CHAPTER 1 : INTRODUCTION

1.1 BACKGROUND OF STUDY

Composite by definition is a material which comprises two or more constituents resulting in a product which is more superior in terms of properties compares to individual material. This material is known for its unique mechanical properties, light weight, high strength applications and low fabrication cost [1]. The general structure of a composite normally involves a bulk phase known as the matrix and a stronger and harder dispersed phase known as the reinforcement. These reinforcements can be in the form of particles, fibers (either continuous or discontinuous) or wires and can be made from carbon, ceramics, carbide, glass or aramid [3] while the matrix is either a polymer, metal or ceramic [4]. Most composites are created to improve combinations of mechanical characteristics such as stiffness, toughness, high resistance to corrosion, ambient and high-temperature strength and reduced wear compared to monolithic materials like steel and alloy [2].

Fiber-reinforced composites (FRC) are divided into two which continuous (aligned) and discontinuous (short). This material is sub classified by fiber length. For short fiber, the fibers are too short to produce significant improvement strength. Fiber-reinforced composite (FRC) is high performance fiber composite which consist of three components; the fibers as the dispersed phase, the matrix as the continuous phase and the fine interphase region known as the interface. On a related note, hybrid fiber composites have more than one type of fibers, thus having more superior properties such as high strength and stiffness, improved fatigue or impact resistance and also reduced weight or cost [5].

Hybrid composites use in the aerospace industry is expanding in particular fiber reinforced composites for structural purposes. This material is also being increasingly used in various applications such as in oil and gas, ships, automobiles, aeronautical, machine tool and sports equipment due to excellent properties such as high specific strength, high damping, high specific stiffness, low thermal expansion, good dimensional stability and an unusual combination of properties not obtainable with metal alloys. Although hybrid composites components are produced to near-net shape, machining is often needed especially drilling, as it turns out necessary to fulfill requirements related with tolerances or assembly needs. The aforementioned applications have led to increased applications of drilling operations for assembling composites components. For instance, more than 100,000 holes are made on a body of a small engine aircraft and million holes are made in a large transport aircraft such as screws, bolted joints and rivets for fastening purposes [8]. Drilling is a frequently practiced machining process in industry owing to the need for component assembly in mechanical pieces and structures. It plays a major role in making holes in fiber composites as these holes are needed in joining an individual component into complex parts.

However, machinability can be problematic especially in conventional drilling due to fiber reinforced composites' inherent anisotropy/in-homogeneity, limited plastic deformation and abrasive characteristics. When hybrid composites parts are subjected to drilling operations, the defects that are likely to appear differ from metallic parts, which make evaluation of the drilled holes quality more difficult. There are damages caused by conventional drilling such as delamination, fiber breakage, fiber/matrix debonding, fuzzing, thermal degradation micro cracking, fiber pull out and matrix burning around the hole that shall eventually cause variation in the residual strength of the component with drilled holes [9]. Drilling of a fiber composite component is dependent on fiber properties of fiber reinforced than on the matrix material.

1.2 PROBLEM STATEMENT

Machining specifically the drilling of fiber composites affects the surface and structure of the drilled holes as well as cause damage especially delamination. These problems affect the performance of the structure developed from fiber composites and also structural applications of hybrid fiber composites. These machining problems occur mainly due to the diverse fiber and matrix properties, fiber orientation, and inhomogeneous nature of the material. These problems can affect the mechanical properties of the produced parts which will result in lower reliability. In this study, by employing the use of hybrid fiber composites, the damage problems are analyzed in terms of damage factor (Fd) and surface roughness (Ra).

1.3 OBJECTIVES

The aim of this project is to examine the machining parameters and analysis results of the drilled holes. Specifically the objectives of the research are:

(a) To fabricate hybrid composites material in a half cylinder shape by the reinforced glass and carbon fiber with epoxy as the continuous phase/matrix. (4 mm of thickness with 40% of fiber volume fraction (15% woven carbon fiber and 25% woven E Glass Fiber).

(b) To determine and measure the damage factor (ratio of original drill bit diameter and delamination diameter) and surface roughness in micrometer of drilled holes on the fabricated hybrid composites material. (3 different feed rates 0.05mm/rev, 0.10mm/rev and 0.20mm/rev at 3 different spindle speeds of 1000rpm, 2000rpm, and 3000rpm)

(c) To perform microscopic analysis on the hybrid composites material structure with the utilization of Field Emission Scanning Electron Microscopy (FESEM).

(d) To determine the optimum cutting or drilling parameters in a hybrid fiber composite in this scope of study based on the analysis results obtained.

1.4 SCOPE OF STUDY

A study conducted to find the optimum parameters among the employed variable of drilling process on hybrid fiber composite. The parameters studied are narrowed to focus on the effects of particular parameters on the composite. In this project, the parameters studied are feed rate and spindle speed of a 40% fiber volume fraction (consisting of carbon and woven glass) of laminate. The laminate will be fabricated in a curved shape using epoxy as matrix with woven glass and carbon as reinforcement. The best parameters will be selected from the used parameters that will, among all parameters, have minimal effects of delamination, fiber pull-out, damage and surface roughness on the drilled holes. The efficiency of the identified cutting parameters is evaluated by measuring surface roughness using a Surface Roughness Tester, fiber-matrix debonding using a Field Emission Scanning Electron Microscope (FESEM), and examination of the delamination zone using a 3-D Non-Contact Machine.

1.5 RELEVANCY OF PROJECT

The damage problems in fiber composites can be reduced with the use of hybrid fiber composites which comes with improved mechanical properties. Obtaining the optimum drilling parameters (cutting speed and feed rate) can minimize the defects in hybrid fiber composite as the process of drilling this material is essential in a wide range of applications; mainly aircraft and oil and gas industries.

1.6 FEASIBILITY OF PROJECT

The project will require some 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.

CHAPTER 2 : LITERATURE REVIEW AND THEORY

2.1 INTRODUCTION

Hybrid refers to a fabric that contains more than one type of structural fiber in its construction. It is a combination of two or more fibers with common type of matrices to achieve better physical and chemical properties. It is more economical as small amount of carbon fiber, which is expensive, is used, in a laminate composed mainly of a cheaper fiber such as E-glass. 'Hybridization effect' is employed by obtaining a composite property, such as tensile strength, whose value is higher than would be predicted from the rule of mixture. With hybridization a composite material system that meets various requirements could be designed. This is due to the fact that the two or more types of fibers have different mechanical properties and the interface they form with the matrix are also different. However, thermal mismatch may occur in thin hybrid composites despite the positive advancement of hybridization

2.2 UTILIZATION OF HYBRID FIBER COMPOSITES

Damage problems in the drilling of fiber composites can be reduced by the introduction of hybrid fiber composites which consist of two different types of fiber matrix. For instance, the development of hybrid fiber which consists of glass fiber and carbon fiber reinforced polyester (HRFP) composite and hybrid fiber (consists of glass fiber and carbon fiber) reinforced epoxy (HFRE) composite have reduced the surface roughness (Ra) and damage factor (Fd) of the drilled holes [12]. In addition to that, the construction of hybrid fiber composite such as glass fiber and carbon fiber within the polmer matrix resulted in lower cost (glass fiber) with improved mechanical properties carbon fiber) compared to the fiber composites [13]. There are studies [14 and 15] performed on drilling hybrid composites but yet more studies need to be developed in order to obtain better feasible results on reducing the damage and defects in drilling of fiber composites.

2.3 DRILLING IN COMPOSITE

There are a number of studies on drilling of hybrid fiber composites and delamination is the most serious problem as it causes loss in mechanical and fatigue strength and can be detrimental to the material durability by reducing the structural integrity of the material which will result in long-term performance deterioration [10]. Capello [21] regards delamination of the composite material as the most critical damage caused by machining operations due to the fact that it can severely impair the performance of the finished component. According to Khashaba [22], delamination is responsible for the rejection of approximately 60% of the components produced in the aircraft industry. The heat generated during drilling may have thermal effects on the matrix material. Drilling in composites depends on the thickness of the laminate as well as the fiber contents [11]. Factors such as cutting parameters, feed rates, end tool geometries/materials must be carefully selected in aiming to obtain the best performance on the drilling operation.

In fiber reinforced plastic composites, Komanduri [16] identified that the fiber orientation is the major influence of cutting properties of FRP. Drilling induced delamination occurs at the entrance and the exit planes of the drilled material. The delamination damage caused by the tool geometry is recognized as one of the main problem during drilling. According to Davim *et. al.* who completed a study on drilling fiber reinforced plastics manufactured by hand lay-up technique, a number of problems such as delamination associated with employed cutting parameters and characteristics of materials were investigated. In order to minize these problems, they performed an experimental work on composites at various cutting parameters (Davim, Reis, & Antonio, 2004) [17 and 18]. On a related note, Khashaba, Seif, and Elhamid (2007) presented a comprehensive study of the influence of drilling parameters (cutting speed and feed rate) on the required cutting forces, torques and delamination that occurs at drill entrance and exit in drilling composites with different fiber volume fractions (FVF). Clear effect of cutting speed on the delamination size was not observed, while the delamination size decreased with decreasing of feed rate [19].

In using carbon fiber reinforced plastic composites (CFRP), Islam shyha, Sein Leung Soo, David Aspinwell and Sam Bradley presented experimental results when twist drilling 0.5 mm diameter holes in 3 mm thick CFRP laminate using tungsten carbide (WC) stepped drills. The control variable considered were prepeg type (3 type) and form (unidirectional (UD) and woven), as well as the drill feed rate (0.2 and 0.4 mm/rev). Best results obtained using the woven MTM44-1/HTS oven cured material (3750 holes) [20]. While CFRP application often requires fewer machining operations compared to standard materials due to near net shape fabrication techniques, fiber delamination when drilling is not uncommon and can have significant impact on component life. Hence, the delamination factor (Fd) is a key performance measure. Karnik et al. (2008) investigated entry delamination in the drilling of woven CFRP 2.5 mm thick using 5 mm carbide twin lipped drills over a range of cutting speeds (63 – 630 m/min) and feed rates (1000 – 9000 mm/min) with different drill point angles. The findings showed that the entry delamination factor (Fd) was responsive to all process parameters examined, however, a combination of high cutting speed, low feed rate and small point angle minimized entry effects.

A study by A.M Abrao, J.C. Campos Rubio, P.E. Faria, and J.P. Davim presented a study on glass fiber reinforced plastic composite using laminate produced by hand lay-up technique and were made up of epoxy matrix reinforced with 50% weight of woven glass fiber with an orientation of $0/90^o$. The findings show that as the feed rate is increased, slightly lower force values are recorded for the high speed steel drill in comparison to carbide tool. With regard to the drill diameter, it is expected to negatively affect the quality of the machined hole [23]. In addition, the effect of softening the matrix produced by temperature increment (caused by an elevation in cutting speed) is negligible since it is not able to affect the properties of the glass fibers. Delamination is most affected by feed rate and best results are obtained at lower feed rate, while the influence of cutting speed is almost negligible.

2.4 THEORY AND FUNDAMENTALS

2.4.1 Types of Hybrid Composites

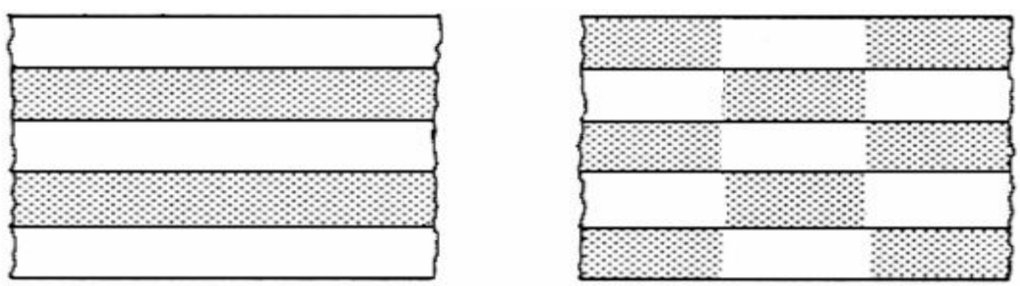
One of the perks of using hybrid composite is the flexibility in choosing the type and distribution of fiber reinforcements. It can be determined how the reinforcement is being laminated and arranged in order to produce the desired composite. Based on a paper by M. M. Schwartz et al. [26], there are four basic types of hybrid composites:

(i) **Type A** - Interply hybrids, consists of plies from two or more different unidirectional composites stacked in a specific sequence.

(ii) **Type B** - Intraply hybrids, consists of two or more different fibres mixed in the same ply.

(iii) **Type C** - Interply-intraply hybrids, in which interply and intraply hybrids are stacked in a specific sequence.

(iv) **Type D** - Superhybrids, that are resin-matrix composite plies stacked in a specific sequence.



a) Interply hybrid b) Intraply hybrid

Figure 1: Interply and intraply hybrids [26]

Type A and Type B hybrids generally have the same matrix. Thermosetting and thermoplastic resins can be used as the continuous phase for hybrid composites, and in this study, thermosetting epoxy will be used . For this project, it is intended that Type A hybrid is used.

2.4.2 Laminates

Laminates are one of the most used composites from the several types of normally used ones. Their major and most distinctive attribute is the existence of layers that are easily detected with naked eye observation. Among the most usual utilizations that can be identified are sandwich materials. Moreover, one of the advantages is also the possibility of combining the alignment of different layers in order to achieve mechanical properties that are previously defined [26]. Laminate is designed as unidirectional if all the layers in a composite have their fibers oriented according to one direction only. Different orientation can be defined for different layers, usually defined as an angle to a reference direction, named as 0º. In that case, to avoid coupling between bending and extension, it is necessary to have a symmetry plan. Layers with angles of 90º and 45º to the reference direction are usually used but other angles like 30º and 60º are also employed.

2.4.3 Matrices (continuous phase)

Thermoplastics or thermosetting resins, minerals and metallic can be employed as matrices. Polyesters, phenolic, silicone, melamine and epoxy are usually used as resins. There are many advantages of using thermosetting polymer, firstly they are well established in processing and application history, they have high temperature properties, good wetting and adhesion to reinforcement and overall, they are better in economics than thermoplastic polymers. The most used thermosetting resins are unsaturated polyester and epoxy due to their low production cost, diversity and good adaptability to simple construction processes.

2.4.4 Fiber Volume Fraction

One of the most significant factors in determining the properties of a composite material is the relative proportions of the matrix and reinforcing materials. These proportions can be given as the weight fractions are easier to be obtained during fabrication or by an experimental method in post fabrication period. However, volume fractions are more significant and are used exclusively in the theoretical analysis of composites material. The expressions for two phase materials are derived and generalized to multiphase material. By employing the rule of mixture, the volume fraction can thus be defined. Rule of mixture is a method of approach to approximate estimation of composite material properties, based on an assumption that a composite property is the volume weighed average of the phases (matrix and dispersed phase) properties. The expressions below are used to determine the weight fraction of the phases:

$$V_m + V_f = V_c \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The volume of the fiber can be expressed as;

$$v_f = \frac{\rho_m W_f}{\rho_f W_m + \rho_m W_f} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Rearranging Eqn (2) yields to;

$$W_m = \frac{\rho_m W_f - V_f \rho_m W_f}{\rho_f V_f} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where V_m : Volume fraction of matrix

V_f : Volume fraction of fiber

V_c : Volume fraction of the composite, total volume fraction of fiber and matrix

ρ_m : Density of matrix

ρ_f : Density of fiber

W_m : Weight fraction of matrix

W_f : Weight fraction of fiber

2.5 DRILLING PARAMETER

2.5.1 Spindle Speed

Cutting speed or surface speed or peripheral speed is the speed of the drill twisting. It is the distance that a point on the circumference of a drill will travel in 1 min. A wide range of drills and drill sizes are employed in cutting various materials and equally wide range of speeds are required for the drill to cut efficiently. For every process, there would be a problem in choosing the most feasible drill speed that will result in the best production rates and the least amount of downtime for regrinding the drill. In this study, there are 3 spindle speeds that will be used which are 500rpm, 1000rpm and 2000rpm.

2.5.2 Feed Rate

Feed is the distance that a drill advances into the work piece for each revolution. Drill feeds can be expressed in decimals, millimeters (mm) or fractions of an inch. Feed rate is one of the determining factors in the drilled hole quality, rate of production and life of the drill, thus it should be carefully chosen for each job. In the drilling of a glass fiber reinforced plastic, delamination does not take place under low feed rates. When feed rate is increased the actual back rake angle becomes negative, thus pushing the work material instead of shearing and causing it delamination. The feed rates that will be employed in this project are 0.05mm/rev, 0.10mm/rev and 0.15mm/rev. Generally feed rate is governed by:

(i) The diameter of the drill
(ii) The condition of the drilling machine
(iii) The material of the workpiece

2.6 RESPONSE VARIABLES

2.6.1 Damage Factor (FD)

The damage generated associated with drilling hybrid fiber composites were observed, both at the entrance and exit during the drilling. Delamination factor is defined by the ratio of maximum diameter of damaged zone over the diameter of the drilled hole. To determine the delamination factor (Fd) around the drilled holes, the maximum diameter (D_{max}) in the delamination zone was measure. The value of the delamination factor can be determined by the equation shown below:

$$FD = D_{max}/D_{drill}$$

Where,

D_{max} : maximum diameter of the delamination zone (mm)

D_{drill} : diameter of the drill (mm)

The equipment that is to be used in observing the Damage Factor (FD) is a 3D Non Contact Measuring System.

2.6.2 Surface Roughness (R_a)

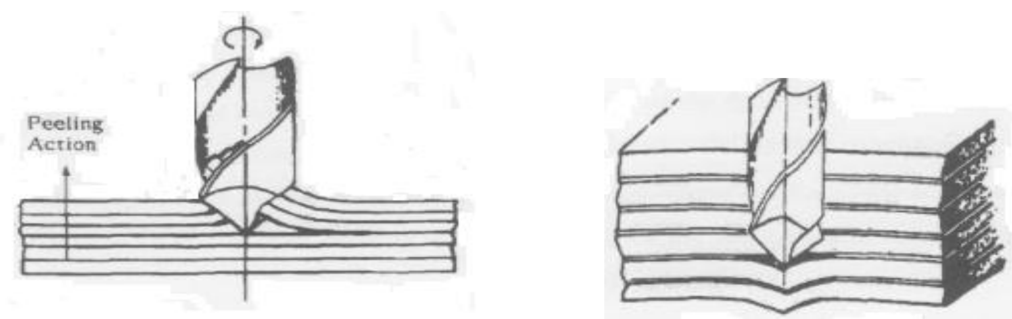
Surface roughness (R_a) is the measure of the texture of the surface around the drilled holes. Internal surface roughness measures the internal surface of the drilled holes when the laminate is cut. The evolution of surface roughness is closely observed with the feed for the cutting or spindle speed values. It can be inferred that the value of R_a increases with the feed rate and decreases with the cutting speed, i.e. to get a better surface finishing it is necessary to employ high cutting speed and low feed rate [24]. In this study the equipment to be used in obtaining the surface roughness is a Surface Roughness Tester or Profilometer.

2.7 MACHINING DAMAGE

The defects or damaged caused by machining in composite parts can be observed in many different aspects. Many types of occurring damage could be looked at for example delamination, fiber breakage, fiber/matrix debonding, fuzzing, thermal degradation micro cracking and fiber pull out. These damage are identified through microstructural analysis using the Scanning Electron Microscope (SEM). In this study, some of the aforementioned problems will be observed due to time and equipment constraints.

2.7.1 Delamination

Delamination is recognized as one of the major causes of damage when drilling fiber reinforced composite. The damage generated associated with drilling fiber reinforced composites were observed mainly at the entrance and the exit during drilling.



Peel up delamination　　Push out delamination

Figure 2: Different forms of drilling induced damage

There are two types of delamination which are peel-up delamination and push-out delamination as shown in Figure 2. However, these types of delamination are et to be encountered during drilling process. The main cause of delamination is interlaminar stress concentration that occurred in the neighborhood of the free edge or around loaded holes on the hybrid fiber composite materials. It is an indentation effect caused by 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 laminate. Delamination will take place if the thrust force exerted by the drill exceeds the interlaminar fracture toughness of the plies. This is refreed as push-out delamination. As for the peel up delamination, it is a consequence of the drill entrance in the upper plies of the laminate. The drill tedns to pull abraded material along the flute as it moves forward. This causes the materials to spiral up.

2.7.2 Debonding

Due to cracks propagation through parallel to the fibers (debonding cracks), fibers may be separated from the matrix material. This may b ecaused by the breakage of the secondary bonds between the fibers and matrix. When fibers are strong while the interfaces are weak, cracking occurs. This debonding crack may be spread at the fiber-matrix interface or in the adjacent matrix.

2.7.3 Fiber pull out

Failure initiated by fiber breakage occurs at the weakest section, as the longitudinal tensile load is increased. This breaking of fibers is a random process where complete rupture of the hybrid composite material occurs. This is due to some cross section of the composite that is weak and not able to support the increasing load.

CHAPTER 3 : METHODOLOGY

3.1 RESEARCH METHODOLOGY

3.1.1 Flow Chart

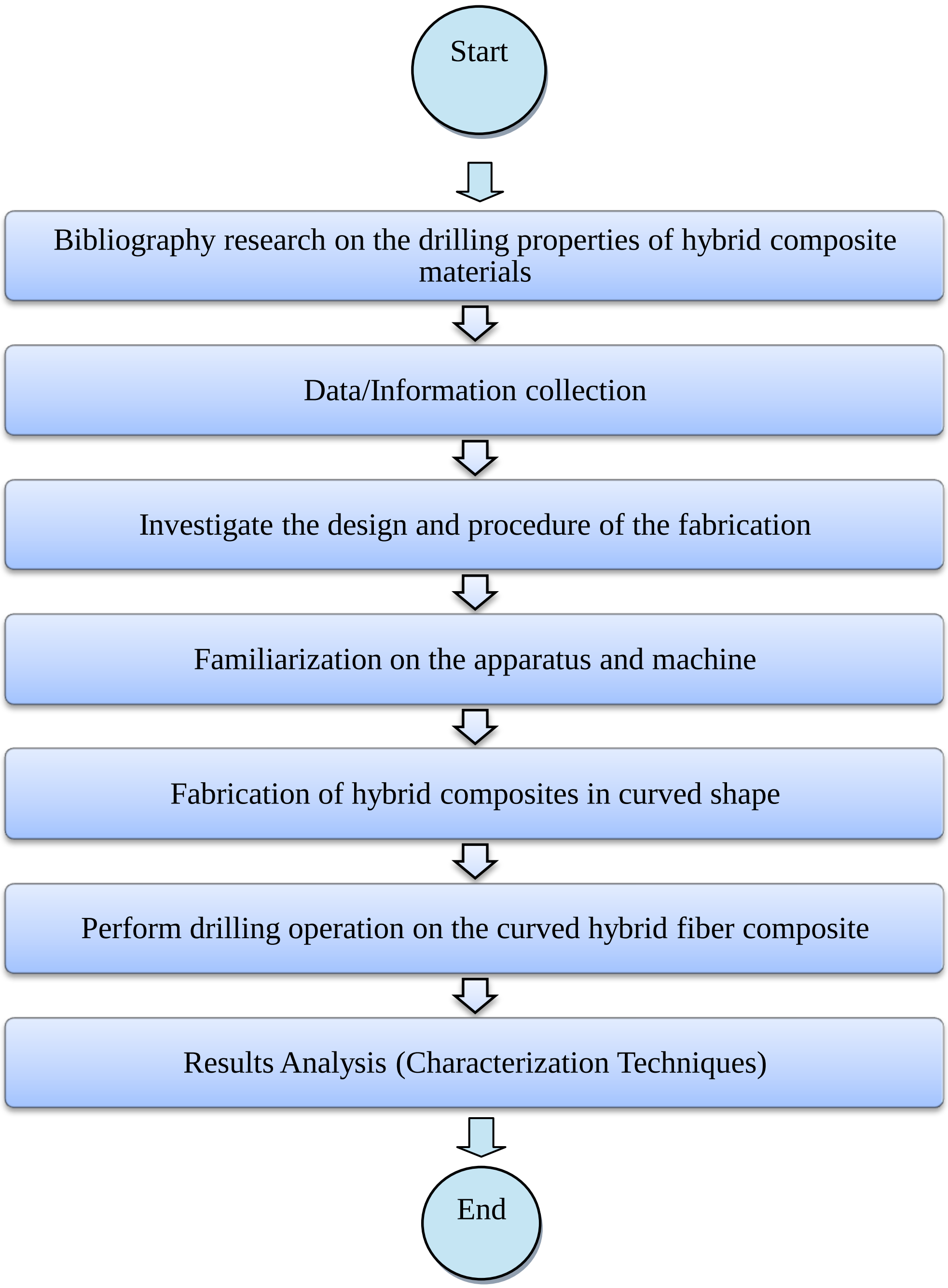


Figure 3: Process flow chart

3.1.2 Research Procedure Details

Study on hybrid fiber composite and the calculation used for the fabrication and drilling analysis

- Study is done based on journals and books related to composites, fiber composites and hybrid fiber composites.

Development of Composite Materials

- 40% fiber volume fraction (FVF) hybrid fiber composite in a curved shape is fabricated using carbon fiber (15%) and glass fiber(25%) as well as epoxy + hardener as matrix material.
- Fabrication of laminate is done by hand lay-up technique on a fabricated mold which is a half cylinder stainless steel.

Drilling of the fabricated hybrid fiber composite

- Drilling of composite holes will be done using a CNC drilling machine with spindle speed and feed rate as control variables

Analysis of the drilled holes

Delamination onset measurement will be done using a 3D non-contact machine for macrograph observation

The drilled holes are cut into half using an abrasive cutter and surface roughness is measured using a profilometer or a surface roughness tester

Scanning electron microscope (SEM) is used for microstructure analysis, ie fiber pullout, fiber-matrix debonding and delamination in layers.

Discussion

- Comparison of data
- Objective achievement
- Recommendation

Figure 4: Research procedure details

3.2 MATERIAL SELECTION

The scope of this research work is the study of defects in the drilled holes of a curved-shape hybrid fiber composite. From the numerous composites available, this project focuses on fiber reinforced epoxy. This type of materials had seen their use widespread in recent years, as its price goes down and reliability goes up. This is also due to the fact that the materials needed are accessible.

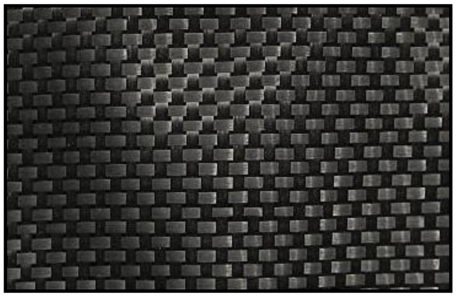


Figure 5: Woven Carbon fiber

Figure 6: Woven E-Glass fiber

3.2.1 Carbon Fiber

Carbon fiber is as a fiber that contains at least 90% of carbon. Carbon fibers are manufactured by the controlled pyrolysis of organic precursors in fibrous form. Oxygen, nitrogen and hydrogen are removed from carbon fibers by heat treatment of the precursor. Mechanical properties of the carbon fibers are improved by increasing the crystallinity and orientation, and by reducing defects in the fiber. To achieve this, highly oriented precursor is used and maintained during the process of stabilization and carbonization through tension. The material offer several advantages besides weight reduction, when used in airplanes, like durability, reduced maintenance, parts consolidation and the possibility of self-monitoring using embedded sensors and 'smart' fibers.The main applications of carbon fibers are in specialized technology including aerospace and nuclear engineering. In general engineering and transportation, carbon fibers are used in engineering components such as bearings, gears, cams, fan blades and automobile bodies. Conductivity in electronics technology provides another application of carbon fibers.

3.2.2 Glass Fiber

A material that is consists of numerous extremely fine fibers of glass. This material is formed when thin strands of silica-based or other formulation glass are extruded into many fibers with small diameters suitable for textile processing. The use of this material is far more extensive, but less associated to high tech products. 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. Glass fiber has a strength that is less than those of carbon. Glass fibers are useful as thermal insulators due to their high ratio of surface area to weight. However, the increased surface area makes them much more vulnerable to chemical attack. The freshest and thinnest fibers are the stronger of all because the thinner ones are more ductile. The use for this material includes reinforcement of various material, the naval industries, domestic appliances, thermal insulation, electric insulation and also in sports and automobile production.

Table 1 : Properties of E-Glass and Carbon HS

Fibers	Advantages	Disadvantages	Remarks
E-Glass 3 .	• Good tensile and compressive • Strength and stiffness • Good electrical properties • Low cost	• Poor impact resistance	Most commonly used
2 . Carbon 3HS	• 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 Epoxy

Epoxy is a thermosetting polymer that is formed from the reaction of an epoxide (resin) with polyamine (hardener). It is a tough polymer with excellent adhesion, chemical and heat resistance, good-to-excellent mechanical properties and very good electrical insulating properties. Epoxy has a wide range of applications including fiber reinforced composite materials, coatings, and adhesive.

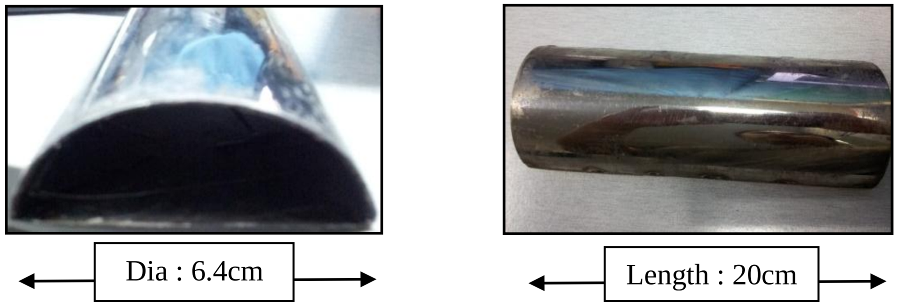
3.3 PROJECT ACTIVITIES : Experimental Procedure

3.3.1 Fabrication of hybrid fiber composite

The technique chosen to fabricate the hybrid fiber composite samples is the hand lay-up technique as it is the simplest and most commonly used method to manufacture prototypes which is suitable for low volume production.

3.3.1.1 Mold Preparation

Prior to fabricating the composite prototypes, molds for each composite should be fabricated. In this case, the author managed use some stainless steel pipes that were cut into half to get the half cylinder shape. A steel plate is then placed as the base of the half cylinder by spot welding the edges of the pipe with the plate. The dimension of the mold is shown in figures 7 with the diameter of 6.4cm and length 20cm. Production mold preparation requires a thorough machine buffing and polishing of the mold. Mold removal wax and silicon lubricant is applied to the mold for the purpose of composite release from mold once the fabrication is complete.



Figures 7 : Dimensions of the mold

3.3.1.2 Hand Lay Up Technique

Hand Lay Up Technique is one of the simplest processes in fabricating a hybrid composite. This technique which is also known as contact lay-up is an open-mold method of molding thermosetting resin in association with fibers. The curing of the resin with a hardener converts the resins into a hard, infusible, and rigid material. This techniques is best used where low volume of production is needed when other forms of production process is unsuitable due to size and cost constraints. In this study, the matrix material (epoxy and hardener) first need to be weighed based on the calculation of rules of mixtures in the next chapter of Results and Discussion. The orientation of fibers used is $0/90^{o}$**.** The 10 pieces of woven carbon fiber layers and 16 pieces of woven glass fiber layers are arranged in an arrangement to minimized delamination for each prototype. Please refer to the Results and Discussion chapter for the design of the fiber layers.

The procedures of one prototype fabrication are explained as follow:

1. Put on proper personal protective equipment (PPE) that includes goggle and gloves. Before proceeding to ensure other safety requirements are followed
2. Mold removal wax and silicon lubricant are applied throughout the top mould surface to remove the impurities and for ease of removal
3. Weigh the matrix material (epoxy and hardener) based on the ratio and calculations made by using a Digital Electronic Weighing Scale.

4. Mix the mixture using an electronic mixture until they are homogeneous.
5. The mixture is applied onto the mould
6. The reinforced fibers of woven carbon or glass are applied based on the design.
7. A roller is used to remove excess air and ensure the layers are glued together.
8. Apply another layer of matrix material and continue the step until the desired layers and thickness are obtained
9. The fibers will be impregnated together with the matrix and the excess air is removed with the help of roller
10. Remove the fabricated fiber composite from the mold
11. The fabricated prototypes are to be cured in an oven for eight (8) hours.

However, since there was only 1 oven that could be used, the author needs to share it with other students. Thus, the fabricated prototypes are left under standard atmospheric conditions and room temperature before being inserted into the oven. Table 2 shows the duration of each prototype cured in room temperature and then the oven.

Table 2 : Curing duration of prototypes

Prototype	Duration in room temperature (hours)	Duration in oven (hours)
1	31	8
2	26	8
3	7	8
4	9	8
5	9	8
6	3	8
7	12	8
8	11	8
9	7	8
10	9	8
11	3	8

Out of the 11 prototype fabricated, only 4 could be used as the other 7 could not be removed from the mold. The prototype that could be used were prototype umber 7,8,9 and 10.

3.3.1.3 Drilling of Hybrid Fiber Composite

The drilling operation was done using MTAB Denford CNC Milling Trainer XLMILL. A jig made of wood with smooth surface finish was fabricated to support the sample when drilling is carried. This drilling test was performed without any backing plate and cutting fluid. The drill bit type that is used for only 5 holes with the same drilling parameters is Benz Werkz High Speed Steel (HSS) with 5mm diameter and 118^{o} point angle. The distance between each drilled hole is set to be 1 cm to avoid cracks and more delamination. Drilling parameters are as follow:

Thickness	4mm								
Drill Bit Type	High Speed Steel (HSS)								
Feed Rate (mm/rev)	0.05			0.1			0.2		
Sample	A1	A2	A3	B1	B2	B3	C1	C2	C3
Speed (rpm)	1000	2000	3000	1000	2000	3000	1000	2000	3000

Figures 8 : Jig to support and hold the sample

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 on the clamped jig. 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.
9. For the remaining samples, repeat the step 6 until all hoes are drilled.
10. Close the CNC program
11. Perform shutdown procedure
12. Perform house keeping

CNC drilling program

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Line 1                    Column  1

[BILLET X150 Y86 Z30 ;
[EDGEMOVE X-75 Y-43 ;
[TOOLDEF T1 D5 ;
O0000 ;
(PROGRAM NAME – HYBRID COMPOSITE)
N100 G21 ;
N102 G49 G80 G90 ;
(5. DRILL TOOL – 1 DIA. OFF. – 1 LEN. – 1 DIA. -5.)
N104 Y6 M6 ;
G0 G90 G54 X180 Y0 M3 S2000 ;
N108 G43 H1 Z5. ;
N110 G99 G81 Z-10 R5. F50 ;
N118 G80 ;
G00 Z10 ;
M05 ;
G91 G28 Z0 ;
G28 X0 Y0 ;
M30 ;
```

Figure 9 : CNC program for drilling operation

Figure 10 : Drilling of the fabricated samples

Figure 11 : Executing the drilling program

3.3.1.4 Damage Factor of Drilled Holes

Damage factor is the consequence of delamination around drilled holes. It proves to be closely related to the level of damage measured by a relative modulus decrease, which occurs at the damage site. To determine the damage factor around drilled holes of specimens, a measurement method is used. The measurement of the damage factor is the ratio of the original hole diameter, D_o which in this study is the diameter of the drill bit used in drilling to the diameter of the delamination, D_d occurred around the drilled holes. This measurement is done using the Mitutoyo 3D Non Contact Measuring System where other than measurement, images of the drilled holes and the defects around them were captured. The damage factor, FD is obtained using the following equation. $Damage\ Factor, F_D = \frac{D_d}{D_o}$

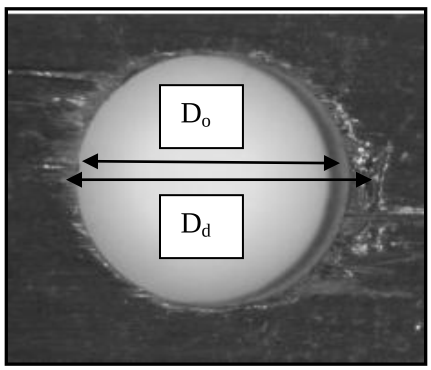


Figure 12 : Delamination zone

Figure 13 : 3D Non-Contact Measuring System

3.3.1.5 Surface Roughness of the Drilled Holes

Surface 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. Surface roughness is typically considered to be the high frequency, short wavelength component of a measured surface. In this study the Mitutoyo Surface Roughness Tester SV 3000 was used to measure the internal surface of the drilled holes. The stylus device of the equipment will be inserted through the hole in order to quantify its roughness of holes across the depth. The aim is to study the effects of surface roughness of part produced from different machining processes and to establish a relationship between material and machining of a specific component. It is also to measure the quality of a surface after manufacturing or machining processes.

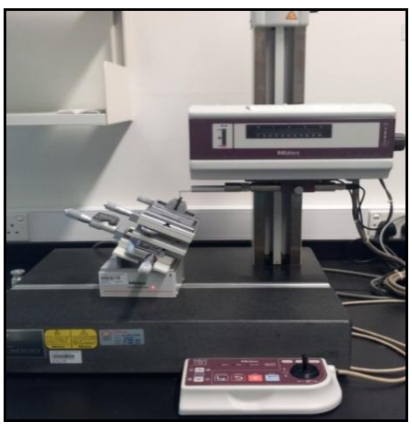


Figure 14: Mitutoyo Surface Roughness Tester SV3000

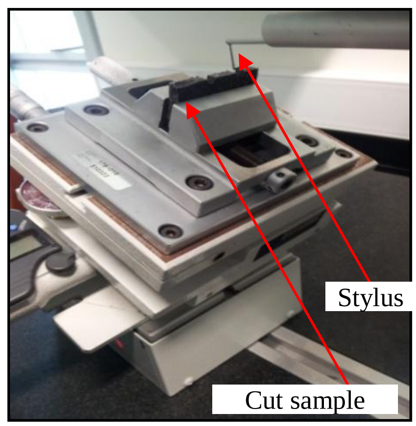


Figure 15: Cut sample clamped to be analyzed using the stylus

The holes need to be halved and samples are cut into pieces with half of the holes on each piece using an abrasive cutter.

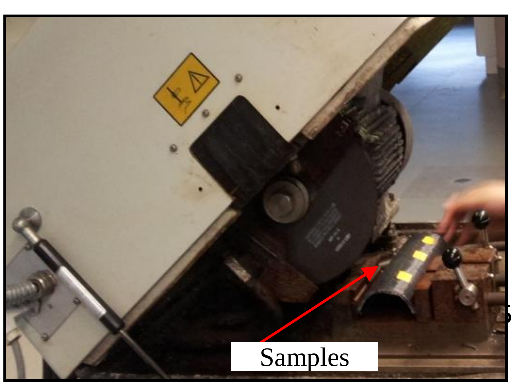


Figure 16: Halving of samples using the Abrasive Cutter

3.3.1.6 Microstructural Analysis through Micrograph Observation

The microstructures of the drilled holes samples are analyzed using a Field Emission Scanning Electron Microscope (FESEM). A FESEM is used to visualize very small topographic details on the surface or entire or fractioned objects. Researchers in biology, chemistry and physics apply this technique to observe structures that may be as small as 1 nanometer (= billion of a millimeter). It operates with a field-emission cathode in the electron gun of a scanning electron microscope, which provides narrower probing beams at low as well as high electron energy, resulting in both improved spatial resolution and minimized sample charging and damage. Micrograph observation of the internal surface of the drilled holes are observed and captured to be analyzed.

Figure 17: An example of a FESEM machine

3.3.1.7 Project Activities throughout the project

Table 3 : Project Activities

Activities	Starting Month	Finishing Month
Read books, journals and paper published on the related topics	4 June 2011	19 June 2011
Studies on methods to perform rule of mixture for the desired fiber volume fraction (FVF)	20 June 2011	31 July 2011
Preparation of materials needed	1 August 2011	20 August 2011
Implementation of calculation done on materials	21 August 2011	15 September 2011
Fabrication of the hybrid fiber composites	26 September 2011	31 October 2011
Drilling process on the fabricated hybrid fiber composite	1 November 2011	15 November 2011
Analysis on the defects of the drilling, ie delamination, damage, surface roughness on the hybrid fiber composite	15 November 2011	31 November 2011
Report documentation	1 December 2011	4 January 2012

3.4 KEY MILESTONE

Table 4 : Key Milestone

	2011								2012
Milestone	M	J	J	A	S	O	N	D	J
Completion of all calculations needed									
Completion of the design of the material									
Completion of material fabrication									
Completion of drilling of material									
Completion of analysis of drilling on material									
Report documentation									

3.5 GANTT CHART

Table 5 : Gantt Chart of Final Year Project 1 (FYP 1)

PROJECT ACTIVITIES	**WEEK**													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Study on hybrid fiber composite (books, journals, papers)														
Work on Extended Proposal Defence														
Study the calculations needed (books, journals, papers)														
Work on proposal defence														
Study and start on the design of														

the FVF and laminate to be fabricated (books, journals, papers)										■	■	■		
Work on Interim Draft Report												■		
Work on Interim Report													■	

Table 6 : Gantt Chart of Final Year Project 2 (FYP 2)

PROJECT ACTIVITIES	**WEEK**														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Fabrication of hybrid fiber composite	■	■	■												
Drilling holes operation in the hybrid fiber composite			■	■	■										
Submission of progress report								■							
Analysis of drilled samples (damage factor and surface roughness)						■	■		■						
Results gathering							■		■	■					
Pre-SEDEX											■				
Submission of draft report												■			
Submission of Dissertation (soft bound)													■		
Submission of Technical Paper													■		
Preparation of Oral Presentation														■	
Submission Project Dissertation (Hard Bound)															■

3.6 TOOLS (EQUIPMENT AND HARDWARE)

As of now, the identified equipment and hardware needed are as follows:

(i) Fabrication of hybrid fiber composite :
- Oven/furnace for matrix(epoxy) curing

(ii) Drilling of the hybrid fiber composite:
- Computer Numerical Control (CNC) Milling machine.

(iii) Cutting hybrid fiber composite with drilled holes:
- Abrasive cutter

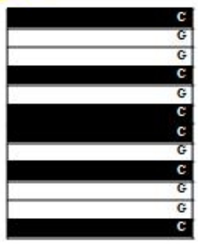
(iv) The delamination zone measurement:
- 3D Non-Contact Measuring System

(v) Microstructural Analysis:
- Field Emission Scanning Electron Microscope (FESEM)

(vi) Surface roughness of the drilled holes:
- Surface Roughness Tester

3.7 SUMMARY OF PROJECT ACTIVITIES

i) Composite design

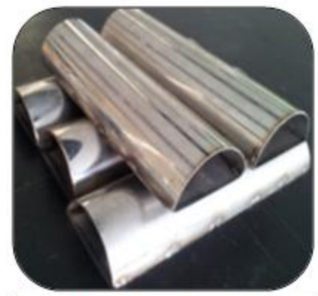


Fiber orientation and calculation of thickness, size & dimensions

→

Weigh woven carbon & E-glass fibers to get weight of matrix material. Calculation using Rules of mixture.

→



Molds: Stainless steel half pipes spot welded to steel plates as base

ii) Fabrication

Hand lay-up technique (0/90° orientation) 40% fiber volume fraction (FVF).Woven carbon fiber (15%), woven E-glass fiber(25%) and epoxy + hardener(matrix material)

→

Curing for 8 hours [Oven]

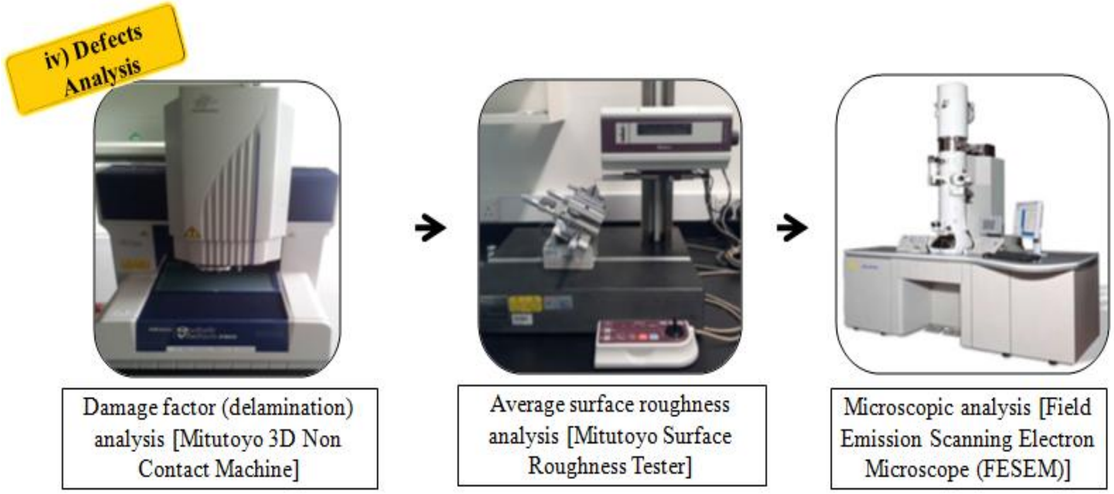
iii) Drilling

Jig fabrication to support sample while drilling

→

Drilling [MTAB Denford CNC Milling Trainer XLMILL]

Feed rate (mm/rev)	0.05, 0.1, 0.2
Spindle speed (rpm)	1000, 2000, 3000
Drill bit (new bit used for every set of drilling parameters)	High Speed Steel (HSS), 0.5mm


iv) Defects Analysis
Damage factor (delamination) analysis [Mitutoyo 3D Non Contact Machine]
Average surface roughness analysis [Mitutoyo Surface Roughness Tester]
Microscopic analysis [Field Emission Scanning Electron Microscope (FESEM)]

CHAPTER 4 : RESULT AND DISCUSSION

4.1 THICKNESS OF SAMPLE

Table 7 : Thickness of woven mat based on materials

No of Layers	Thickness (mm)	
	Woven carbon fiber	Woven glass fiber
1 layer	0.19	0.17
6 layers	1.14	1.02
10 layers	1.9	1.7

A single layer thickness of both the woven carbon and glass fibers were measured using vernier caliper. The mat should be folded into several layers and in this case it is 6 layers and 10 layers to ensure precision in readings.

The thickness of 4mm for the hybrid composite is chosen by the author. This is because the 4mm composite half cylinder is strong enough in terms of structural and suitable for drilling process. The 4 mm thickness composite incorporated 6 layers of woven carbon fiber and 10 layers of glass fiber stacked in specific sequences which totaled up to 16 layers. This is in accordance with the 15% usage of carbon fiber and 25% of glass fiber involving the calculation of mass and area. The length and diameter of the half circle that are chosen are 20cm and 6.4cm respectively. The size is chosen because it is feasible to fabricate and suitable to drill holes.

4.2 RULES OF MIXTURE

The rules of mixture was used in order to obtain the weight of the matrix in fabricating the desired hybrid composite based on the decided fiber volume fraction. In this study, 40% of fibers are used which comprise 15% of woven carbon fiber and 25% of woven glass fiber. The calculated matrix used which were epoxy and hardener can be obtained using the following steps.

Firstly, the woven carbon fiber and glass fiber were weighed using a digital electronic weighing scale. The weights of the fibers are as follows:

Table 8 : Woven fibers weight based on area

Fiber composite type	Area	Weight
Carbon Fiber	5.3cm x 5.6cm = 29.68cm^2	0.515g
	20cm x 20cm = 400cm^2	6.9407g
Glass Fiber	5.5cm x 5.5cm = 30.25cm^2	0.54g
	20cm x 20cm = 400cm^2	7.14g

Diameter of half cylinder mold: 6.4cm

Radius of half cylinder mold: 3.2cm

Thickness of composite: 0.4cm

Diameter of composite half cylinder: 7.2cm

6.4cm + 0.4cm + 0.4cm = 7.2cm

Radius of composite half cylinder: 3.6cm

3.2cm + 0.4cm = 3.6cm

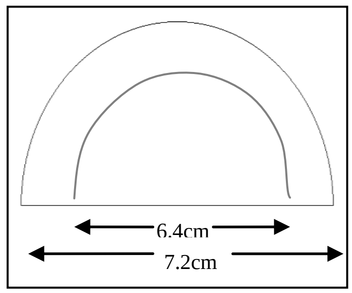


Figure 18 : Dimension of molds (OD and ID)

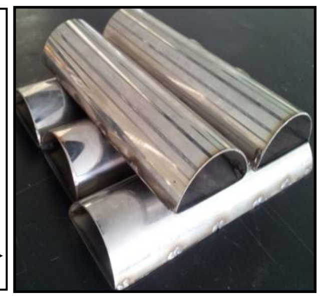


Figure 19 : Molds obtained by halving stainless steel pipes and spot weld with plate at bottom

0.4cm/15 layers = 0.02666666cm length different between each layer

Circumference (cm): 2π r

Circumference of half circle (cm): π r for each layer

Area of each layer (cm^2): circumference of half circle x length of composite ; π r x 20cm

Weight of each carbon fiber layer (g) : Area of each layer (cm^2)/400 x 6.9407g

Weight of each glass fiber layer (g) : Area of each layer (cm^2)/400 x 7.14g

Example of calculation for layer 1(carbon fiber) with radius of 3.2cm:

Circumference of half circle: π r = π (3.2cm) = 10.05309649cm

Area of each layer (cm^2) = π r x 20cm

= 10.05309649cm x 20cm

= 201.0619299cm^2

Weight of layer 1(carbon fiber) (g) = 201.0619299cm^2/400cm^2 x 6.9407g

= 3.488776341g

*For the subsequent layers radiuses, 0.02666666cm is added to the radius of previous layer. For example,

Radius of layer 2 = 3.2cm + 0.02666666cm = 3.226666666cm

For carbon fiber layer, 6.9407g is used for 400cm^2 fiber as reference. For glass fiber layer, 7.14g is used for 400cm^2 fiber as reference.

The calculated weight of each fiber layer and total weight of fiber are presented in the table below:

Table 9 : Weight data

Layer	**Arrange-ment**	**Radius of half circle (cm)**	**Circumference/2**	**Area of each layer(cm^2)**	**Weight of each layer(g)**
1	C	3.2	10.05309649	201.0619299	3.488776341
2	G	3.226666666	10.13687229	202.7373965	3.618862528
3	G	3.253333332	10.2206481	204.4128632	3.648769608
4	G	3.279999998	10.3044239	206.0883299	3.678676688
5	C	3.306666664	10.3881997	207.7637965	3.605065456
6	G	3.33333333	10.4719755	209.4392632	3.738490848
7	G	3.359999996	10.5557513	211.1147299	3.768397928
8	C	3.386666662	10.63952711	212.7901965	3.692282293
9	C	3.413333328	10.72330291	214.4656632	3.721354571
10	G	3.439999994	10.80707871	216.1411299	3.858119168
11	G	3.46666666	10.89085451	217.8165965	3.888026248
12	C	3.493333326	10.97463031	219.4920632	3.808571408
13	G	3.519999992	11.05840612	221.1675299	3.947840408
14	G	3.546666658	11.14218192	222.8429965	3.977747488
15	G	3.573333324	11.22595772	224.5184632	4.007654568
16	C	3.59999999	11.30973352	226.1939299	3.924860522
				total fiber weight (g)	**60.373496071**

total area carbon (cm2)	**1281.767579**	**total carbon weight(g)**	**22.240910592**
total area glass(cm2)	**2136.279299**	**total glass weight (g)**	**38.13258548**

To determine the mass of matrix (epoxy and hardener) that is to be used, the calculation using rules of mixture are done as follows:

Total weight of fiber (carbon and glass): 60.37349607g

Total weight of carbon fiber: 22.240910592g

Total weight of glass fiber: 38.13258548g

Total volume of fiber = $\frac{W_g}{\rho_g} + \frac{W_c}{\rho_c}$

$$= \frac{38.13258548\,g}{2.5g/\text{cm}^3} + \frac{22.240910592\,g}{1.8g/\text{cm}^3}$$

$= 15.25303419\text{cm}^3 + 12.35606144\text{cm}^3 = 27.60909563\text{ cm}^3$

0.4FVF = 27.60909563cm^3

1FVF= 69.02273907cm^3 ⟶ Volume of composite

$V_m + V_f = V_c$

$V_m = 69.02273907\text{cm}^3 - 27.60909563\text{cm}^3 = 41.41364344\text{ cm}^3$

$W_m = \rho_m\ V_m$

$= (1.2g/\text{cm}^3)(41.41364344\text{ cm}^3)$

= 49.69637213g of matrix per sample

<u>Obtaining the weight or mass of epoxy and matrix required.</u>

The ratio between epoxy and hardener was 10:6, thus the calculations are as follow:

Hardener : 6/16 x 49.69637213g = 18.63613955g

Epoxy : 10/16 x 49.69637213g = 31.06023258g

4.3 FABRICATED SAMPLES OF HYBRID FIBER COMPOSITE

Hybrids have unique features that can be used to meet design requirements in a more cost-effective way than advanced or conventional composites [27]. Type A hybrid composite which is made of intermingling fibers of different types in a common epoxy will lead to a better properties of the particular composites. Using fiber glass and carbon fiber is a good combination as price and good mechanical properties can be balanced according to the desired laminates. As shown in the illustration, the inexpensive E-glass fiber is incorporated 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.

Carbon fibers are arranged in the middle of the laminate for the purpose of delamination reduction. The hybrid composite will be fabricated with a thickness of 4mm with 40% of combined volume fraction of both fibers. The initial design structure for the sample of the fiber reinforced epoxy show below:

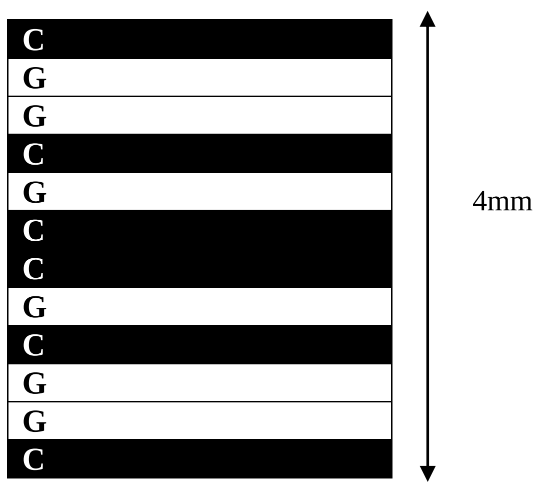


Figure 20: Initial Design of the Hybrid Composite

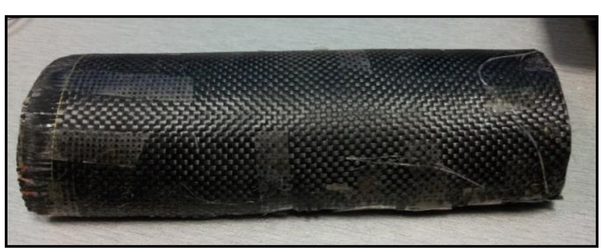


Figure 21 : One of the 11 fabricated hybrid fiber composites

11 samples were fabricated and only 4 out of the 11 could be used. This issue will be further explained further in the problem faced section in this chapter. Due to the curved shape of the half cylinder mold, precautions had to be taken to avoid the matrix material from flowing down to the sides of the mold. The matrix material were carefully spread throughout each of the composite layer to ensure constant thickness and

4.4 DRILLING PARAMETERS

Drilling of composite material, irrespective of the application horizon, is regarded a critical operation owing to the tendency of delamination occurring around the holes when subjected to mechanical stresses. Delamination appears to be the most critical defects among others caused by drilling in composite. In this study, different spindle speed (rpm) and feed rate (mm/rev) were employed to drill 12 holes in each of the 4 samples. 5 holes were drilled with the same spindle speed (rpm) and feed rate (mm/rev). The drill bit used was a 5mm high speed steel (HSS) drill bit. To neglect the effect of drill wear and in complying with ISO standard, a new drill bit was used for each set of spindle speed (rpm) and feed rate (mm/rev). The table below shows the drilling parameters of the samples drilled.

Table 10: Drilling Parameters

Sample label	Feed Rate (rev/mm)	Speed (rpm)	
A1	0.05	1000	5 holes
A2		2000	5 holes
A3		3000	5 holes
B1	0.1	1000	5 holes
B2		2000	5 holes
B3		3000	5 holes
C1	0.2	1000	5 holes
C2		2000	5 holes
C3		3000	5 holes

Figure 22: Holes drilled in one of the fabricated samples

4.5 DEFECTS OF THE DRILLED HOLES

Increasing demand on cutting tool functions and performance and high demands as well as hole and edge quality on material that is developing, makes it more difficult to machine. Hole quality is the main indicator here with delamination being the key factor of hole assessment. This aforementioned quality could not be examined by naked eyes, only a mere observation could be visible. Thus after the drilling operation, two different means are to be used in analyzing the drilled holes quality. The equipments used in this study are 3D Non-Contact Measuring System and Field Emission Scanning Electron Microscope (FESEM). These equipments are used to examine any delamination occurred and for macrographic observation. As for the surface roughness of the drilled holes, a surface roughness tester or a profilometer is used.

The results obtained from the 3D Non-Contact Measuring System has not shown any sign of delamination occurring around the circular area of the 45 holes that were drilled with different sets of spindle speed (rpm) and feed rate (mm/rev). This is due to the residual fibers occurring in the interior and exterior of the hole. This splintering problem occured may be due to poor cutting action and the shape and structure of the composite half cylinder itself. This will further be discussed at the end of this chapter.

4.6 DAMAGE FACTOR

After the drilling of composite materials, the damage that is most evident would be delamination. This damage can be seen around the circular area of the hole. The diameter of delamination observed will lead to the calculation of the damage factor, F_d and can be determined using a Mitutoyo 3D Non Contact Measuring System. However, in the results obtained no delamination can be found as there were splinters on the surfaces of all holes entry. Thus, the diameter measured was the residual fibers in the holes calculated with the diameter of the drill bit in obtaining the damage factor, Fd. The images of all the drilled holes were captured using the same equipment. The best Fd obtained is sample A3 (3000 rpm, 0.05 mm/rev). The best result taken is the value that is near to the value of 1. The following table shows the Damage Factor, Fd of the drilled holes.

Table 11: Damage Factor, Fd of the drilled holes

Sample	Hole number	Feed Rate (mm/rev)	Spindle Speed (rpm)	Drill Bit Diameter, D_o (mm)	Delamination Diameter, D_d (mm)	Damage Factor, FD	Damage Factor, Fd (5 samples average)
A1	H1	0.05	1000	5	4.8173	0.36772	0.391
	H2	0.05	1000	5	1.7405	0.34556	
	H3	0.05	1000	5	3.0634	0.30736	
	H4	0.05	1000	5	0.8609	0.24594	
	H5	0.05	1000	5	3.722	0.68842	
A2	H1	0.05	2000	5	2.3748	0.43748	0.426112
	H2	0.05	2000	5	1.8766	0.40912	
	H3	0.05	2000	5	2.2922	0.38758	
	H4	0.05	2000	5	1.8057	0.6387	
	H5	0.05	2000	5	3.6311	0.25768	
A3	H1	0.05	3000	5	0.8059	0.96346	0.568164
	H2	0.05	3000	5	1.1186	0.3481	
	H3	0.05	3000	5	1.7699	0.61268	
	H4	0.05	3000	5	2.1349	0.17218	
	H5	0.05	3000	5	2.6414	0.7444	

B1	H1	0.1	1000	5	2.0812	0.41624	0.346456
	H2	0.1	1000	5	2.487	0.4974	
	H3	0.1	1000	5	2.009	0.4018	
	H4	0.1	1000	5	0.7595	0.1519	
	H5	0.1	1000	5	1.3247	0.26494	
B2	H1	0.1	2000	5	1.5406	0.33626	0.310524
	H2	0.1	2000	5	3.5562	0.3807	
	H3	0.1	2000	5	1.0348	0.30864	
	H4	0.1	2000	5	1.5593	0.23908	
	H5	0.1	2000	5	2.1092	0.28794	
B3	H1	0.1	3000	5	1.6813	0.76158	0.426076
	H2	0.1	3000	5	1.9035	0.51972	
	H3	0.1	3000	5	1.5432	0.40936	
	H4	0.1	3000	5	1.1954	0.29586	
	H5	0.1	3000	5	1.4397	0.14386	
C1	H1	0.2	1000	5	2.1874	0.16118	0.338828
	H2	0.2	1000	5	2.0456	0.22372	
	H3	0.2	1000	5	1.9379	0.35398	
	H4	0.2	1000	5	3.1935	0.42698	
	H5	0.2	1000	5	1.2884	0.52828	
C2	H1	0.2	2000	5	3.8079	0.30812	0.392004
	H2	0.2	2000	5	2.5986	0.71124	
	H3	0.2	2000	5	2.0468	0.20696	
	H4	0.2	2000	5	1.4793	0.31186	
	H5	0.2	2000	5	0.7193	0.42184	
C3	H1	0.2	3000	5	1.8386	0.47496	0.479216
	H2	0.2	3000	5	1.7278	0.37532	
	H3	0.2	3000	5	1.5368	0.45844	
	H4	0.2	3000	5	1.2297	0.36114	
	H5	0.2	3000	5	3.4421	0.72622	

4.6.1 Relationship between Spindle Speed (RPM) and Damage Factor, Fd at 0.05, 0.1 and 0.2 mm/rev

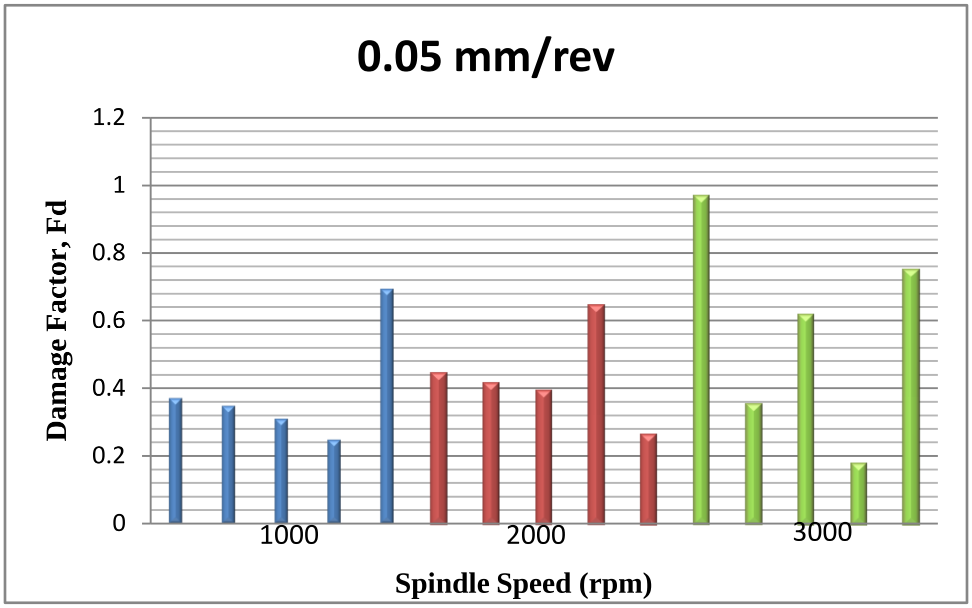


Figure 23: Samples A1, A2 & A3 with 0.05 mm/rev & spindles speeds of 1000, 2000 & 3000 rpm respectively

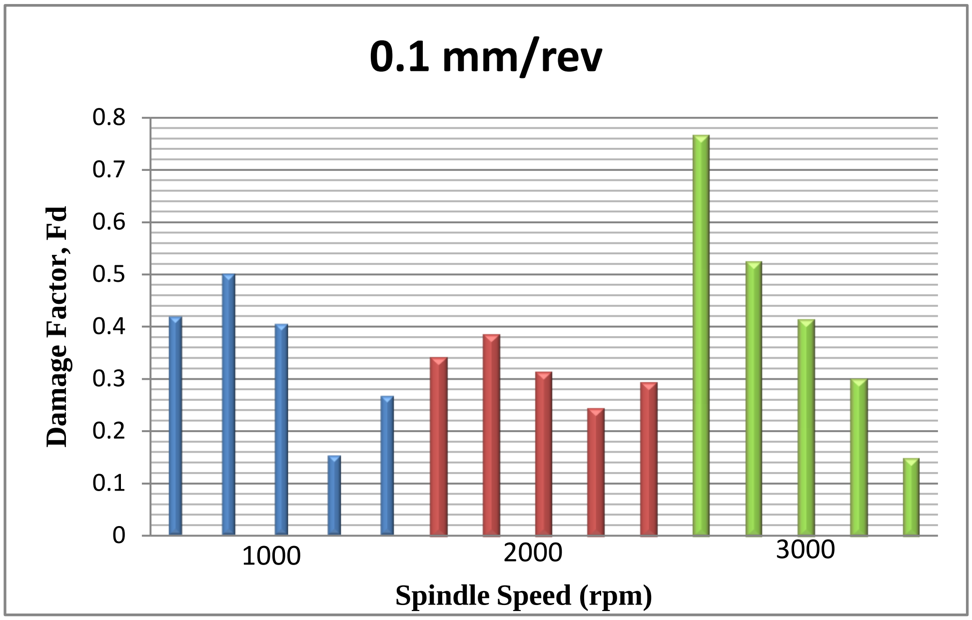


Figure 24 : Samples B1, B2 & B3 with 0.1 mm/rev & spindles speeds of 1000, 2000 & 3000 rpm respectively

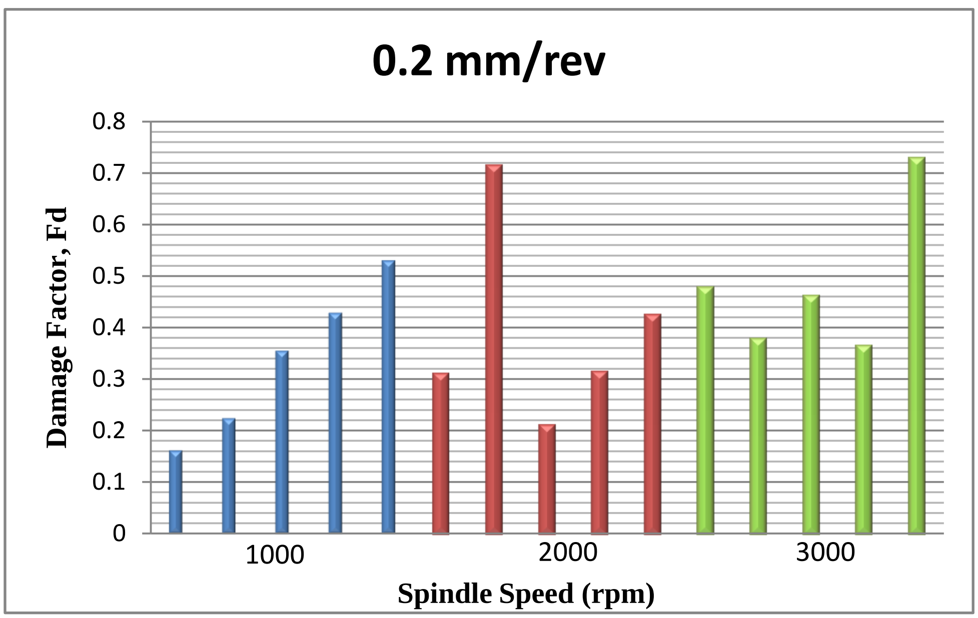


Figure 25 : Samples C1, C2 & C3 with 0.2 mm/rev & spindles speeds of 1000, 2000 & 3000 rpm respectively

4.6.2 Relationship between Feed Rate (mm/rev) and Damage Factor, Fd at 1000, 2000 and 3000 rpm

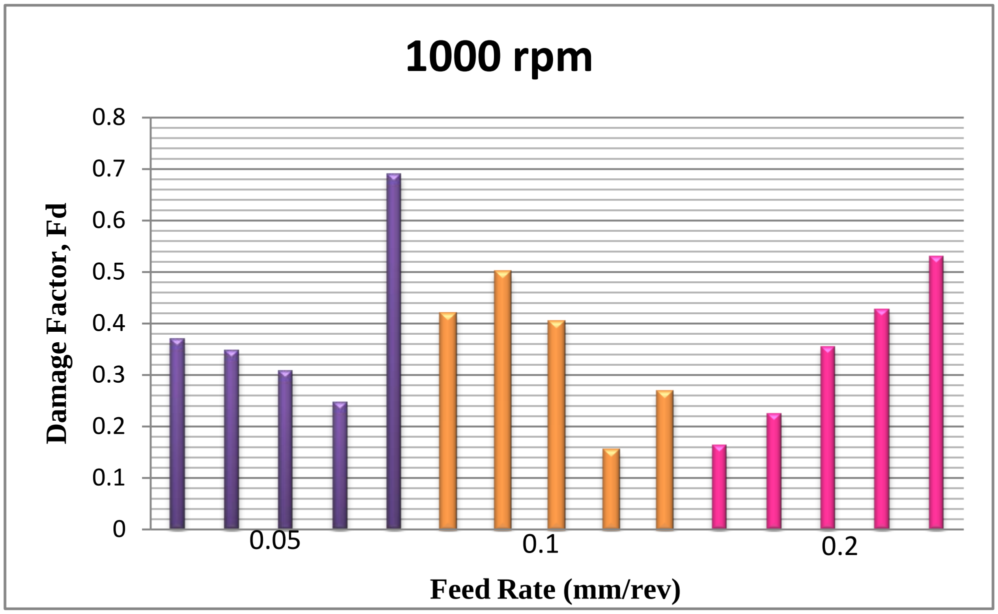


Figure 26: Samples A1, B1 & C1 with 1000 rpm & feed rate of 0.05,0.1 and 0.2 mm/rev respectively.

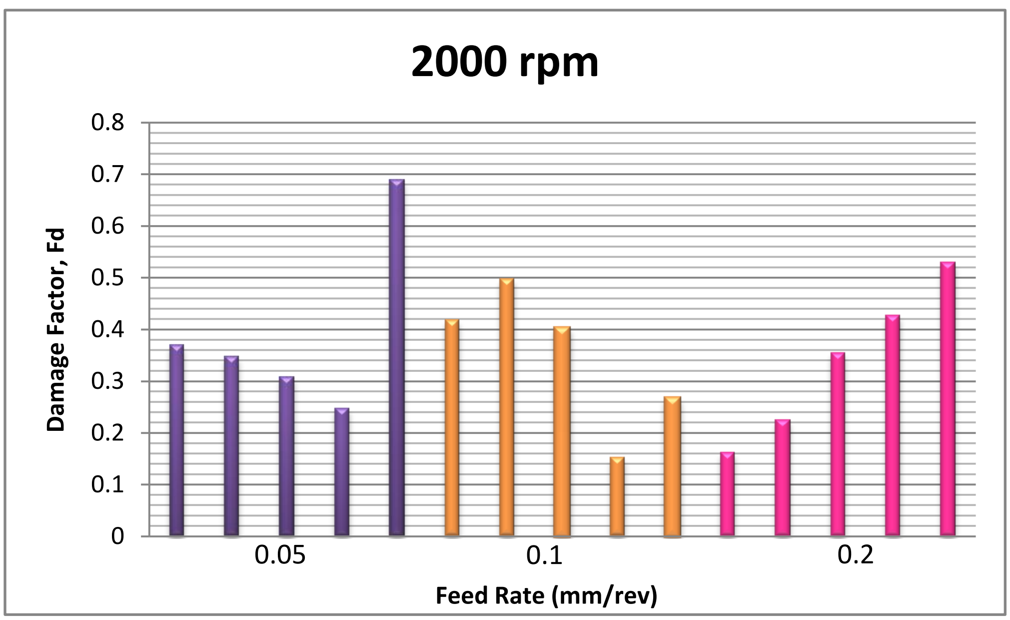


Figure 27: Samples A2, B2 & C2 with 1000 rpm & feed rate of 0.05, 0.1 and 0.2 mm/rev respectively.

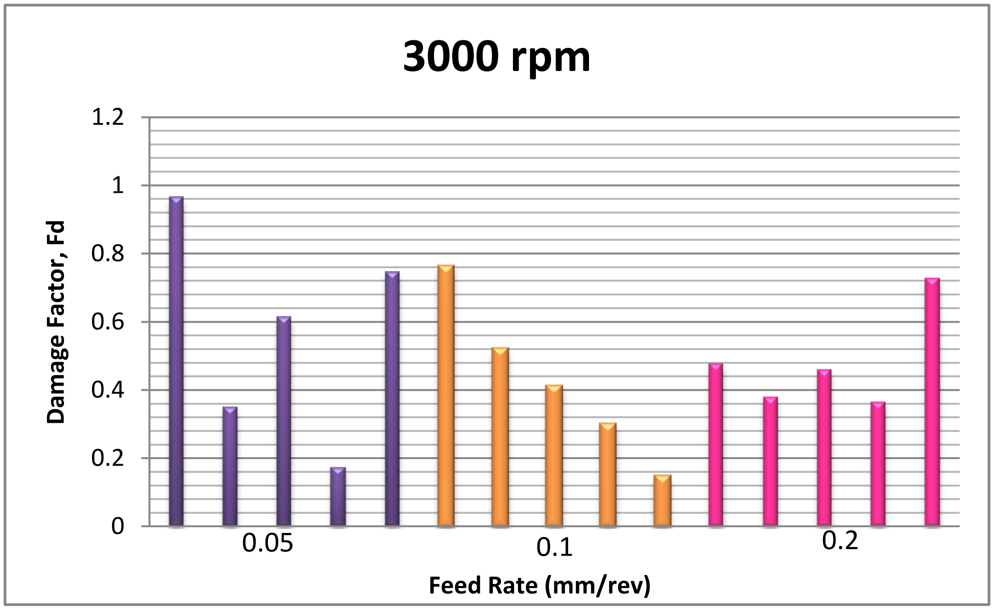


Figure 28: Samples A3, B3 & C3 with 1000 rpm & feed rate of 0.05, 0.1 and 0.2 mm/rev respectively.

4.6.3 Effect of feed rate and spindle speed on damage factor

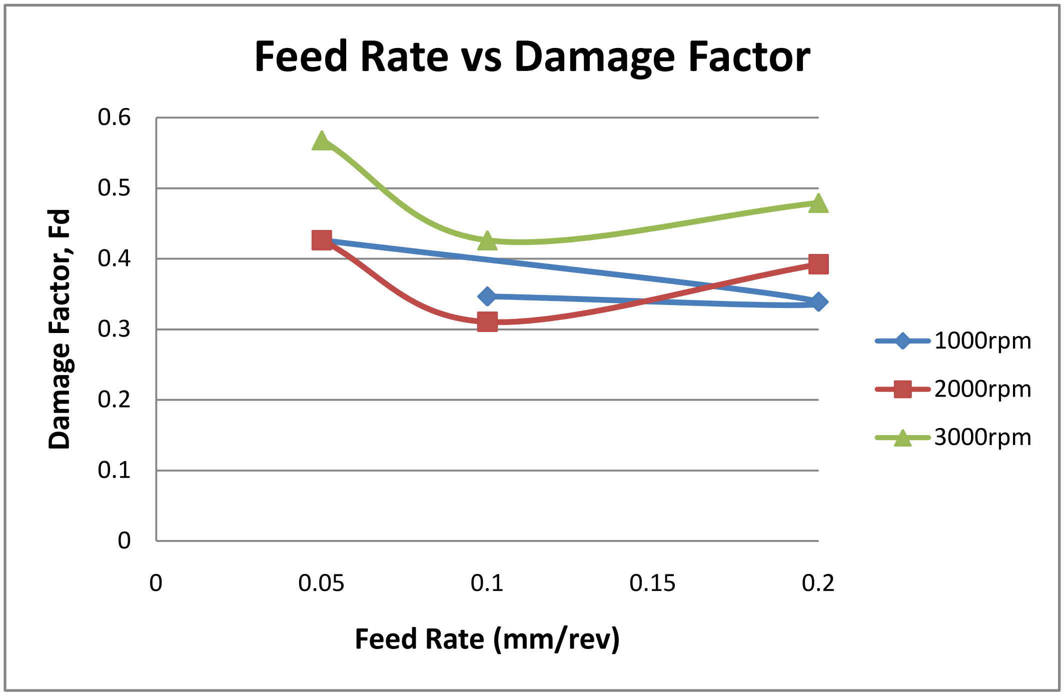


Figure 29 : Effect of Feed Rate on Damage factor, Fd at 1000, 2000, and 3000 rpm

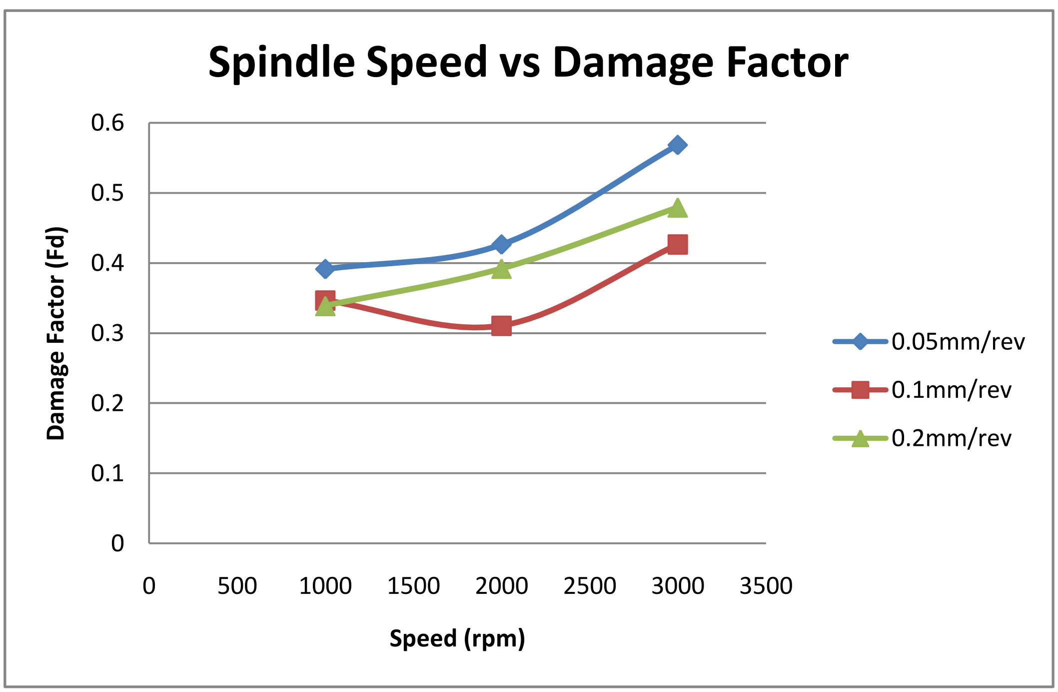
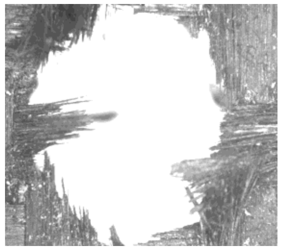
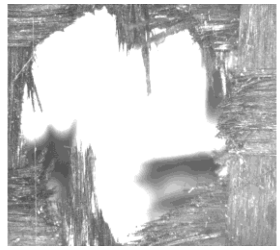
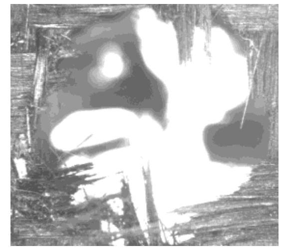
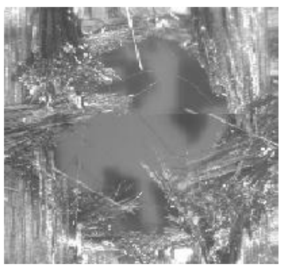
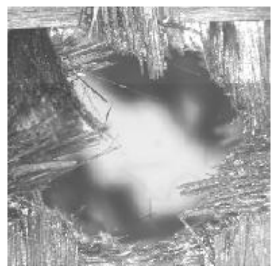
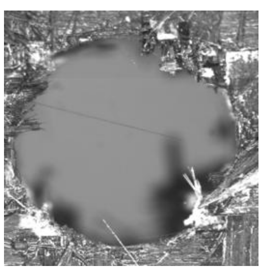
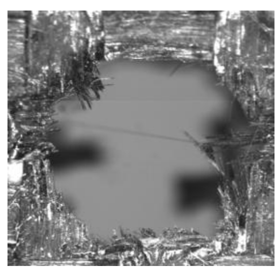
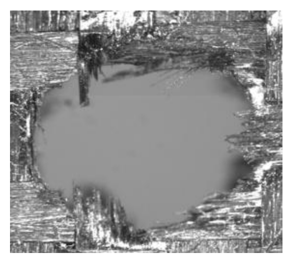
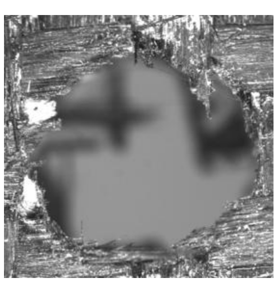
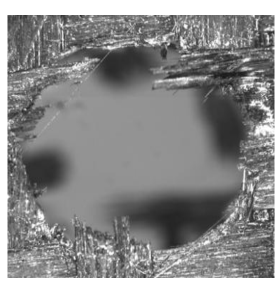
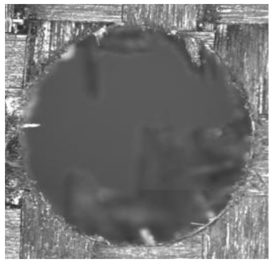
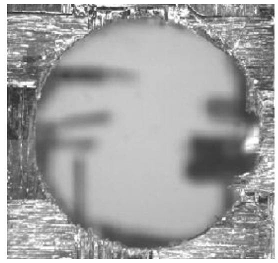
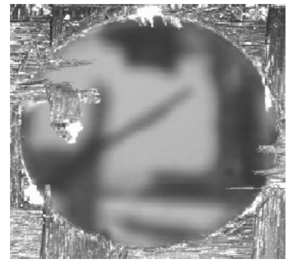
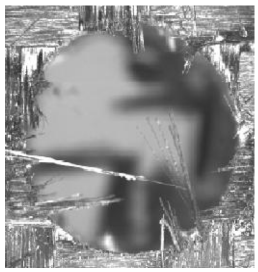
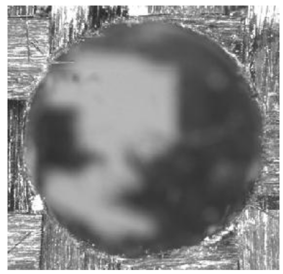


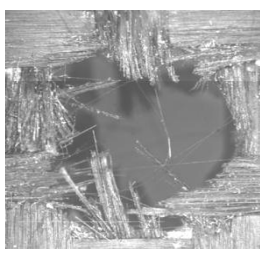
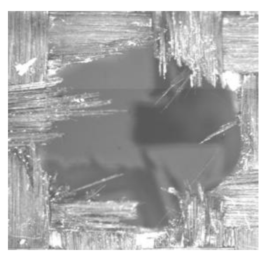
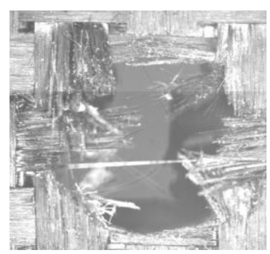
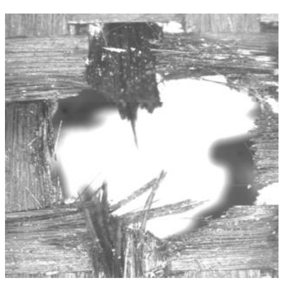
Figure 30 : Effect of Spindle Speed on Damage factor, Fd at 0.05, 0.1 and 0.2 mm/rev

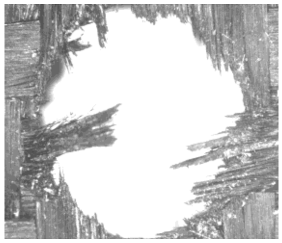
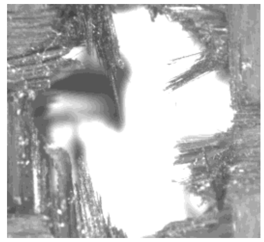
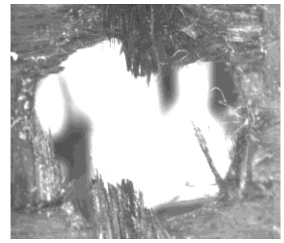
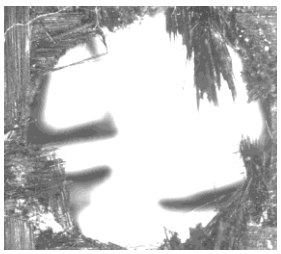
4.6.4 3D Non Contact Images of the drilled holes entry

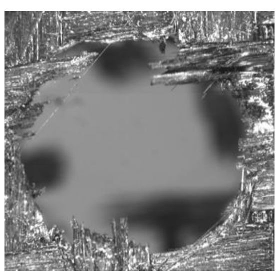
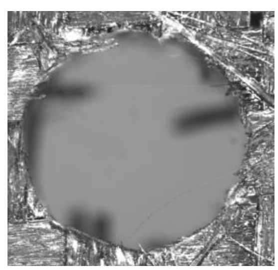
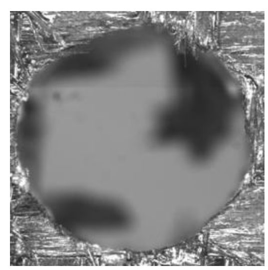
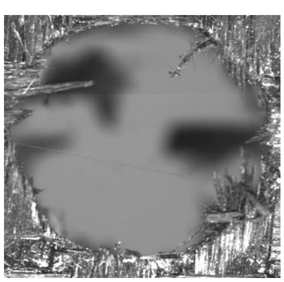
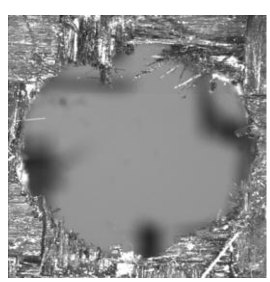
A1 Hole 1	**A1 Hole 2**	**A1 Hole 3**
		
F_D=0.36772	FD=0.34556	FD =0.30736
A1 Hole 4	**A1 Hole 5**	
		
FD =0.24594	FD =0.68842	

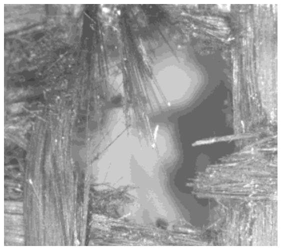
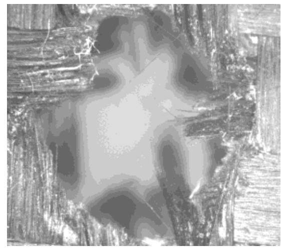
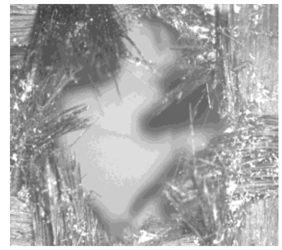
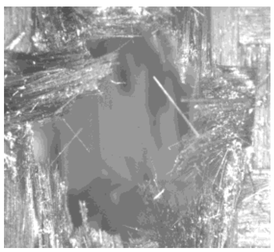
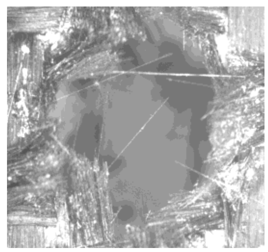
A2 Hole 1	**A2 Hole 2**	**A2 Hole 3**
		
F_D=0.43748	FD=0.40912	FD =0.38758
A2 Hole 4	**A2 Hole 5**	
		
FD =0.63870	FD =0.25768	

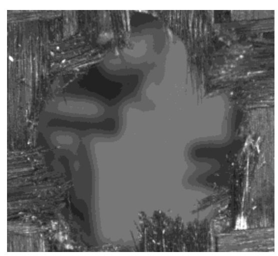
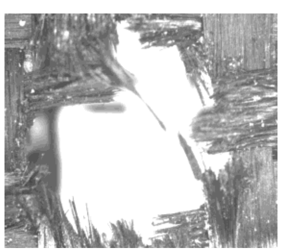
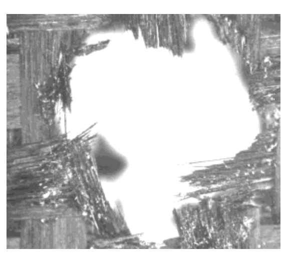
A3 Hole 1	A3 Hole 2	A3 Hole 3
		
F_D=0.96346	FD=0.34810	FD =0.61268
A3 Hole 4	**A3 Hole 5**	
		
FD =0.17218	FD =0.74440	

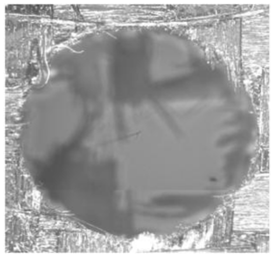
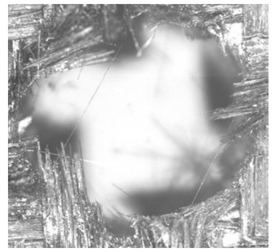
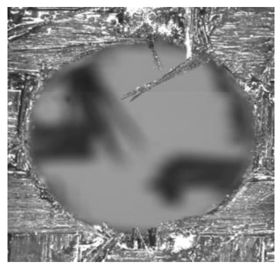
B1 Hole 1	B1 Hole 2	B1 Hole 3
		
F_D=0.41624	FD=0.49740	FD =0.40180
B1 Hole 4	**B1 Hole 5**	
		
FD =0.15190	FD =0.26494	

B2 Hole 1	**B2 Hole 2**	**B2 Hole 3**
 F_D=0.33626	 FD=0.3807	 FD =0.30864
B2 Hole 4	**B2 Hole 5**	
 FD =0.23908	 FD =0.28794	

B3 Hole 1	**B3 Hole 2**	**B3 Hole 3**
 F_D=0.76158	 FD=0.51972	 FD =0.40936
B3 Hole 4	**B3 Hole 5**	
 FD =0.29586	 FD =0.14386	

C1 Hole 1	**C1 Hole 2**	**C1 Hole 3**
		
F_D=0.16118	FD=0.22372	FD =0.35398
C1 Hole 4	**C1 Hole 5**	
		
FD =0.42698	FD =0.52828	

C2 Hole 1	**C2 Hole 2**	**C2 Hole 3**
		
F_D=0.30812	FD=0.71124	FD =0.20696
C2 Hole 4	**C2 Hole 5**	
		
FD =0.31186	FD =0.42184	

C3 Hole 1	C3 Hole 2	C3 Hole 3
 F_D=0.47496	 FD=0.37532	 FD =0.45844
C3 Hole 4	**C3 Hole 5**	
 FD =0.36114	 FD =0.72622	

Tables 12 – 20 : Images of drilled holes from 3D Non Contact Measuring System

Tables 12 – 20 show the drilled holes images captured by the Mitutoyo 3D Non Contact Measuring Device. 5 holes with the same spindle speed (rpm) and feed rate (mm/rev) were drilled. Based on the results obtained, the damage factor vs spindle speed (rpm) and feed rate (mm/rev) graphs were plotted.

The results obtained for the holes drilled with the same parameters may seem contradictory to one another. The damage factor, Fd values obtained were not precise and constant. There is no delamination identified in any of the drilled holes at the surface, and thus no delamination diameter was obtained to be used to calculate the damage factor, Fd. Instead, the damage factor, Fd was calculated using the splintering diameter of the splinters and uncut fibers occurring at the surface of all the drilled holes. This may be due to the shape and structure of the composite that affects the distribution of stress and the thrust force applied whilst drilling may differ to the drilling of composite plates. The thrust force also increases as the spindle speed increases.

However, the thrust force and torque could not be analyzed due to the unavailability of appropriate equipment which is the dynamometer.

The composite were observed to have higher higher damage factor (Fd) as the feed rate increases. These results were in agreement with Caprino and Tagliaferi who assumed that the damage occurred at higher drilling feed was due to the impact phenomena of the drilling process. Damage factor (Fd) of GFRP composite was observed to increase with increasing cutting speed from 1000 rpm to 2000 rpm. This was in agreement with Davim et. al. results when they drilled a 15 mm GFRP composite comprising of 65% FVF. Although they are using higher cutting speed and higher thickness of GFRP, but almost similar pattern of damage factor (Fd) pattern was observed with the current study.

Poor cutting action is also one of the reason of such results occurring. Higher cutting speeds increase the risk of thermal damage as it causes the softening of the matrix material. This will lead to a loss of mechanical strength of the uncut plies of the laminate. From the results obtained, it can be seen through the 3D Non Contact Measuring System that the hole with the best quality is in sample A3 with a damage factor of 0.96346 and minimized splintering problem. This hole was drilled with the lowest feed rate (mm/rev) and highest spindle speed (rpm) of the study which are 0.05 mm/rev and 3000 rpm respectively.

No delamination can be found in any holes by using the equipment. This was not expected as delamination is a common mode of failure for composite materials. This may be owing to the high stiffness of the composite half cylinder compared to the common composite plates. Tool geometry may also be the reason of such results obtained. It is a relevant aspect to be considered in drilling of fiber-reinforced composites, particularly when the quality of the machined hole is critical. The point angle of the drill bit which is 118^o is low enough in preventing delamination to occur. However, this angle may not be suitable to drill composite half cylinder and leads to critical splintering problems.

No backside support on surface also causes this splintering problem. To aid in maintaining hole integrity, a backing material is sometimes needed. This material is typically a fine filament fiberglass fabric that is added to the laminate as either a localized patch or a complete layer. Its purpose is to support the outer plies of the laminate and not to splinter significantly when the drill enters or exits. In this study it is found that sample A3 has the lowest splintering problem which has the combination of the highest rpm with the lowest feed rate. This shows that these operating parameters are important for creating a splinter free dimensionally correct hole; namely, a high rpm and a low feed rate. The correct combination allows the drill enough time to grind the composite away without causing splintering. Even with high rotational speeds, small diameter abrasive tools cannot achieve the high surface velocities recommended for composites. Therefore, the feed rate is kept low to permit complete grinding. If either of these two parameters are off, the splintering that occurs upon backside exit cannot be completely removed and the hole remains splintered.

This problem may also occur due to the poor surface finish of the composite. The silicon lubricant and mold removal wax used help in a smooth surface finish, however only the inside part of the half cylinder were exposed to these aforementioned substance. This is because of the shape of the half cylinder itself.

These findings indicate that the optimum cutting parameters for composite half cylinder and laminate plates are different. The use of CNC machine, enabling variable feed rate strategy os a good option to consider when drilling composites. The results obtained were much different as anticipated as there was no delamination problem to be analyzed.

4.7 AVERAGE SURFACE ROUGHNESS (Ra)

Each hole in the samples were cut into two halves using an abrasive cutter and the internal average surface roughness of the drilled hole walls were measured using the Mitutoyo Surface Roughness Tester. The hole halves were labeled A and B for each side of the hole. The surface roughness of the holes were measured at the middle of the laminate thickness. However, for holes with uncut fibers occurring on the internal surface, the measurements were taken as near as possible to the middle or center line.

The values in the tables below are the Average Surface Roughness (Ra) taken in average of the 5 holes that were drilled with the same drilling parameters. Internal average surface roughness Ra of both sides of the halves which is Side A and Side B were measured and the results are as follow:

Side A

Table 21 : Surface Roughness of Side A

Sample	Speed (RPM)	Feed Rate (mm/rev)	Ra (5 samples average)
A1	1000	0.05	3.6592
B1	1000	0.1	4.4346
C1	1000	0.2	5.1664
A2	2000	0.05	1.9892
B2	2000	0.1	2.453
C2	2000	0.2	4.0646
A3	3000	0.05	1.4816
B3	3000	0.1	2.198
C3	3000	0.2	3.1368

Side B

Table 22 : Surface Roughness of Side B

Sample	Speed (RPM)	Feed Rate (mm/rev)	Ra (5 samples average)
A1	1000	0.05	3.735
B1	1000	0.1	4.5252
C1	1000	0.2	5.2602
A2	2000	0.05	2.079
B2	2000	0.1	3.1074
C2	2000	0.2	3.4462
A3	3000	0.05	1.905
B3	3000	0.1	2.896
C3	3000	0.2	3.9798

Result and graph of Average Surface Roughness obtained from the Mitutoyo Surface Roughness Tester SV3000. Displayed below is one of the results obtained which is the Average Surface Roughness (Ra) for Hole 2 of sample A3 (3000 rpm, 0.05 mm/rev). This hole displayed the best Ra obtained which is 1.343 (µm)

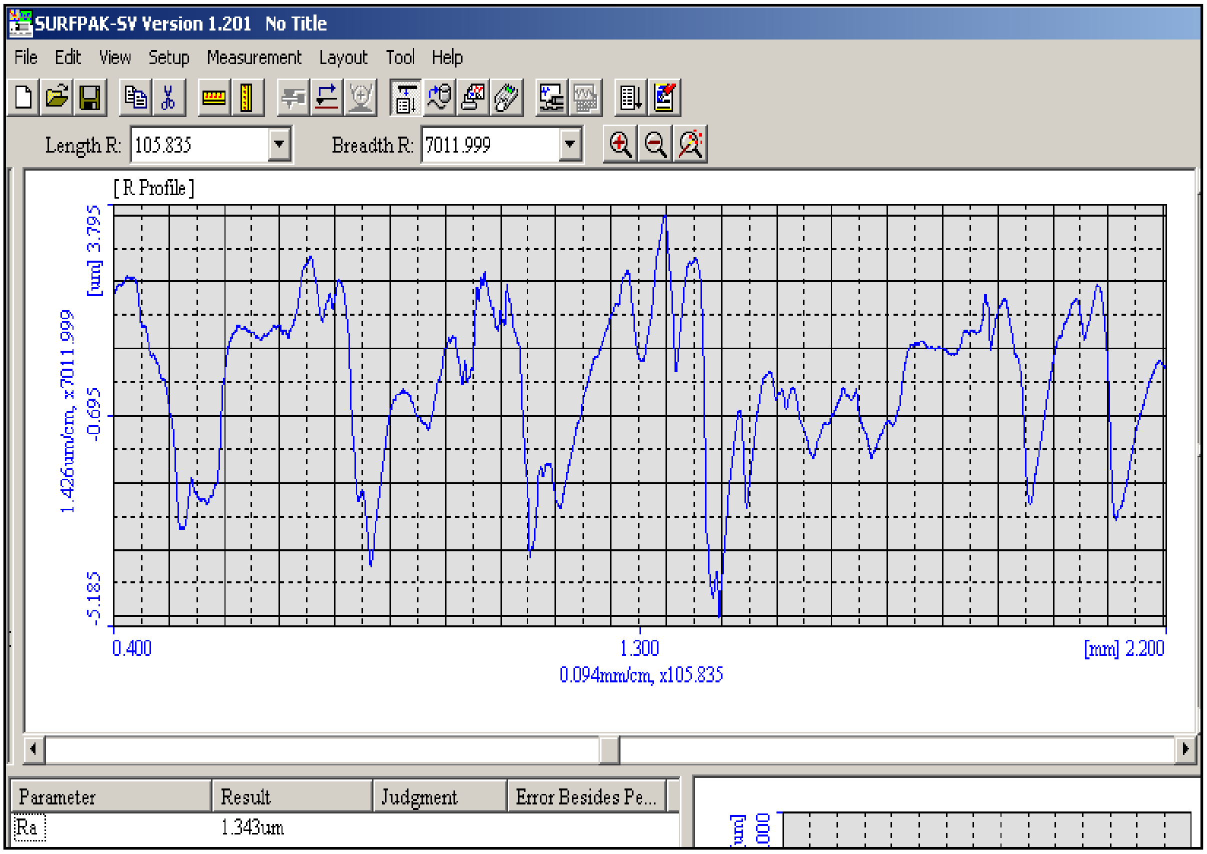


Figure 31: Ra of Sample A3 (Hole 2) with (3000 rpm, 0.05 mm/rev) obtained from Mitutoyo Surface Roughness Tester SV3000

4.7.1 Effect of feed rate on Ra at 1000, 2000, and 3000 rpm

Side A

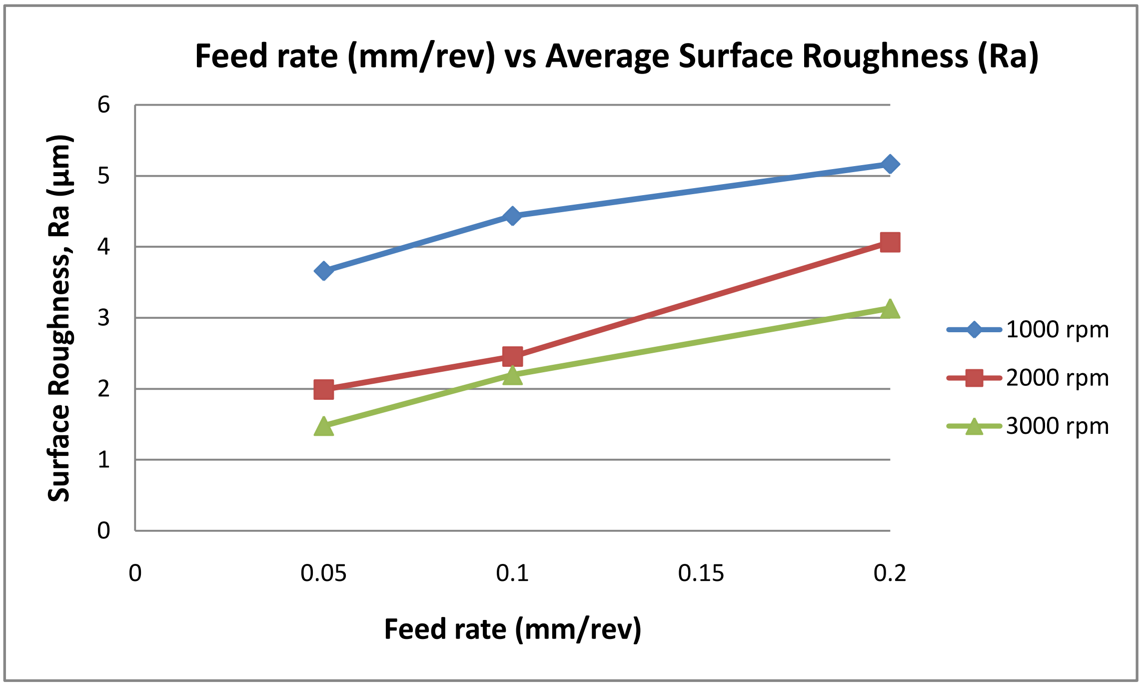


Figure 32: Effect of Feed Rate on Ra at 1000, 2000, and 3000 rpm for Side A of holes

Side B

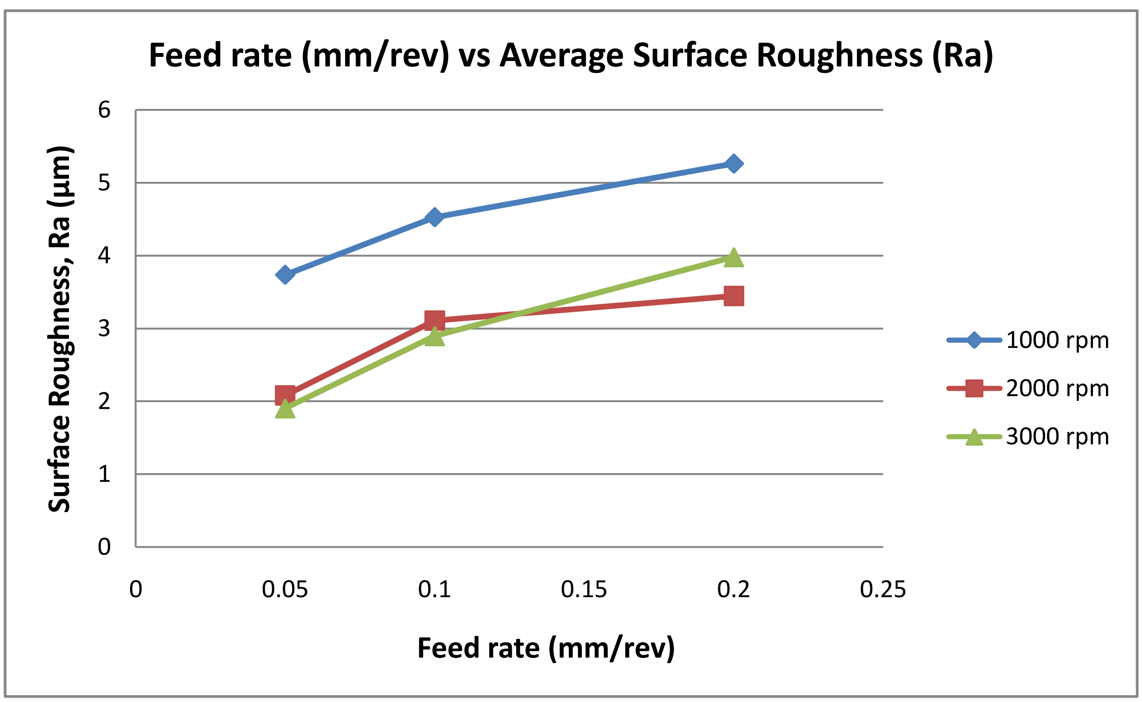


Figure 33: Effect of Feed Rate on Ra at 1000, 2000, and 3000 rpm for Side B of holes

4.7.2 Effect of spindle speed on Ra at 0.05, 0.1 and 0.2 mm/rev

Side A

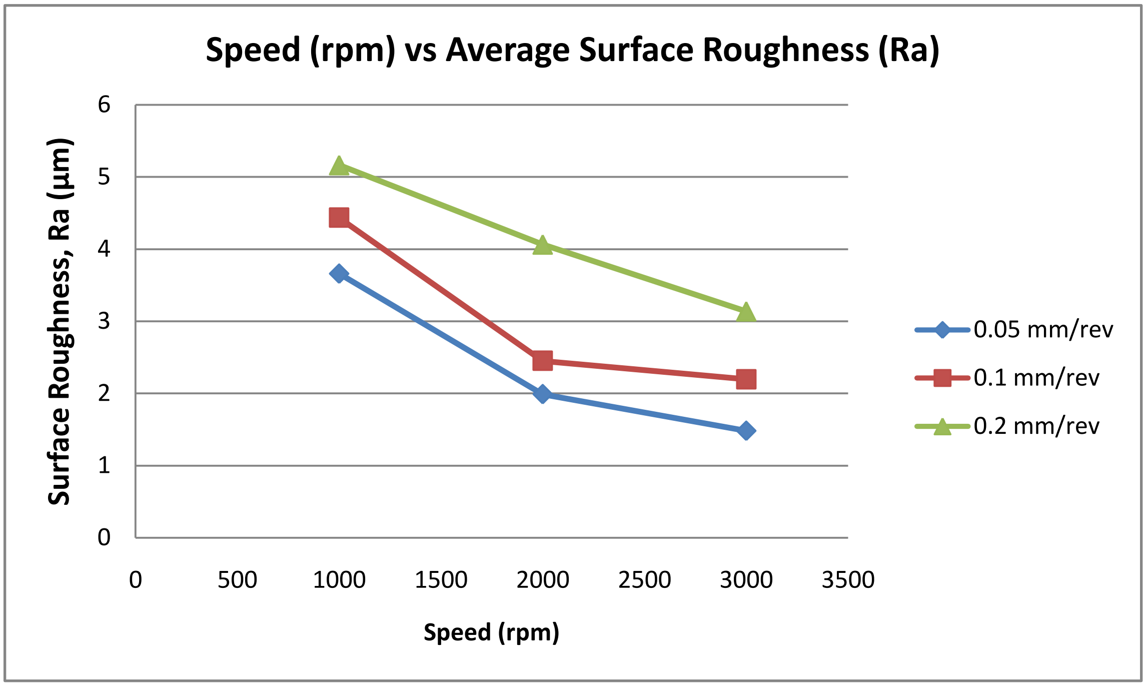


Figure 34: Effect of Spindle Speed on Ra at 0.05, 0.1 and 0.2 mm/rev for Side A of holes.

Side B

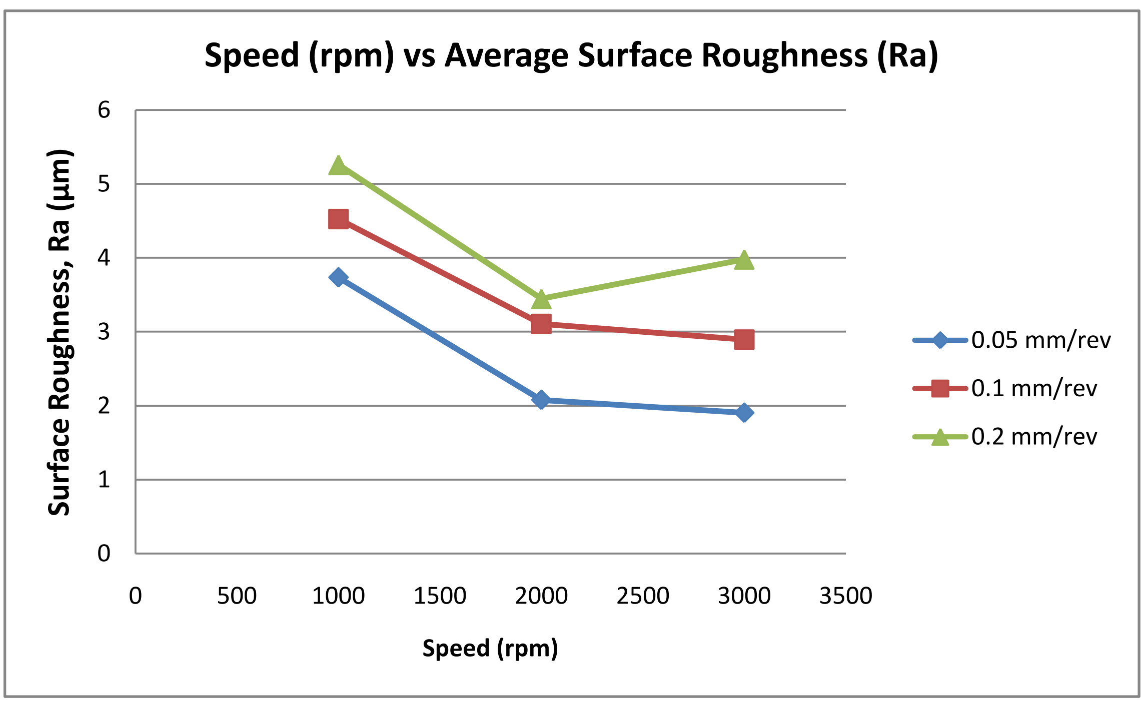


Figure 35: Effect of Spindle Speed on Ra at 0.05, 0.1 and 0.2 mm/rev for Side B of holes.

Both surface roughness measured for Side A and Side B of the same holes show that the surface roughness of the holes drilled at 0.2mm/rev is higher compared to 0.05mm/rev. This shows that as the feed rate increases, the surface roughness, Ra increases. It is due to the drill tends to pull out the fiber instead of shearing or breaking them. The results were in agreement with Ramulu et.al [14] when they drilled Gr/Bi composites using carbide drill at 0.25mm/rev feed rate and 660 rpm cutting speed. Drilling the 4mm thick hybrid fiber composites half cylinders using 0.05mm/rev feed rate showed that the surface roughness decreases as the cutting speed increases from 1000rpm to 300rpm.

The best results of Average Surface Roughness obtained is Hole 2 of sample A3 (3000 rpm, 0.05 mm/rev) with Ra of 1.343 (μm**).** This is also the same case for the speed increment of 1000rpm, 2000rpm, and 3000rpm drilled with 0.1mm/rev and 0.2mm/rev feed rates. This result agree with Davim et.al [18]. They found that the surface roughness increased as the feed rate increased and decreased as the cutting speed increased. Davim et.al drilled the glass fiber composites at higher cutting speed (from 3500 rpm to 4500 rpm). In this study, higher feed rate led to higher thrust force when drilling hybrid fiber composites of thickness 4mm. However, there is one slight change in the trend when the composite when drilled at 0.2mm/rev from 2000rpm to 3000rpm at side B. When the speed is increased with the same feed rate, the surface roughness is observed to increase. This may be due to uncut fibers on the surface that cause the roughness.

4.8 MICROSTRUCTURAL ANALYSIS

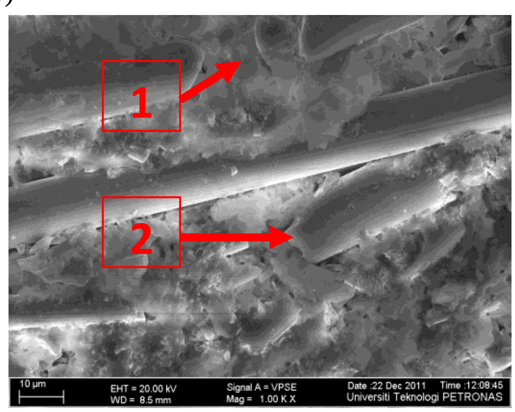
A more detailed study of the surface finish was also carried out with the aid of a Field Emission Scanning Electron Mircoscope (FESEM). In order to examine the microstructure of the drilled holes wall, the drilled hole was cut into two halves using abrasive cutter and examined under a field electron scanning electron microscope (FESEM). The surface of the holes were examined under the FESEM for analyzing the delamination, fiber pull-out and matrix cracking at the walls of drilled holes.

Due to limited use of the Field Electron Scanning Electron Microscope (FESEM), only four samples were able to undergo microstructural analysis. The four selected samples include samples drilled with medium speed and medium feed rate, highest feed rate and lowest speed, highest feed rate and highest speed and also lowest feed rate and lowest speed. The highest, medium, and lowest cutting parameters mentioned are in this scop of study. The figures below show the results:

(a)

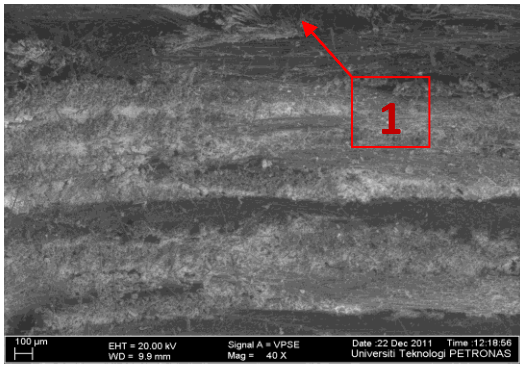
Sample A1 (1000 rpm, 0.05 mm/rev).
Magnification : 100x

(b)



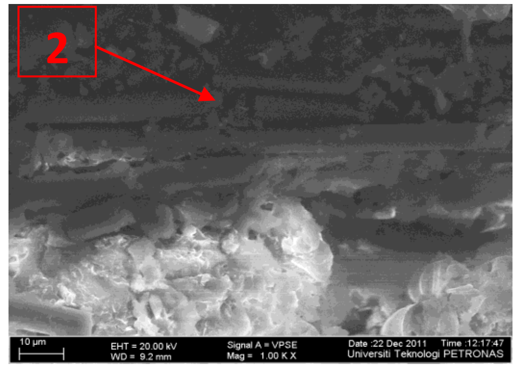
Sample A1 (1000 rpm, 0.05 mm/rev).
Magnification : 1000x

(c)



Sample B2 (2000 rpm, 0.1 mm/rev).
Magnification : 1040x

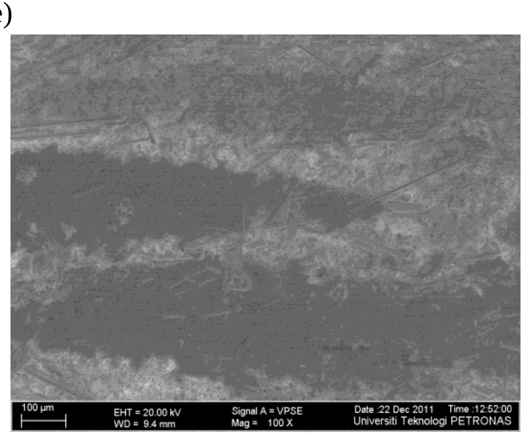
(d)



Sample B2 (2000 rpm, 0.1 mm/rev).
Magnification : 1000x

Figure 36 (a) and (b) show the FESEM images of Sample A1 with speed of 1000 rpm and feed rate of 0.05 mm/rev and magnification of 100x for figure 36 (a) and 1000x for figure36 (b). Figure 36 (c) and (d) show the FESEM images of Sample B2 with speed of 2000 rpm and feed rate of 0.1 mm/rev and magnification of 100x for figure 36 (c) and 1000x for figure 36 (d).

(e)

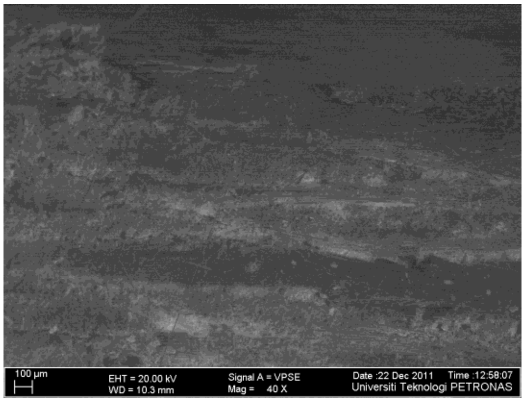


Sample C1 (1000 rpm, 0.2 mm/rev).
Magnification : 100x

(f)

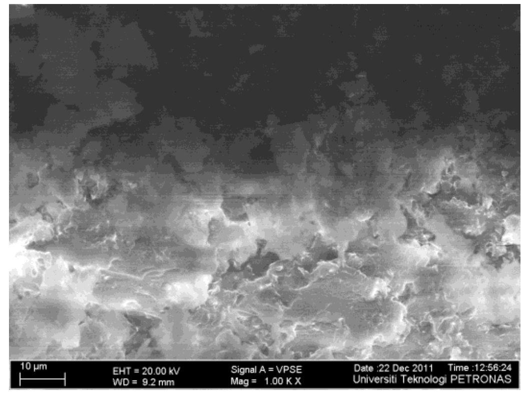
Sample C1 (1000 rpm, 0.2 mm/rev).
Magnification : 1000x

(g)



Sample C3 (3000 rpm, 0.2 mm/rev). Magnification : 100x

(h)



Sample C3 (3000 rpm, 0.2 mm/rev). Magnification : 1000x

Figure 36 (e) and (f) show the FESEM images of Sample C1 with speed of 1000 rpm and feed rate of 0.2 mm/rev and magnification of 100x for figure 36 (e) and 1000x for figure 36 (f). Figure 36 (g) and (h) show the FESEM images of Sample C3 with speed of 3000 rpm and feed rate of 0.2 mm/rev and magnification of 100x for figure 36 (g) and 1000x for figure 36 (h).

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.

Micrograph images that were observed under the SEM, showed several types of microstructural defects as a result of the drilling operation. Failure mechanisms that could be identified include matrix cracking, fiber fracture, fiber-matrix debonding, delamination, and fiber pullout. Figures 36 (a) and (b) of sample A1 show the occurrence of microstructure defect at the wall of the holes of the hybrid fiber composite where separation of the fiber from the matrix can be seen.

This is known as fiber-matrix debonding. In some cases, cracks can run through or around the fiber. Fiber pullout could also be observed due to weak interface between fiber and matrix. This happens when parts of a fractured composite separate. The fibers which have debonded can fracture remote from the principal fracture plane. The energy is absorbed by frictional forces as the fiber is pulled from the opposite face. Debonding and pullout absorbs high energies and results in a tough material

Meanwhile, fiber-matrix debonding which occurred due to weakness in their interface is observed in Figure 36 (d). As shown in Figure 36 (c) fiber push out delamination was observed on the inside wall (upper part) of the drilled holes of sample B2 composite. Delamination is the failure mode in which cracks propagate between the layers (lamina) of the composite. In this study no delamination could be identified both at the surfaces of the entry and exit drilled holes. However, delamination in layers is indentified and it usually happens through separation of the layers. Delamination may be avoided using Z-pinning and 3-D reinforcement (often woven and stitched) which is applied in this study.

As shown in Figures 36 (e) and (f), the composite displayed 2 microstructural defects when observed under the FESEM, they were, debris and fiber pull out. As for figure 36 (g) and (h), no known damage could be identified. In this study, 4 types of damage observed on hybrid fiber composites were fiber pull out, delamination, and fiber matrix debonding. One of the main as pect to be focused on in avoiding failure is laminate staking sequence.

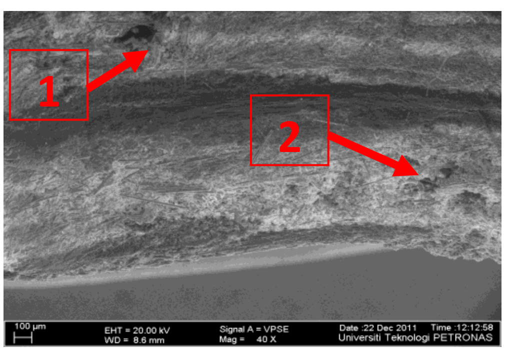


Figure 37: One the of the drilled hole walls with uncut fibers.

4.9 PROBLEMS FACED

The main problem currently faced by the author was the unavailability of the Scanning Electron Microscope (SEM) as it is down and has not been fixed to this date. Only one such equipment is available in the university and the author has found a solution to the problem by using equipment with a similar function which is the Field Emission Scanning Electron Microscope (FESEM). The other problem encountered and solved by the author was that the samples fabricated could not be used as they were stuck and glued to the mold. The first batch fabricated by the author was 6 samples and none of them could be used which results in a one week lag of project works. Prior to placing the fiber layers and matrix material on the mold, sufficient amounts of silicon lubricant and mold removal wax were used. However, the finished composites were stuck and glued to the mold. The author had to come up with a solution and managed to wrap the mold with a plastic wrap before applying the mold removal wax and the silicon lubricant. This method turned out to be a success in the next batch of fabrication where 4 out of 5 fabricated samples can be removed easily from the mold.

CHAPTER 5 : CONCLUSION

The methodologies and the techniques adopted to study the machinability aspects of the hybrid fiber composites are presented. The study reported here is limited to the domain of carbon-glass fiber reinforced epoxy matrix composites.

This study comprises five main stages which are composite structure design, fabrication and analysis of the drilled holes. The literature review is most essential in designing stage to ensure no major issue will occur during the subsequent stages of the designing process as the project integrates all the five stages. The author has mustered effort in closely following the Gantt chart and project activities planned initially in ensuring the project is feasible and a success.

The author has finished the entire project. The literature review for designing, machining and analysis are done based on journals and other reading materials from reliable sources. 11 hybrid fiber composite prototypes have been fabricated. From the study, in determining the properties of the desired hybrid fiber composite, fiber volume fraction plays an important part. The fabrication process is followed by the drilling process with specified drilling parameters for all 45 drilled holes. The author has done the measurement of the damage factor, FD using the Mitutoyo 3D Non Contact Measuring System, the measurement of the surface roughness, Ra and microstructural observation through the Field Emission Scanning Electron Microscope (FESEM).. The results obtained were different from the anticipated results which may occur due to the shape and structure of the composite half cylinder and poor cutting action. All the results and discussion can be reviewed in Chapter 4 of this report. There is more that could be done for the project given that the equipment needed is accessible. The thrust force associated with delamination is one of the important variables that could be analyzed. However, the equipment needed which is the dynamometer is not accessible.

The important analysis obtained from the study are:

1. No delamination obtained from 3D Non-Contact Measuring System caused by residual fibers occurring in the interior and exterior of the hole.

2. Splintering problem is caused by poor cutting action and the shape & structure of the composite.

3. To obtain Damage Factor, Fd the diameter of residual fibers in the holes were measured instead.

4. The Damage Factor, Fd values were not precise, not constant and may seem contradictory in holes with the same drilling parameters. The shape and structure of the composite affects the distribution of stress, torque and thrust force applied whilst drilling.

5. However, the thrust force and torque could not be analyzed due to the unavailability of appropriate equipment which is the Drill Tool Dynamometer.

6. The measured Average Surface Roughness Ra shows increment with increase in feed rate and decrease in spindle speed. Feed rate has more significant effect on the Ra.

7. In this study, there are 4 types of damage observed on hybrid fiber composites from microstructural analysis through the FESEM which are fiber pull out, delamination, and fiber matrix debonding.
8. These findings indicate that the optimum drilling parameters for composite half cylinders and composite laminate plates are different.

The recommendations below are the matters that should be focused on to further improve the project:

1. One of the main aspects to be focused on in avoiding failure is laminate staking sequence.
2. The composite may be fabricated with a base or backing plate to support the outer plies of the laminate and not to splinter significantly when the drill enters or exits.

3. The measurement of torque and thrust components of the drilling force associated with delamination are among the most important variables that could not be analyzed due to unavailability of equipment.

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