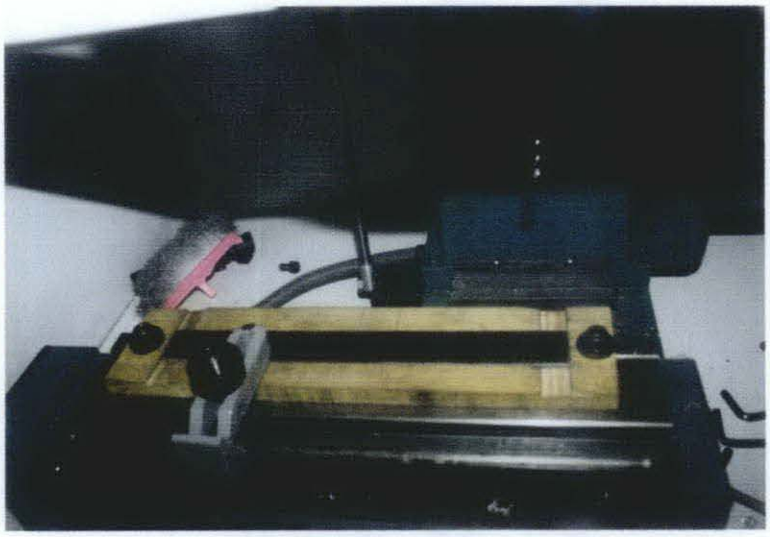


Figure 3.11: CNC drilling process using a Jig.

```
[BILLET X100 Y100 Z10 ;
[EDGEMOVE X-50 Y-50 ;
[TOOLDEF T2 D10 ;
G21 G94 ;
G91 G28 Z0 ;
G28 X0 Y0 ;
M06 T1 ;
M03 S1250 ;
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 3.12: CNC Coding for Drilling Process.

3.11 Mechanical Test Process

3.11.1 Scanning Electron Microscope [7]

Industrial Applications:

- The machine is to analyse the material composition of any metals, composites, polymers and ceramics

Principle:

- 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.

Capability:

- Able to produce micrograph (microstructure images) and composition analysis results (weight-%) concurrently from the same material's specimen. Limited capability for nanomaterials.

Experiments Objective:

- To analyse microstructure of any material specimen
- To produce a quantitative data analysis by using EDAX attachment
- To perform the failure analysis through microscopic approach

3.11.2 Universal Testing Machine (UTM) [7]

Industrial application:

- 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

Principle:

- UTM is used normally 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 ne performed using screw or a hydraulic mechanism.

Experimental objective:

- To determine and establish the mechanical properties of materials (tensile, stress, strain and compression)
- To simulate a cyclic load and condition for fatigue testing

3.11.3 Surface Roughness Testing [7]

Industrial application:

- Machine allows production with improved accuracy in precise and rapid surface measurement

Principle:

- Certain material and products are highly manufactured for near shape accuracy and fine surface finished for high technology applications

Capability:

- Increase the capability for production measurement technology
- Equally suitable for measuring surface roughness and waviness

- The machine provides a great variety of parameters conforming to most of the world standard

Experimental objectives:

- To study effects of surface roughness of part produced form different machining processes
- To establish relationship between material and machining on a specific product/part/component
- To measure quality of surface after manufacturing processes have been done

3.6 Gantt Chart

Table 3.6: Gantt Chart.

Activities	**1**	**2**	**3**	**4**	**5**	**6**	**7**		**8**	**9**	**10**	**11**	**12**	**13**	**14**
Project work continues: Sample Fabrication Continuation															
Perform Drilling Operation 1. Jig preparation 2. CNC programming			Δ												
Project work continues: Damage factor of drilled samples.					Δ										
Progress Report Preparation															
Submission of Progress Report 1								**Mid Semester Break**	Δ						
Perform Tensile Testing on fabricated samples									Δ						
Analysis by using SEM															
Result gathering															
Poster Exhibition												Δ			
Submission of Dissertation final draft															Δ
Oral presentation															Δ
Submission of Dissertation (hard bound)									7 days after oral presentation						

CHAPTER 4
RESULT AND DISCUSSION

4.1 Drilling Results

4.1.1 Damage around the Hole Area

Different techniques and parameters were used to assess the damage caused by drilling. Twelve (12) groups of drilled samples were examined under Optical Microscopic and Mitutoyo 3D Non Contact Machine. Observation shows that the samples are suffering from the structural damage caused by the drill. There are several structural damages generated during drilling of hybrid fiber composites such as delamination, splintering, matrix cratering and thermal damage. Figure 4.1, 4.2, 4.3, 4.4 and 4.5 are the image taken during observation around the drilled hole of samples.

Figure 4.1: Matrix Cratering Observed at the Surface near the Drill Area using OM.

Figure 4.2: Presence of Delamination Observed at the Edge of Drilled Area using OM.

Figure 4.3: Presence of Delamination Observed around the Drill Area using Non Contact Machine.

Figure 4.4: Splintering Observed around the Drill Area using OM.

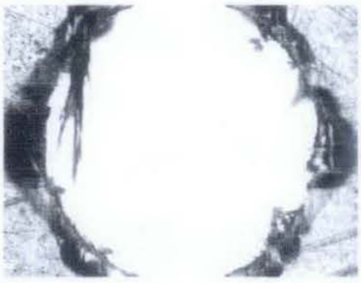


Figure 4.5: Splintering Observed around the Drill Area using Non Contact Machine.

4.1.2 Results for Damage Factor

The damage at the drilled holes wall were monitored under Mitutoyo 3D Non Contact Machine. Table 4.1 shows the average of five readings of drilled samples. So the results here presented are their average.

Table 4.1: Pictures of Damage and the Damage Factor of Samples of 0.05 mm/rev.

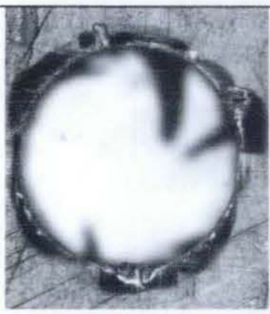
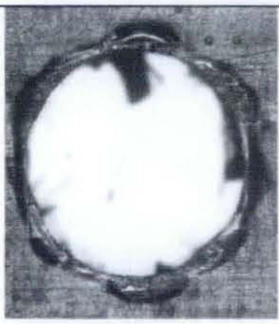
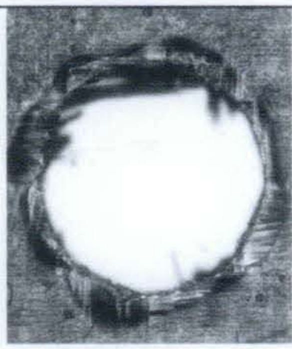
Feed Rate 0.05 mm/rev			
Sample	A	B	C
			
D_o(mm)	5.0000	5.0000	5.0000
D_d(mm)	6.1675	6.0970	5.991
F_d(mm)	**1.2335**	**1.2194**	**1.1982**
Sample	**D**	**E**	**F**
			
D_o(mm)	5.0000	5.0000	5.0000
D_d(mm)	5.9647	5.9908	6.0798
F_d(mm)	**1.1929**	**1.1982**	**1.2159**

Table 4.2: Pictures of Damage and the Damage Factor of Samples of 0.15 mm/rev.

Feed Rate 0.15 mm/rev			
Sample	G	H	I
			
D_o(mm)	5.0000	5.0000	5.0000
D_d(mm)	6.491	6.3770	6.2672
F_d(mm)	**1.2982**	**1.2754**	**1.2534**
Sample	J	K	L
			
D_o(mm)	5.0000	5.0000	5.0000
D_d(mm)	6.2651	6.3075	6.3625
F_d(mm)	**1.2530**	**1.2615**	**1.2725**

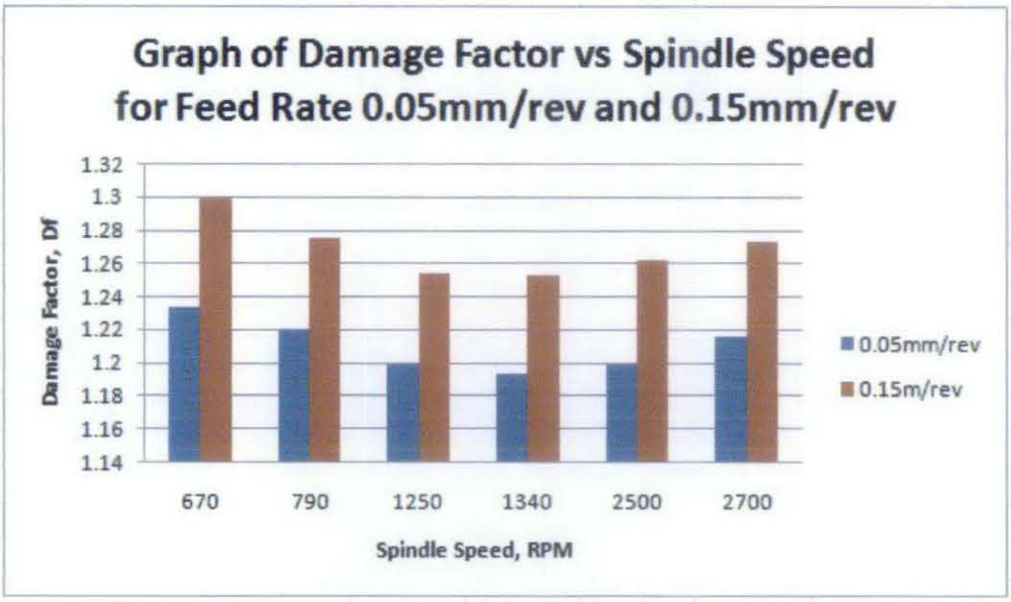


Figure 4.6: Graph of Damage Factor vs RPM of Variable Feed Rate.

The graph in figure 4.6 shows result of the damage factor calculated and compared with for each group of samples. The comparisons are against variation of spindle speed and feed rate for each group. Spindle speed and feed rate variations involved are 690rpm, 790 rpm, 1250 rpm, 1340 rpm, 2500 rpm, and 2700 rpm, and 0.05 mm/rev and 0.15 mm/rev, respectively.

In general, these results from figure 4.6 are adequate to identify an optimum domain of parameters combining low feed rates with medium spindle speeds. Higher spindle speed of 1340 rpm, 2500 rpm, and 2700 rpm increase the risk of thermal damage as it causes the softening of the matrix material [13]. A consequence of that phenomenon can be a loss of mechanical strength of the uncut plies of the laminate, leading to extended delamination. The optimum spindle speed observed from this experiment was 1340 rpm compared to the other type of spindle speed for drilling hybrid fiber composite using 5 mm diameter HSS drill bit. Meanwhile, drilling hybrid fiber composite of lower spindle speed of 670 resulted in highest damage on top of the drilled holes wall. This is because the spindle speed is too low compared to the feed rate given because bigger thrust force is applied. This too, increase the risk of thermal damage as it causes the softening of the matrix material [13].

Regardless the drill geometry and the cutting speed, a clear trend was found regarding the effect of feed rate where the optimum way of drilling hybrid fiber composite os observed as low feed rate of 0.05 mm/rev used in drilling process. Regarding the experimental set used in this work, it is not surprising to observe that a feed rate of 0.05 mm/rev has resulted as the best option. However, it must be remembered that a low feed rate of 0.05 mm.rev also increases the heating of the hole machined walls during machining. In some cases, the possibility of matrix softening should be taken into account. The use of CNC machines, enabling a variable feed rate strategy is a good option to consider when drilling laminate plates [13].

4.2 Tensile Test Result

4.2.1 Tensile Properties

In Figure 4.7, the typical failures of samples are reported. Similar type of fracture occurred to all samples which categorized as brittle fracture.

Figure 4.8 shows the graph that represents the behavior of samples during tensile testing. All the sample including the undrilled ones showing the similar graph in Figure 4.8 even though different load is used in tensile testing.

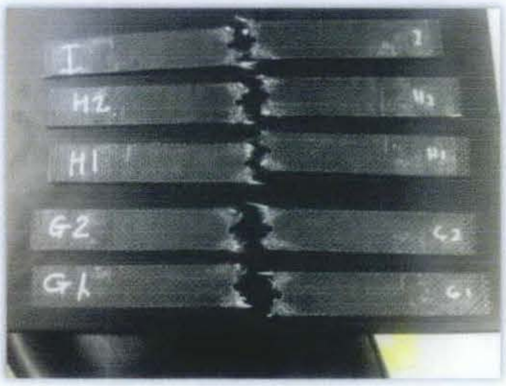


Figure 4.7: Condition of Samples after Tensile Test.

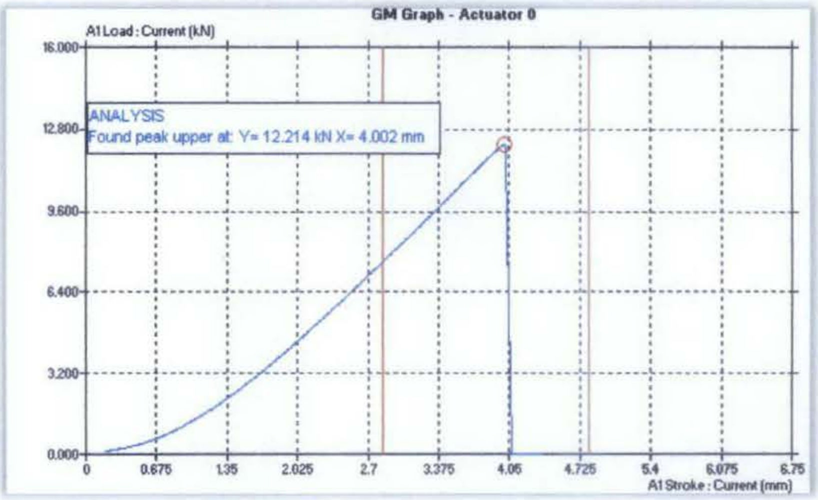


Figure 4.8: Graphical Behaviour of a Sample during Tensile Test.

Table 4.3: Properties of Each Sample after Tensile Test.

Sample	Load (kN)	Tensile Strength (MPa)	Elongation	Elastic Modulus (GPa)
A	12.5420	313.5500	0.01694	18.5100
B	12.4110	310.2750	0.01662	18.6700
C	12.7810	312.6250	0.01653	19.3300
D	11.8080	295.2000	0.01651	18.3100
E	12.7190	317.9750	0.01550	20.5100
F	12.0990	300.2250	0.01661	18.1000
G	12.3980	309.9500	0.01557	19.9000
H	12.3180	307.9500	0.01700	18.1400
I	11.8070	295.1750	0.01662	17.7600
J	12.2240	305.6000	0.01683	18.1600
K	12.5800	314.5000	0.01627	19.3300
L	12.5820	314.5500	0.01681	19.3300
O	18.8190	376.3800	0.01986	18.9600

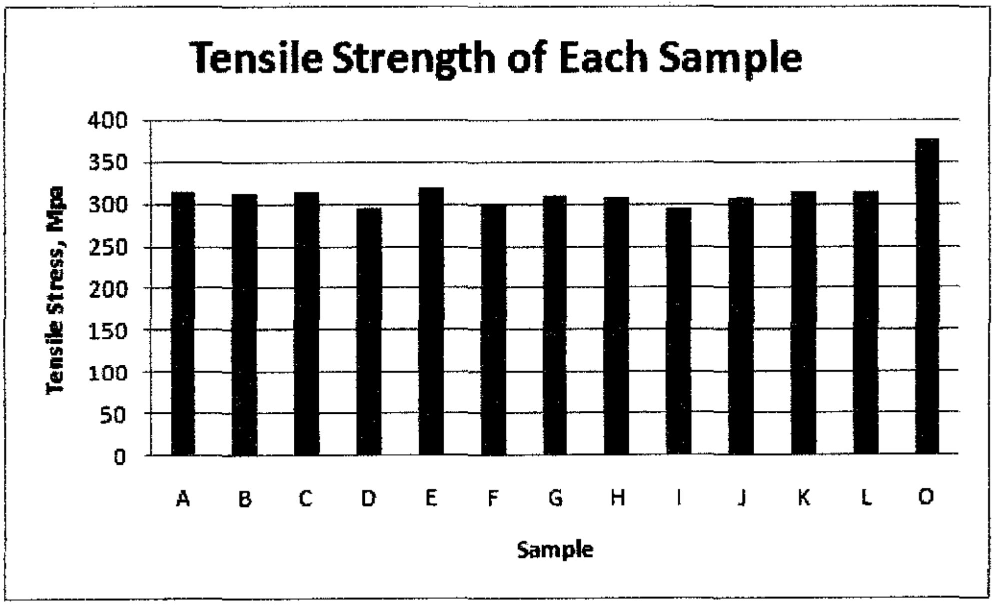


Figure 4.9: Graph Showing Tensile Stress of Each Sample.

Table 4.3 indicates that the properties gained for each group of samples after tensile test. Tensile Strength and Elastic Modulus is obtained by inserting the load and elongation value into specific formulas for the tensile properties. The graph in Figure 4.9 shows the comparison of tensile stress value for each sample.

Generally the graph shows the significant difference between the tensile strength of non-drilled sample and the drilled samples. Drilling hybrid composite significantly affected the mechanical strength of hybrid fiber composite samples due to the damage caused during drilling process [11]. Based on the data obtained, the samples lost an average of 20% of its original strength when it is drilled with 5 mm diameter HSS drill bit. Comparison made between the drilled samples ranging of group A to group L, there are no significant difference of drilling parameters of the samples to the tensile strength. Insignificant trend was found due to the strength of each sample test resulting in random data between 296 MPa to 315 MPa, and the strength is not inversely proportional to the damage factor found on each sample. Since the original tensile strength of GFRP is 278 MPa, the combination of carbon fiber and glass fiber composite have proven that in this study, the boost of mechanical strength is achieved where the strength ranging from 296 MPa to 315 MPa [17].

0.05 mm/rev and 0.15 mm/rev feed rate did not show significant difference in the tensile strength of the samples. This concludes that the feed during drilling process did not show any influence in the strength of drilled composite. However, higher feed rate might create severe damage to the hole that is not practical for its tensile strength.

4.2.2 Delamination after Tensile Test

Figure 4.10 shows the delamination occur in the sample of 0.05 mm/rev feed rate while figure 4.11 shows for the sample of 0.15 mm/rev feed rate. The image was taken using Mitutoyo 3D Non Contact Machine to measure the length of delamination from the drill hole.

The figure on the left side shows the magnified view of the ending of delamination in the sample while on the right side shows the commencement of the delamination. The length measured for sample of 0.05 mm/rev feed rate is 9.427 mm while for sample of 0.15 mm/rev is 14.250 mm. The result is an extension to the damage factor of the sample due to the drilling effect. The sample of 0.15mm/rev feed rate experience larger damage factor and after the tensile test it also shows the tendency for a severe delamination, compared to the sample of 0.05 mm/rev. Variation in drilling parameters during drilling might not affect the tensile strength, but it appears that the damage on the sample for higher feed rate during drilling process is more severe. By referring to the previous figure 4.6, higher feed rate resulting more structural damage to the sample because more heat is produced causing greater thermal damage and delamination.

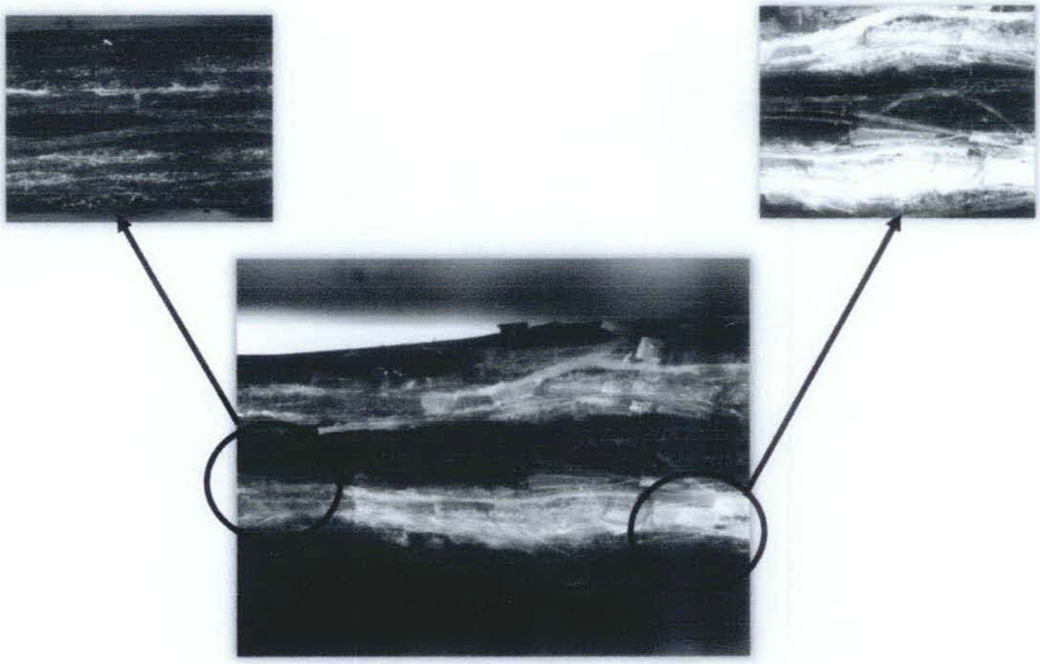


Figure 4.10: Enlarged view of Post-Tensile Sample of 0.05 mm/rev Feed Rate.

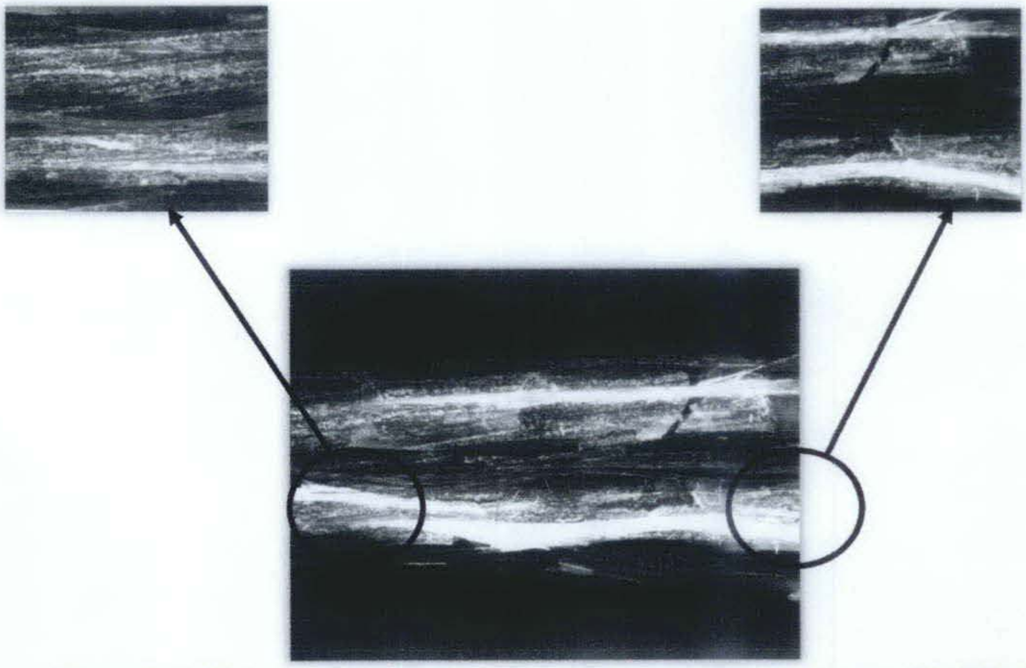


Figure 4.11: Enlarged view of Post-Tensile Samples of 0.15 mm/rev Feed Rate.

4.3 Surface Roughness

Using a Profilometer, the surface roughness is determined at the drilled holes wall. Surface roughness plays an important role in determining how a real object will interact with is environment because roughness is often a good predictor of the performance of a mechanical component because irregularities on the surface may form nucleation sites for cracks or corrosion.

As expected, the result shows that the sample of 0.05 mm/rev feed rate gives lower value (smooth), which is 1.895 μm, than the other sample, which is 1.962 μm. This is such because lower feed rate produces smoother surface than higher feed rate. Surface roughness is the first symptom that can be quantified to predict the damage factor and the delamination length for the particular sample [18]. Samples that have smoother surface roughness will produce the results of lesser damage factor and shorter delamination [18].

Figure 4.12: Surface Roughness of 0.05 mm/rev sample; 1.895 μm

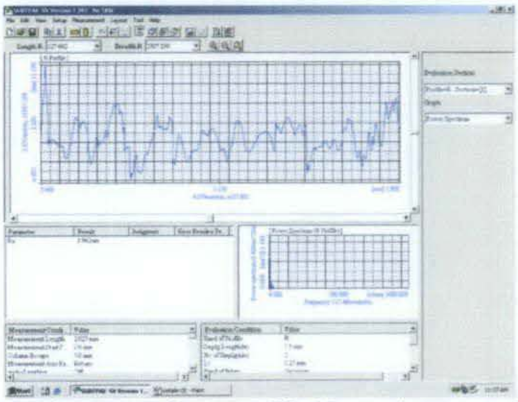


Figure 4.13: Surface Roughness of 0.15 mm/rev sample; 1.962 μm

4.4 Scanning Electron Microscope (SEM)

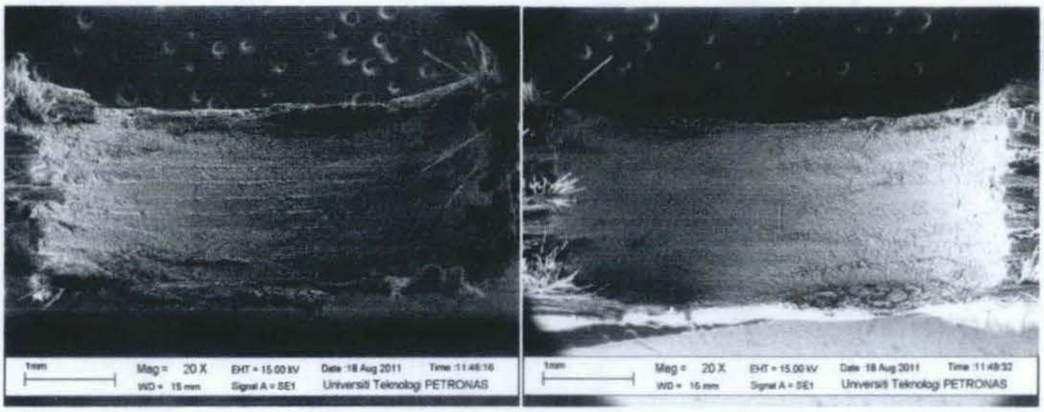


Figure 4.14(left) and 4.15 (right): Comparison of the Middle Section of Drilled Sample between 0.15mm/rev (left) and 0.05mm/rev (right).

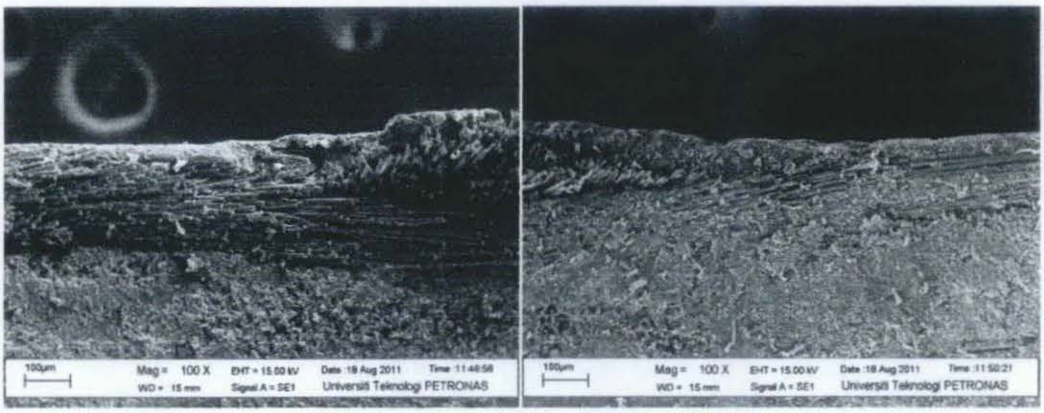


Figure 4.16 (left) and 4.17 (right): Comparison of Drilling Entry between 0.15mm/rev (left) and 0.05mm/rev (right).

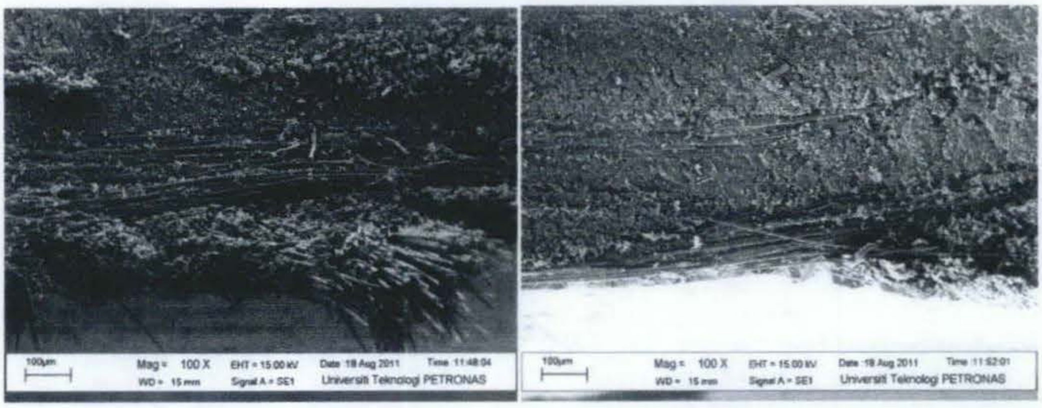


Figure 4.18 (left) and 4.19 (right): Comparison of Drilling Exit between 0.15mm/rev (left) and 0.05mm/rev (right).

Figure 4.14 and Figure 4.15 show the image taken using SEM of the middle section of the drilled hole after the tensile test. Figure 4.15 (0.05 mm/rev) shows smoother surface after drilling while Figure 4.14 (0.15 mm/rev) shows rougher surface. The figures indicate that lower feed rate while drilling is more favourable because smoother surface of the drilled holes wall can be acquired thus low surface roughness will be obtained.

Figure 4.16 and Figure 4.17 show the image taken at the the surface where the drilling bit starts to touch the surface of the sample and begin the drilling process. The comparison between those figures shows that the feed rate of 0.15 mm/rev produces rougher surface than 0.05 mm/rev. The same indications are showed in Figure 4.18 and Figure 4.19 where smoother surface is visible on the picture of feed rate of 0.05 mm/rev. Drilling hybrid fiber composite at lower feed rate is more favourable due to the ability of producing the smoother surface finish.

The orientation and condition of fibers after tensile test is the same for both feed rate, as shown In Figure 4.20. Figure 4.21 shows the detail view of a fiber breakage indicating that it has experienced brittle failure during the tensile testing.

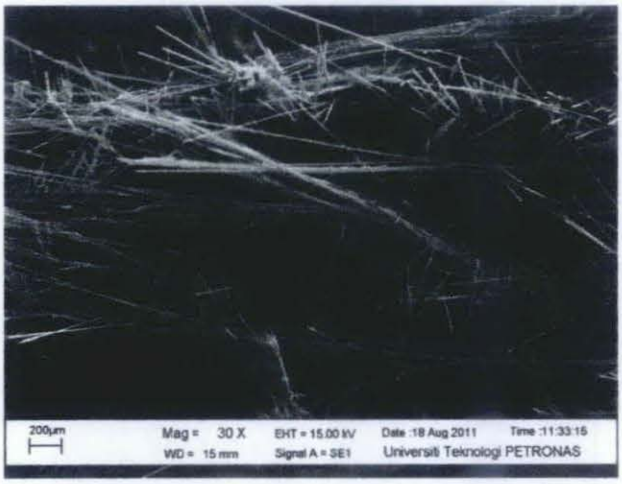


Figure 4.20: Condition of Fibers after Tensile Testing.

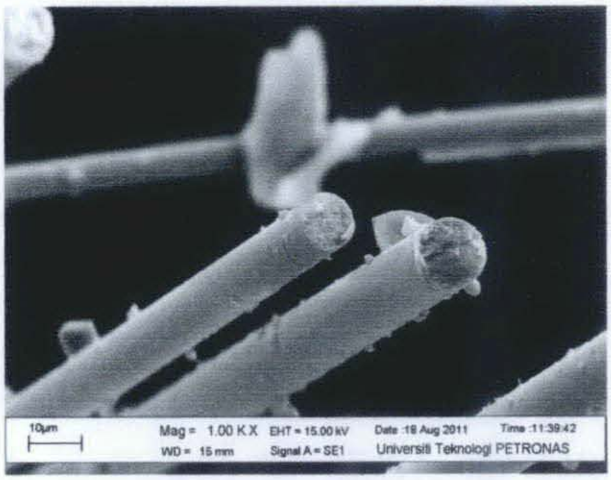


Figure 4.21: Enhanced View of Fibers after Tensile Test.

CHAPTER 5
CONCLUSION

Hybrid fiber composites have proven that it has better tensile strength and lower cost compare to fiber composite. This study found that since thin plate are more exposed to thermal damage and thermal mismatch among the fibers and composite, drilling in low feed rate is the best option in drilling process of composite. Production rate might be slow but low feed rate offers smoother surface along the drill path, that reducing the damage factor and delamination in the composite. This study also found that the drilled composite lost an average 20% of their strength compared to the non-drilled samples. The drilling parameters did not affect the tensile strength of the drilled composite but it affects the damage of the composite will experience during tensile test because higher feed rate produces severe delamination than lower feed rate during the tensile testing.

Several lines are still open for further study on this topic. A study of severity of delamination caused by variation of feed rate in drilling process can be made by comparison of fatigue life of the samples.

REFERENCES

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

[2] ADMET Inc, Quality Test & Inspection, *Tensile Testing Basics, Tips and Trends*. Norwood, MA.

[3] 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.

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

[5] Guido Kickelbick, "Hybrid Materials, Synthesis, Characterization and Applications", WILEY-VCH.

[6] M. K. A Mohd Ariffin, M. I. Mohd Ali, S. M. Sapuan and N. Ismail, "An Optimize Drilling Process For An Aircraft Composite Structure Using Design Of Experiments", Faculty of Engineering, Department of Mechanical and Manufacturing Engineering, Universiti Putra Malaysia, July 2009.

[7] Universiti Teknologi Petronas Laboratory Facilities Handbook

[8] L. Ceschini a,*, G. Minak b, A. Morri a, "Tensile and fatigue properties of AA6061/20 vol.% Al2O3p and AA7005/10 vol.% Al2O3p composites", Institute of Metallurgy, University of Bologna, V.le Risorgimento 4, I-40136 Bologna, Italy

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

[10] 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;

[11] Persson, E., Eriksson, I., Zackrisson, L., "Effects of hole machining defects on strength and fatigue life of composite laminates", Composites A, 28, pp. 141-151, 1997;

[12] Park, K. Y., Choi, J. H., Lee, D. G., "Delamination-free and high efficiency drilling of carbon fibre reinforced plastics", J. of Composite Materials, 29, pp. 1988-2002, 1995;

[13] Luis M. Durao, Antonio G. Magalhaes, Antonio T. Marques and Joao Manuel R. S. Tavarers, "Damage assessment of drilled hybrid composite laminated", Dept. of Mechanical Engineering/CIDEM/ISEP – Polytechnic Institute of Porto, Portugal.

[14] Persson, E., Eriksson, I., Zackrisson, L., "Effects of hole machining defects on strength and fatigue life of composite laminates", Composites A, 1997, 28, 141-151.

[15] Chen, W. C., "Some experimental investigations in the drilling of carbon fibre reinforced plastic (CFRP) composite laminates", Int. J. Machine Tools & Manufacture, 1997, 37, 1097, 1110

[16] C. C. Tsao C. C., Hocheng, H., "Computerized tomography and C-Scan for measuring delamination in the drilling of composite materials using various drills", Int. J. of Machine Tools and Manufacture, 2005, 45, 1282-1287

[17] Anthony Kelly, "Concise Encyclopedia of Composite Materials", MIT Press, 1990.

[18] K. Alam, A. V Mitrofanov, V. V. Silberschmidt, "Measurement of Surface Roughness in Conventional and Ultrasonically Assisted Bone Drilling", Wolfson School of Mechanical and Manufacturing Engineering, Loughborough University, UK.