Effects of Drilling Induced Defects and Mechanical Properties of GFRE Composites

by

Khairul Ashraf Bin Minhat

Supervised by: AP Dr Faiz Ahmad

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)
May 2012

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Approved by,

……………..

AP Dr. Faiz Ahmad

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31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF ORIGINALITY

I declare that this research is the result of my own research except as cited in the references. The research report has not been accepted for any degree and is not currently submitted on candidature of any degree.

……………………………………..

(KHAIRUL ASHRAF BIN MINHAT)

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ABSTRACT

Glass fiber reinforced epoxy composites become highly demanded on the way to producing parts in various industry uses for example in aerospace and oil and gas fields. Drilling of fiber composites is one type of machining that mostly applied for assembly uses and it can be problematic especially at the drilled holes. Damages occurred at the drilled holes could lead to adverse impact on its functions. The condition of fiber composite which is in homogeneity of the materials per part is one main cause that makes drilling of fiber composite becoming troubles. In this study, GFRE composite was developed using wet hand lay-up technique with 40% fiber volume fraction of woven glass fiber. 9 samples were prepared with geometry from standard ASTM D3039 was referred and each sample was tested by different parameters. Parameters studied are narrowed to focus on the feed rate (0.05 mm/rev, 0.1 mm/rev, and 0.2 mm/rev) and spindle speed (1000, 2000 and 3000 rpm) of drilling process using 10 mm HSS drill bit for each cutting parameter on MTAB Denford CNC Milling Trainer XLMILL machine. Drilled samples were analyzed on its holes in term of damage factor using 3D Non-contact Measuring Machine where delamination of plies ratio with drill bit diameter around the drilled holes was measured. Tensile strength of drilled samples were also been obtained in this study by using Universal Testing Machine and 100 kN of load was applied to find the correlation between damage factor to the tensile strength of each samples. Best result for damage factor was obtained on sample F (0.1mm/rev, 3000 rpm) and it also showed highest tensile strength rather than others. From the results obtained, it can be related that increasing of damage factor will lead to minimal value of tensile strength.

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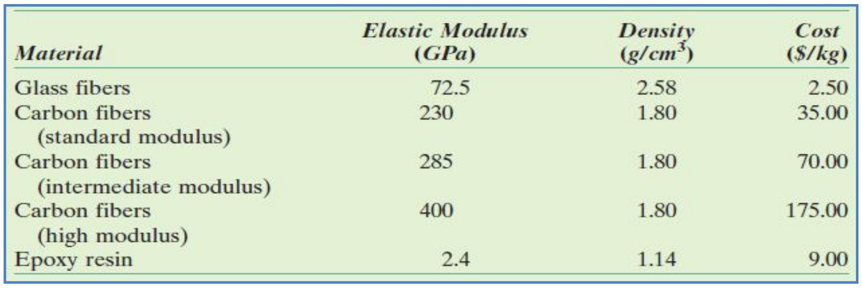
CHAPTER 1

INTRODUCTION

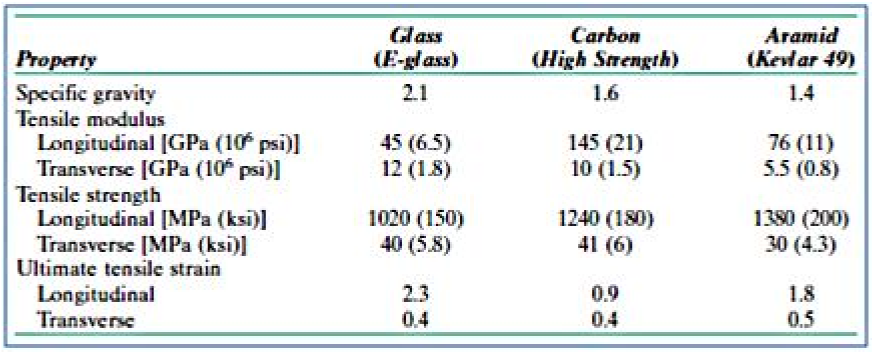
1.1 Background of study

In recent years, fiber reinforced composites have become an interesting type of material due to the uniqueness in its mechanical properties like low weight, high strength and stiffness [1]. Composite by its definition is a material composed of two or more different materials, with the properties of the resultant material being superior to the properties of the individual materials that make up the composites [1]. Composites are made from matrices of epoxy, unsaturated polyester, some other thermosets and few thermoplastics. Reinforcements for composites could be glass, graphite, aramid, thermoplastic fibers, metal and ceramics [3]. Those reinforcements can be continuous, woven or chopped fiber where it used to enhance the mechanical properties of the composites and it can be in continuous or discontinuous which specified by the fiber length. Short fiber (discontinuous) usually is not as effective as continuous fiber reinforcements in increasing creep strength, long term strength characteristics and distributing applied loads and strains through the entire structure [1]. Glass fiber reinforced plastic is an example of composite material used widely in various applications. Fiberglass is a lightweight, extremely strong, and robust material but strength properties and stiffness of glass fiber are somewhat lower than carbon fiber which is expensive [12].



Material	*Elastic Modulus (GPa)*	*Density (g/cm^3)*	*Cost (\$/kg)*
Glass fibers	72.5	2.58	2.50
Carbon fibers (standard modulus)	230	1.80	35.00
Carbon fibers (intermediate modulus)	285	1.80	70.00
Carbon fibers (high modulus)	400	1.80	175.00
Epoxy resin	2.4	1.14	9.00

Table 1.1: Elastic modulus, density and cost data comparison [17]



Property	*Glass (E-glass)*	*Carbon (High Strength)*	*Aramid (Kevlar 49)*
Specific gravity	2.1	1.6	1.4
Tensile modulus			
Longitudinal [GPa (10^6 psi)]	45 (6.5)	145 (21)	76 (11)
Transverse [GPa (10^6 psi)]	12 (1.8)	10 (1.5)	5.5 (0.8)
Tensile strength			
Longitudinal [MPa (ksi)]	1020 (150)	1240 (180)	1380 (200)
Transverse [MPa (ksi)]	40 (5.8)	41 (6)	30 (4.3)
Ultimate tensile strain			
Longitudinal	2.3	0.9	1.8
Transverse	0.4	0.4	0.5

Table1.2: Properties of aligned fibers reinforced epoxy in longitudinal and transverse direction (V_f = 0.60) [17]

1.2 Drilling process on composite

Machining for composite parts is needed for assembly and also in related to tolerance even the parts are produced near to net shape. Drilling is one of the machining process that important especially for assemble the parts and components. For example, in aerospace industry, there are many holes are made in composite parts for example at spoiler, fan cowl and fairings which will be functioned to apply screws, bolted joints and rivets. However, machining of composites could be problematic especially the results of drilling process. Usually, defects will occur at the entrance and exit of the holes where the factors can be due to its tendency to delaminate when subjected to mechanical stresses and also because of the combination of various materials per part. Surface delamination, fiber or resin pullout, fiber or matrix debonding, thermal degradation in micro cracking and inadequate surface roughness of the holes wall will regard to the quality of the machining parts. From the research, delamination is considered the major concerns of applying fiber reinforced composites materials in various industries [11]. Thus, it is shown that delamination will give a big impact on the performance of the composite. While according to Kishore, Tiwari, Dvivedi, and Singh, variation in the residual strength of the component with drilled holes will occur due to the damages around the drilled holes [6]. Drilling of fiber composite component is dependent on fiber properties of fiber reinforced than on the matrix material. In term of the force applied from the drill bit, size of delamination zone could be related to the thrust force developed during drilling process and it is believed that free damage will be obtained on critical thrust force. To find the parameter value of the critical thrust force, few researches relate the drill geometry and feed rate to the produced delamination or damage factor which leads to reduction in load carrying capacity of the composite part. Fiber orientation is the major influence of cutting properties of GFRE. Drilling induced defects occurs at the entrance and exit planes of the drilled GFRP. From various studies on drilling fiber reinforced plastics manufactured by hand lay-up technique, numbers of defects like delamination related with cutting parameters used. With different fiber volume fractions, comprehensive study of the influence of drilling parameters on the required cutting forces, torques and delamination has been presented. From the researches, delamination size decrease with decreasing of feed rate. Delamination is most affected by feed rate and lower feed rate will lead to better results. But, feed rate is most important in industry where it will affect to the time consumption used per composite part.

1.3 Problem statement

Drilling process of fiber composite by machining can be in defects situation due to its attribute that in-homogeneity, limited plastic deformation and abrasive. Delamination is the main type of damage that could happen and it will affect the performance of composite parts and structure developed from the fiber. With the diversion of fiber and matrix properties, various type of damages capable to occur. Parameters used in drilling process will affect to damages and lead to resulting mechanical properties of glass fiber reinforced epoxy. Thus, in this study, relationship of the damage factor of the drilled holes and tensile strength of drilled glass fiber reinforced plastic will be investigated

1.4 Objectives

The aim of this project is to examine the damage and mechanical properties of drilled fiber composite. Specifically, the objectives of the research are:

- To fabricate 4mm thickness of solid laminate glass fiber reinforced epoxy composite, with 40 % of fiber volume fraction.
- To determine and measure the damage factor of the drilled holes (ratio of original drill bit diameter and delamination diameter) with 3 different feed rates 0.05 mm/rev, 0.10 mm/rev and 0.20 mm/rev at 3 different spindle speeds at 1000 rpm, 2000 rpm and 3000 rpm.
- To determine in-plane tensile properties of drilled GFRE.
- To determine optimum drilling parameters for GFRE based on analysis of the results.

1.5 Scope of work

In this project, glass fiber will be the reinforcing material while epoxy will be the matrix of specimen preparation. Fiber volume fraction is important as it is the most significant factor in determining properties of fiber composites. Fabricating glass fiber composite by hand lay-up technique will be focused on for preparation of specimen. Relative proportion of the matrix and glass fiber can be given as the rule of mixture. After curing process, drilling operations will start referring to parameters of spindle speed and feed rate of drilling decided earlier. MTAB Denford CNC Milling Trainer XLMILL will be used in drilling process. Process of measuring using 3D non-contact measuring system will begin after complete drilling on the specimen of fiber composite to investigate damage factor of the drilled holes. Those specimens prepared for determining mechanical properties using universal testing machine. In this test, standard test method for tensile properties of polymer matrix composite materials will be used which is ASTM D3039.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Glass fiber reinforced plastic used widely in various areas of industries due to its abilities in physical and chemical properties. With a combination use of fibers and epoxies, make it in-homogeneity type of materials [1]. GFRE composites are common in construction where the main components are the matrix and the reinforcing glass, which cooperate to provide the special properties of the composite [14]. As the fields of application expand, machining of glass fiber composite is important in fabricating composite parts especially drilling process. Tagliaferri, Caprino and Diterlizzi (1989) mentioned that machining of composite materials requires a better understanding of cutting processes to achieve accuracy and efficiency [8]. For assembly of composite parts, mechanical joints require good surface quality holes for bolts and rivets. But then, few problems occurred due to machining process especially drilling.

2.2 Damages of drilled GFRE composite

From work of various authors, when reporting on drilling damage of composite materials, it is shown that damage factor and resulting mechanical properties at drilled areas are strongly dependent on cutting parameters, tool geometry and cutting forces. According to Chen (1997) he studied the variations of cutting forces with or without onset damage during the drilling operations and concluded that the damage-free drilling processes may be obtained by the proper selections of tool geometry and drilling parameters [9]. Hochenga and Tsao mentioned that twist drill is commonly used in the industry to produces holes rapidly and economically. Once the twist drill has a chisel edge, it utilizes the peripheral distribution of the thrust force of the drilling [4].

Besides that, Jain and Yang (1994) mentioned that the major damage is certainly the delamination that can occur both on the entrance and exit sides of the drilled work piece [10]. These machining defects cause a loss of the load carrying capacity of the laminate, which is undesirable [7]. According to Tagliaferri, he classified the damages of drilling composite into four categories which are delamination at drill entry, geometric defects, temperature-related damages and delamination at drill exit. Delamination is the serious problem because it causes loss in mechanical and fatigue strength. Koenig, Wulf, Grass and Willerscheid (1985) added that the size of the delamination zone has been shown to be related to the thrust force developed during the drill process and it is believed that there is a "critical thrust force" below which no damage occurs [11]. Besides that, according to Mohan, Kulkarni and Ramachandra (2006), critical force generated during delamination is influenced by feed rate, spindle speed, tool diameter and materials thickness [7].

2.3 Mechanical properties of drilled composite

In term of resulting mechanical properties, the damage generated during the drilling of GFRP laminates can be detrimental to the mechanical behavior of the product [15]. Furthermore, according to Singh and Bhatnagar investigation, it is concluded that there is a strong correlation between the drilling-induced damage with the tensile strength of the drilled specimen for all drill point geometries. They also find out that at low speed-low feed combination ratio, the damaged area shows a minimum, whereas the residual tensile strength is maximized at this condition [15]. From the review, it is clear that all the factors of drilling method need to be analyzed in order to obtain feasible mechanical properties results and can reducing damages on drilled fiber composite. Damage factor is one of the damage assessments that can be conducted to obtain the ratio of damage holes with the original diameter of hole.

Below is the finding from other author that conducted glass fiber reinforced epoxy [12].

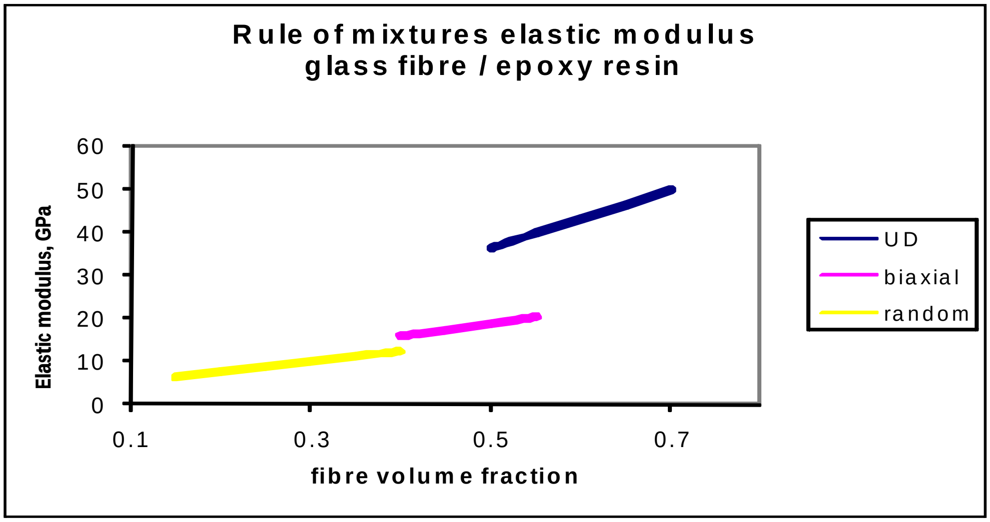


Figure 2.1: Rules of mixtures elastic modulus GFRE

2.4 Fiber Volume Fraction

In order to determine properties of a composite material, relative proportions of the matrix and reinforcing materials is importantly be referred from fiber volume fraction, V_f which is more significant and used significantly in theoretical analysis of composite materials. Rule of mixtures used to define V_f where it is the method to approximate estimation of the properties from assumption that volume weighed average of the phases properties. The expressions below used to determine weight fraction of the phases [16]:

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

Where V_f can be expressed as;

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

By rearranging equation (2),

$$W_m = \frac{\rho_m W_f - V_f \rho_m W_f}{\rho_f V_f}$$

CHAPTER 3

METHODOLOGY

3.1: Project flow chart

Figure 3.1 shows a project flow chart in this study.

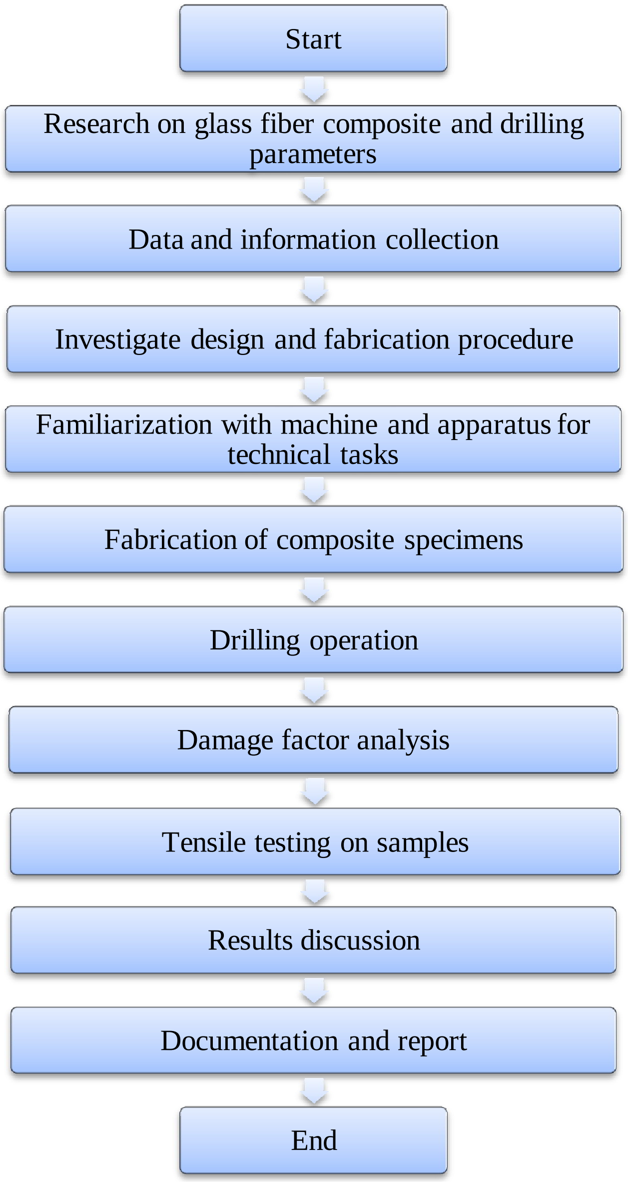


Figure 3.1: Project flow chart

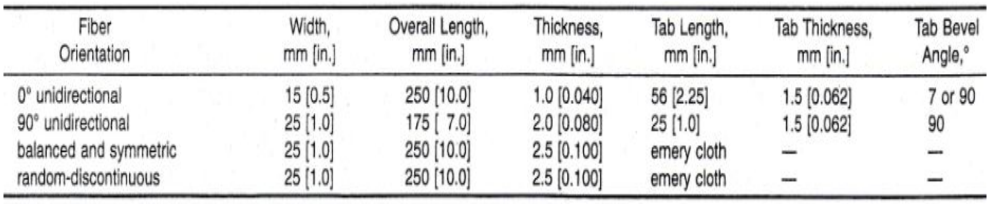
3.2 Fabricating laminates of GFRE

Preparation for fabricating solid laminate of GFRE composite samples consists of preparation of mould and raw materials which are woven glass fiber, epoxy resin and the hardener. Aluminum base plate is used to produce flat surface of specimens. It is polished using 3M scotch-brite to obtain clean and mirror look aluminum plate. For surface preparation, acetone was wiped on the plate to avoid from any contaminations. Wax was coated uniformly on the aluminum plate acted as mould release. During sample fabrication trials, silicone spray also had been used as replacement of wax. Fiber orientation of woven glass fiber is symmetrical with thickness of around 0.8 mm per layer. 5 woven glass fibers were cut using cutter with 300x300 mm where it will leave tolerance of 1.5 inches from tip of fiber to the edge of base plate when it was located on the center of the aluminum base plate. Masking tape is used to protect the end of glass fiber layer from separated with the woven fiber. In this study, 40% of woven glass fibers are used. Weight of matrix can be obtained using this data. Each layer was weighed to find total weight of fiber.

Layer	Fiber type	Fiber orientation	Area (cm^2)	Weight (g)
1	Glass woven	Balanced & symmetric	30x30.5 = 915	17.28
2	Glass woven	Balanced & symmetric	30.3x30 = 909	17.17
3	Glass woven	Balanced & symmetric	29.8x30 = 894	16.88
4	Glass woven	Balanced & symmetric	30x30 = 900	17.0
5	Glass woven	Balanced & symmetric	30x30.2 = 906	17.11
			Total fiber weight (g)	85.44

Table 3.1: Weight and area of each layer

Hand lay-up technique was conducted on the base plate where 5 layers of glass fiber will be used. Matrix thermosetting epoxy mixed with hardener using ratio (10:6) was rolled on the fiber by using roller and this process was repeated layer by layer. Second aluminum plate with mould release then was put onto the laid up fiber with epoxy acted as intensifier. Specimen was cured for 24 hours in a room temperature. Cured specimen then was checked by thickness and the result is around 4mm. Then, it was cut by following the geometry recommendations from ASTM D3039 which is 250 mm of length times 50 mm of width (250x50 mm). Shearing machine was used to obtain specimens.



Fiber Orientation	Width, mm [in.]	Overall Length, mm [in.]	Thickness, mm [in.]	Tab Length, mm [in.]	Tab Thickness, mm [in.]	Tab Bevel Angle,°
0° unidirectional	15 [0.5]	250 [10.0]	1.0 [0.040]	56 [2.25]	1.5 [0.062]	7 or 90
90° unidirectional	25 [1.0]	175 [7.0]	2.0 [0.080]	25 [1.0]	1.5 [0.062]	90
balanced and symmetric	25 [1.0]	250 [10.0]	2.5 [0.100]	emery cloth	—	—
random-discontinuous	25 [1.0]	250 [10.0]	2.5 [0.100]	emery cloth	—	—

Table 3.2: Tensile specimen geometry recommendations from ASTM D3039

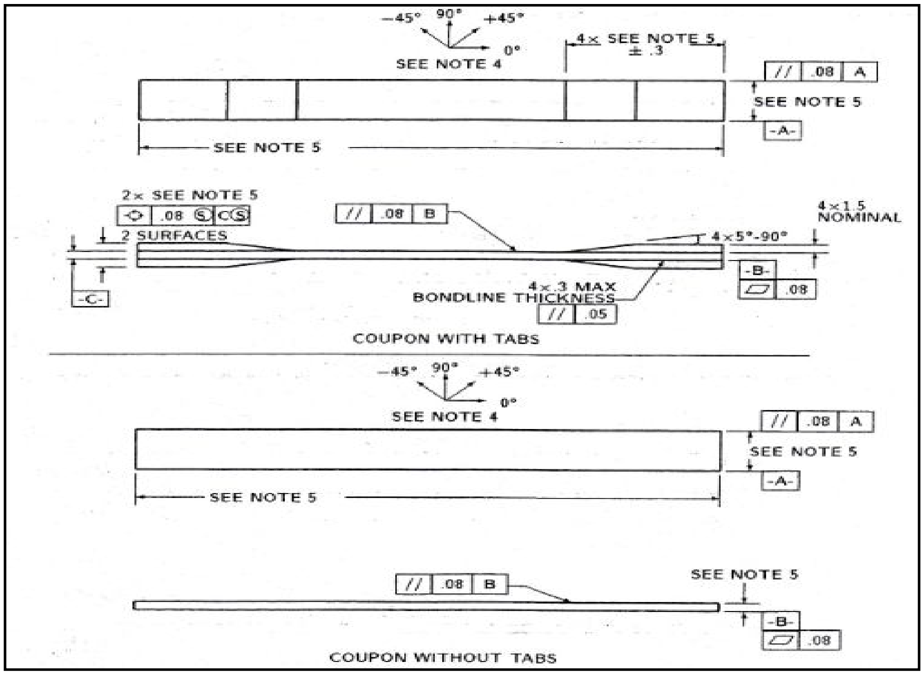


Figure 3.2: Tension test specimen drawing from ASTM D3039

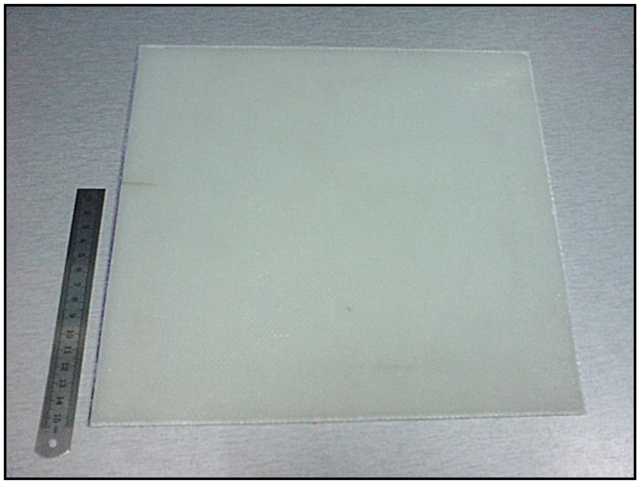


Figure 3.3: Fabricated GFRE composite sample (300x300 mm)

Figure 3.4: GFRE sample (250x50 mm)

3.3 Parameters of Drilling

CNC drilling method will be used as feed rate and spindle speed are controlled parameter. Drill bit used in this operation is stainless steel twist drill bit. 250x50x4 mm size of specimens are drilled at the center with feed rates used were **0.05 mm/rev, 0.1 mm/rev and 0.2 mm/rev. Spindle speed are 1000, 2000 and 3000 revolutions per minute (rpm).**

CNC machine name : MTAB Denford CNC Milling Trainer XLMILL

Drill bit type : Benz Werkz HSS Drill Bit, 10 mm diameter

Sample	A	B	C
Thickness, mm	4.0		
Feed Rate, mm/rev	0.05		
Spindle speed, rpm	1000	2000	3000

Table 3.3: Drilling parameters of samples (Feed rate, 0.05 mm/rev)

Sample	D	E	F
Thickness, mm	4.0		
Feed Rate, mm/rev	0.1		
Spindle speed, rpm	1000	2000	3000

Table 1.4: Drilling parameters of samples (Feed rate, 0.1 mm/rev)

Sample	G	H	I
Thickness, mm	4.0		
Feed Rate, mm/rev	0.2		
Spindle speed, rpm	1000	2000	3000

Table 3.5: Drilling parameters of samples (Feed rate, 0.2 mm/rev)

Figure 3.5: Drilling of GFRE samples

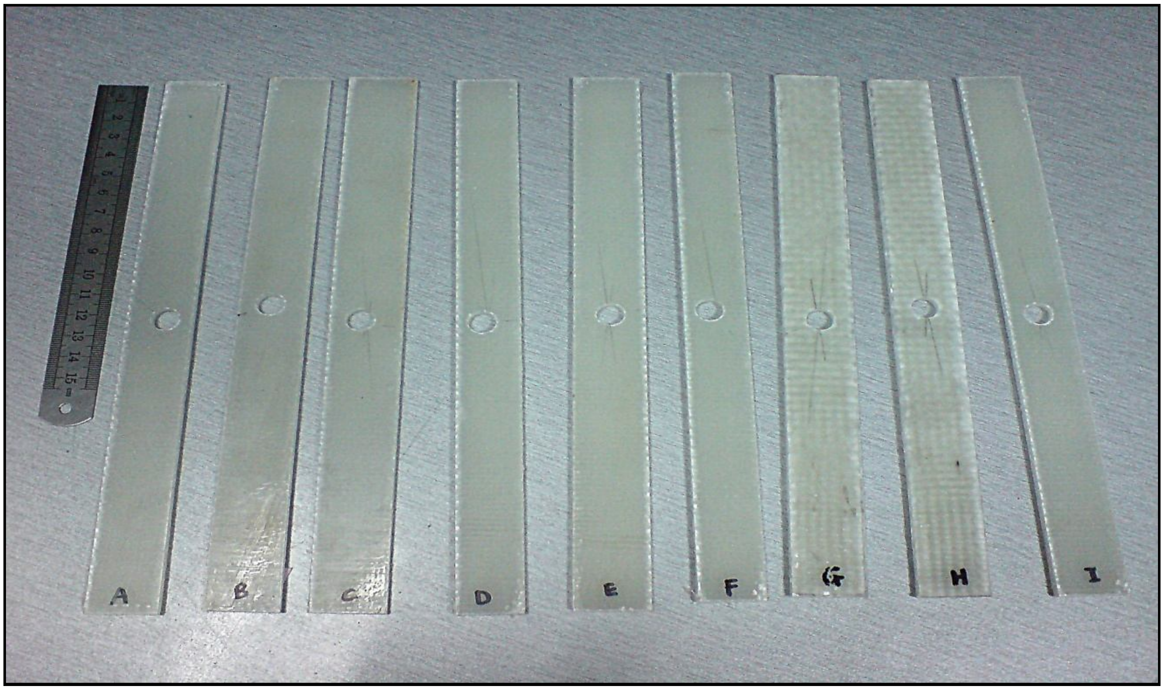


Figure 3.6: Drilled samples

3.4 Damage factor assessment

Damage factor is the consequence of delamination around drilled holes. 3D non contact measuring machine was used to get image of drilled holes and delamination length at the drilled hole. To determine damage factor, measurement method is used where ratio of delamination diameter, D_d over original drill bit diameter, D_o. Damage factor is obtained using this equation,

Damage Factor, $F_D = D_d / D_o$ ……………..(4)

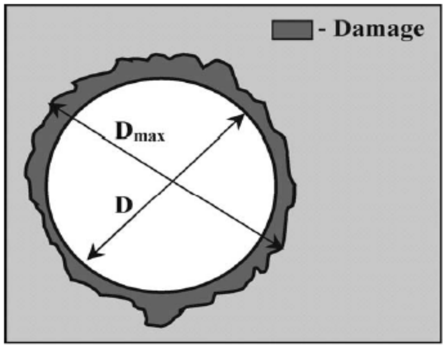


Figure 3.7: Illustration of damage around hole

3.5 Tensile test

After damage factor is determined, tensile test was conducted to determine in-plane tensile properties of glass fiber reinforced epoxy composite by using universal testing machine. Dimensions used for samples were following the standard **ASTM D3039**. Load indicator on the testing machine will indicate total load of 100 kN that being carried by the test specimen. One directional force at both ends is applied on the specimen. Gradually increase of load will results to increase deformation. When fracture occurred, the load will be recorded as ultimate tensile strength or simply tensile strength. Stress versus strain curve will be plotted and thus, data are obtained.

Figure 3.8: Universal Testing Machine

From the analysis and testing, graphs that can be obtained are:

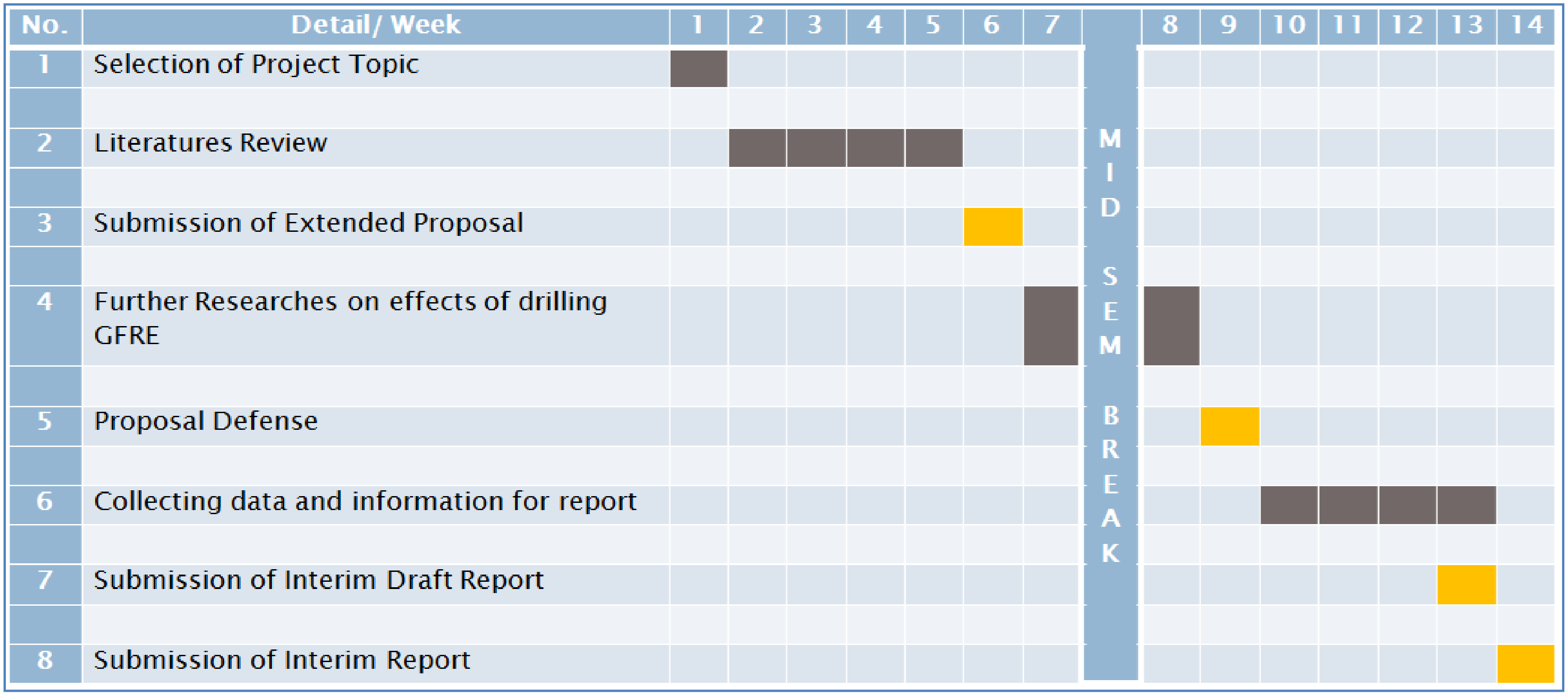
1) Feed rate vs Damage factor
2) Spindle speed vs Damage factor
3) Damage factor vs Tensile strength

Relationship of the parameters of drilling glass fiber reinforced epoxy composite with damage factor was analyzed to find out optimum parameters that meet the performance which is the strength of the composite. From the experiments, it is undeniable that the results could lead to few tolerances and not precise results especially during finding out the delamination diameter of the drilled holes. Thus, proper operating procedures were followed in order to get feasible results and to neglect any errors or accidents.

3.6 Gantt Charts

These tables below are the Gantt Chart for FYP 1 and 2.

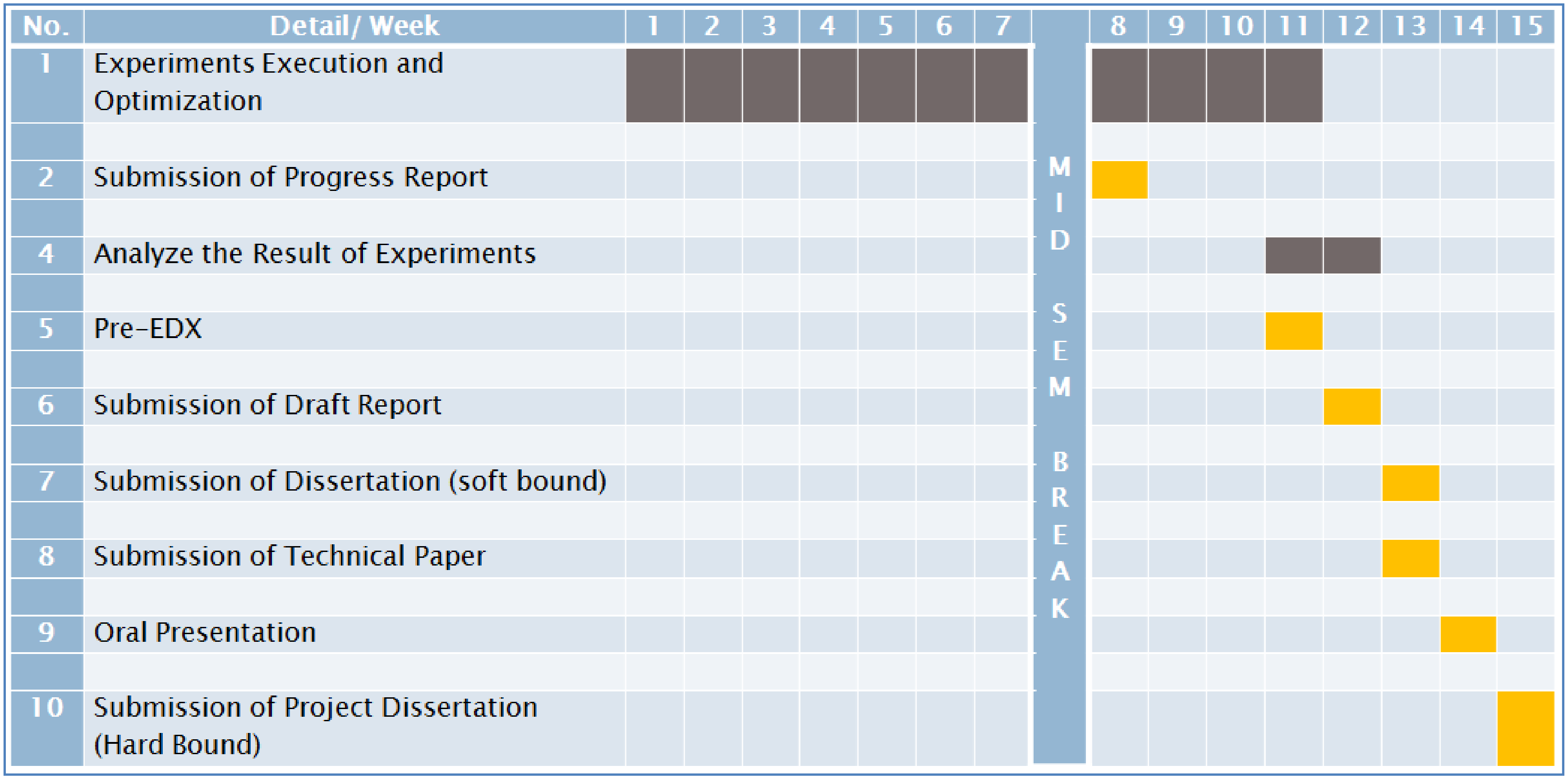
1. FYP 1



No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project Topic	■							MID SEM BREAK							
2	Literatures Review		■	■	■	■										
3	Submission of Extended Proposal						🟨									
4	Further Researches on effects of drilling GFRE							■		■						
5	Proposal Defense										🟨					
6	Collecting data and information for report											■	■	■	■	
7	Submission of Interim Draft Report														🟨	
8	Submission of Interim Report															🟨

Figure 3.9: Gantt Chart for FYP 1

2. FYP 2



No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
1	Experiments Execution and Optimization	■	■	■	■	■	■	■	MID SEM BREAK	■	■	■	■				
2	Submission of Progress Report									🟨							
4	Analyze the Result of Experiments												■	■			
5	Pre-EDX												🟨				
6	Submission of Draft Report													🟨			
7	Submission of Dissertation (soft bound)														🟨		
8	Submission of Technical Paper														🟨		
9	Oral Presentation															🟨	
10	Submission of Project Dissertation (Hard Bound)																🟨

Figure 3.10: Gantt Chart for FYP 2

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

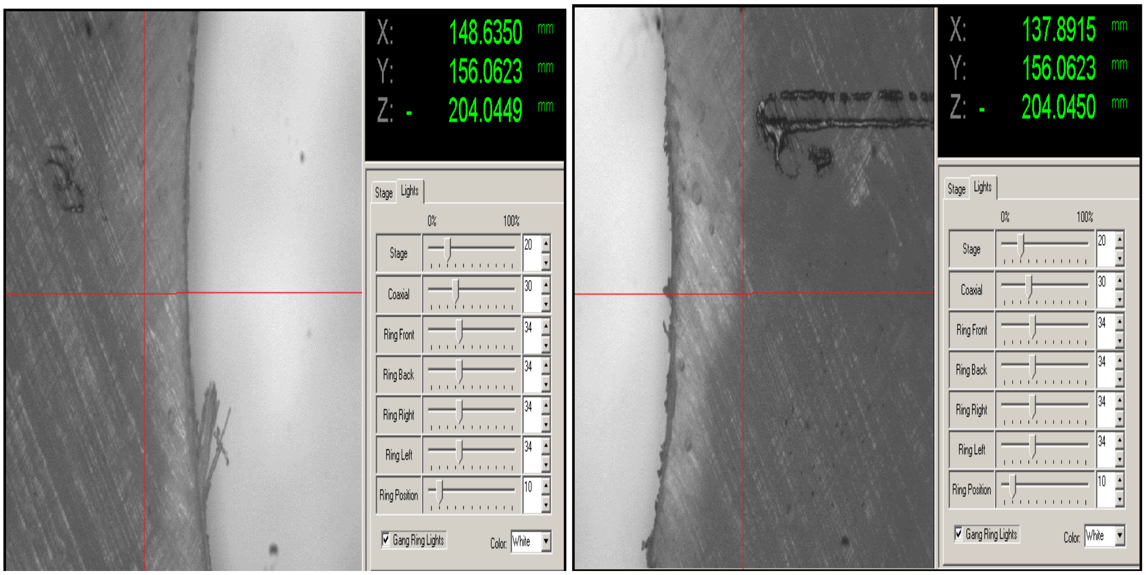
With increasing demand of drilling machining process, damages occurred brings the difficulties for achieving high hole quality. The quality of each drilled holes are the indicator here where damage factor from delamination is the hole assessment process. Delamination cannot be seen with naked eye and thus evaluation microscopically is needed in order to analyze the results.

4.2 Effect of drilling parameters on damage factor, F_d

Results obtained from 3D Non-contact Measuring System have shown delamination around drilled holes on samples. Nine samples were drilled with different sets of spindle speed (rpm) and feed rate (mm/rev). Each sample showed damage around drilled holes and thus damage factor was measured. Measuring process was conducted by selecting most delaminated part from around the circumference of drilled holes. Point was selected, dragged to the center of drilled hole and measuring process ended at the other perpendicular side for each sample. Axis Y and Z were not change to find out the difference length of axis X only.

From the results, it showed that damage factor increase with the increasing of feed rate for each cutting speed. From the category of 1000 rpm speed, damage factor increase when feed rate increasing while in term of feed rate, increasing speed showed different orientation of damage level. For example of 0.05 mm/rev feed rate, result showed a decreasing value for 2000 rpm but then the damage factor increase back when 3000 rpm test for 0.05 mm/rev feed rate. Below are the images of measuring damage factor for nine samples.

1. Sample A (1000 rpm, 0.05 mm/rev)



X: 148.6350 mm
Y: 156.0623 mm
Z: - 204.0449 mm

Stage 20
Coaxial 30
Ring Front 34
Ring Back 34
Ring Right 34
Ring Left 34
Ring Position 10
☑ Gang Ring Lights
Color: White

X: 137.8915 mm
Y: 156.0623 mm
Z: - 204.0450 mm

Stage 20
Coaxial 30
Ring Front 34
Ring Back 34
Ring Right 34
Ring Left 34
Ring Position 10
☑ Gang Ring Lights
Color: White

Figure 4.1: Images of sample A measured using 3D Non-contact Measuring System

Delamination diameter, D_d = 148.6350 – 137.8915

= 10.7435 mm

Damage factor, F_d = D_d / D_o

= 10.7435 / 10

= 1.04735

2. Sample B (2000 rpm, 0.05 mm/rev)

X: 158.6559 mm
Y: 150.8972 mm
Z: - 204.0449 mm

Stage 20
Coaxial 30
Ring Front 34
Ring Back 34
Ring Right 34
Ring Left 34
Ring Position 10
☑ Gang Ring Lights
Color: White

X: 147.6044 mm
Y: 150.8972 mm
Z: - 204.0449 mm

Stage 20
Coaxial 30
Ring Front 34
Ring Back 34
Ring Right 34
Ring Left 34
Ring Position 10
☑ Gang Ring Lights
Color: White

Figure 4.2: Images of sample B measured using 3D Non-contact Measuring System

Delamination diameter, D_d = 158.6559 – 147.6044

= 11.0515 mm

Damage factor, F_d = D_d / D_o

= 11.0515 / 10

= 1.10515

3. **Sample C (3000 rpm, 0.05 mm/rev)**

X: 144.8624 mm
Y: 156.1693 mm
Z: - 204.0449 mm

Stage 20
Coaxial 30
Ring Front 34
Ring Back 34
Ring Right 34
Ring Left 34
Ring Position 10
☑ Gang Ring Lights
Color: White

X: 134.2656 mm
Y: 156.1717 mm
Z: - 204.0449 mm

Stage 40
Coaxial 30
Ring Front 24
Ring Back 24
Ring Right 24
Ring Left 24
Ring Position 10
☑ Gang Ring Lights
Color: White

Figure 4.3: Images of sample C measured using 3D Non-contact Measuring System

Delamination diameter, D_d = 144.8624 - 134.2656

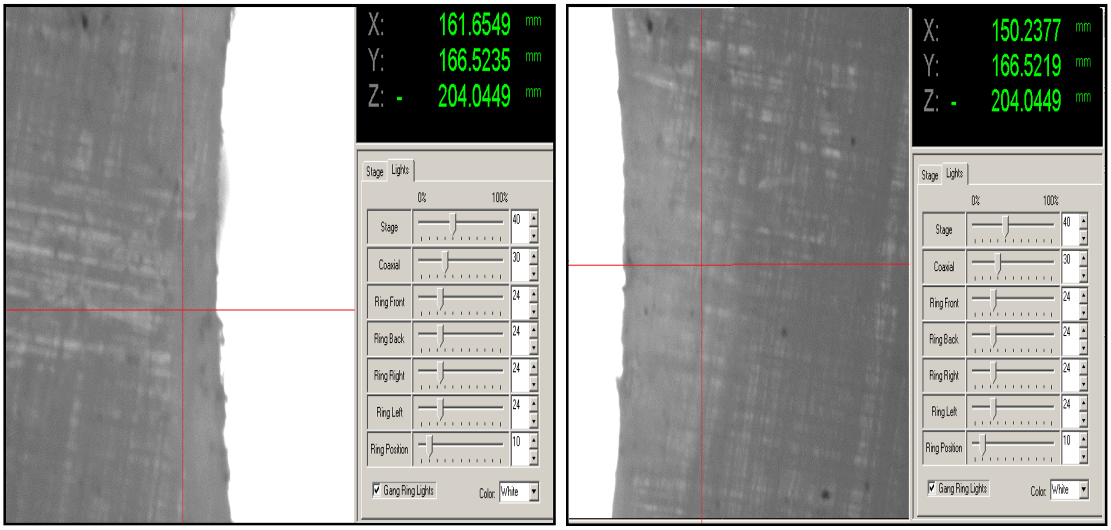
= 10.5968 mm

Damage factor, F_d = D_d / D_o

= 10.5968 / 10

= 1.05968

4. Sample D (1000 rpm, 0.1 mm/rev)



X: 161.6549 mm
Y: 166.5235 mm
Z: - 204.0449 mm

Stage 40
Coaxial 30
Ring Front 24
Ring Back 24
Ring Right 24
Ring Left 24
Ring Position 10
☑ Gang Ring Lights
Color: White

X: 150.2377 mm
Y: 166.5219 mm
Z: - 204.0449 mm

Stage 40
Coaxial 30
Ring Front 24
Ring Back 24
Ring Right 24
Ring Left 24
Ring Position 10
☑ Gang Ring Lights
Color: White

Figure 4.4: Images of sample D measured using 3D Non-contact Measuring System

Delamination diameter, D_d = 161.6549 – 150.2377

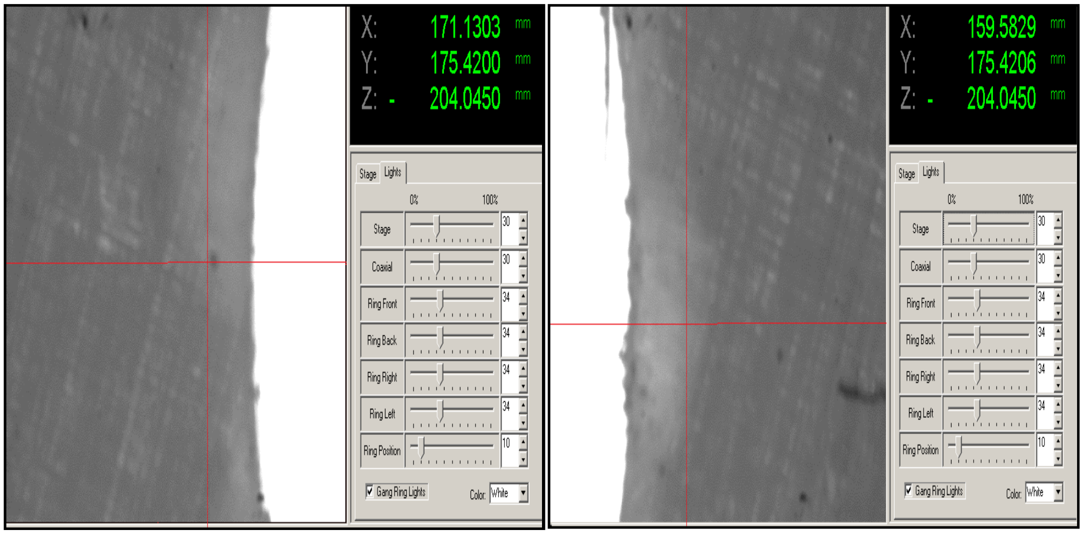
= 11.4172 mm

Damage factor, F_d = D_d / D_o

= 11.4172 / 10

= 1.14172

5. Sample E (2000 rpm, 0.1 mm/rev)



X: 171.1303 mm
Y: 175.4200 mm
Z: - 204.0450 mm

Stage 30
Coaxial 30
Ring Front 34
Ring Back 34
Ring Right 34
Ring Left 34
Ring Position 10
☑ Gang Ring Lights
Color: White

X: 159.5829 mm
Y: 175.4206 mm
Z: - 204.0450 mm

Stage 30
Coaxial 30
Ring Front 34
Ring Back 34
Ring Right 34
Ring Left 34
Ring Position 10
☑ Gang Ring Lights
Color: White

Figure 4.5: Images of sample E measured using 3D Non-contact Measuring System

Delamination diameter, D_d = 171.1303 – 159.5829

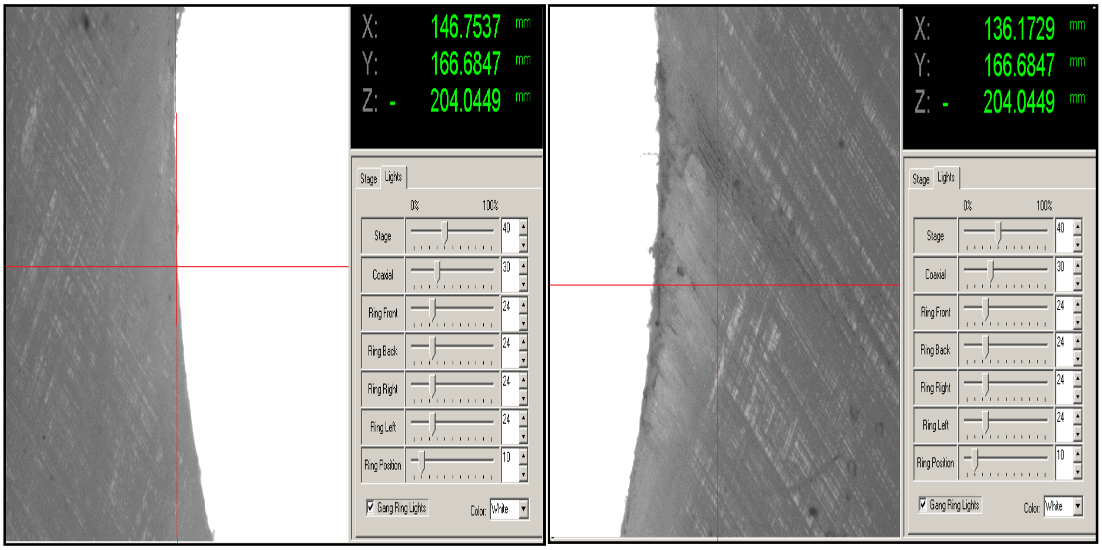
= 11.5474 mm

Damage factor, F_d = D_d / D_o

= 11.5474 / 10

= 1.15474

6. Sample F (3000 rpm, 0.1 mm/rev)


X: 146.7537 mm
Y: 166.6847 mm
Z: - 204.0449 mm

Stage 40
Coaxial 30
Ring Front 24
Ring Back 24
Ring Right 24
Ring Left 24
Ring Position 10
☑ Gang Ring Lights
Color: White

X: 136.1729 mm
Y: 166.6847 mm
Z: - 204.0449 mm

Stage 40
Coaxial 30
Ring Front 24
Ring Back 24
Ring Right 24
Ring Left 24
Ring Position 10
☑ Gang Ring Lights
Color: White

Figure 4.6: Images of sample F measured using 3D Non-contact Measuring System

Delamination diameter, D_d = 146.7537 – 136.1729

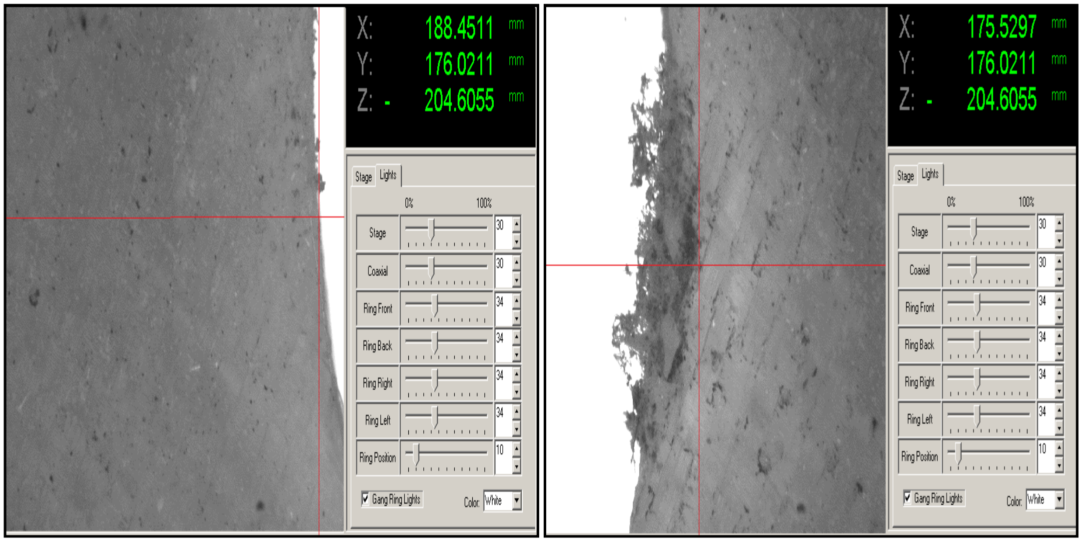
= 10.5808 mm

Damage factor, F_d = D_d / D_o

= 10.5808 / 10

= 1.05808

7. Sample G (1000 rpm, 0.2 mm/rev)


X: 188.4511 mm
Y: 176.0211 mm
Z: - 204.6055 mm

X: 175.5297 mm
Y: 176.0211 mm
Z: - 204.6055 mm

Stage 30
Coaxial 30
Ring Front 34
Ring Back 34
Ring Right 34
Ring Left 34
Ring Position 10
☑ Gang Ring Lights
Color: White

Figure 4.7: Images of sample G measured using 3D Non-contact Measuring System

Delamination diameter, D_d = 188.4511 – 175.5297

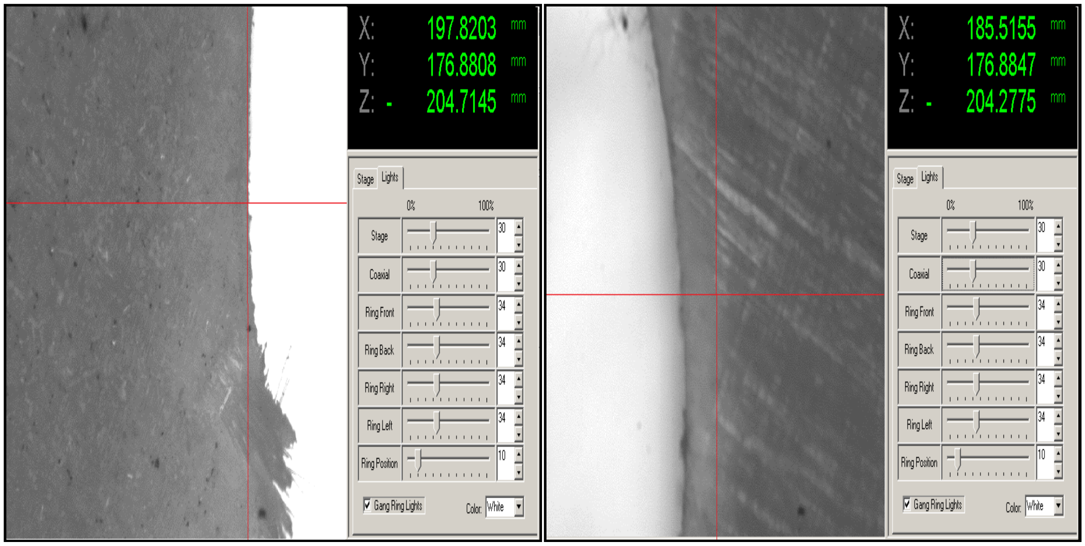
= 12.9214 mm

Damage factor, F_d = D_d / D_o

= 12.9214 / 10

= 1.29214

8. Sample H (2000 rpm, 0.2 mm/rev)


X: 197.8203 mm
Y: 176.8808 mm
Z: - 204.7145 mm

X: 185.5155 mm
Y: 176.8847 mm
Z: - 204.2775 mm

Stage 30
Coaxial 30
Ring Front 34
Ring Back 34
Ring Right 34
Ring Left 34
Ring Position 10
☑ Gang Ring Lights
Color: White

Figure 4.8: Images of sample H measured using 3D Non-contact Measuring System

Delamination diameter, D_d = 197.8203 – 185.5155

= 12.3048 mm

Damage factor, F_d = D_d / D_o

= 12.3048 / 10

= 1.23048

9. Sample I (3000 rpm, 0.2 mm/rev)

X: 217.6150 mm
Y: 175.7538 mm
Z: - 204.0932 mm

Stage 30
Coaxial 30
Ring Front 34
Ring Back 34
Ring Right 34
Ring Left 34
Ring Position 10
☑ Gang Ring Lights
Color: White

X: 205.3552 mm
Y: 175.7537 mm
Z: - 204.0931 mm

Stage 30
Coaxial 30
Ring Front 34
Ring Back 34
Ring Right 34
Ring Left 34
Ring Position 10
☑ Gang Ring Lights
Color: White

Figure 4.9: Images of sample I measured using 3D Non-contact Measuring System

Delamination diameter, D_d = 217.6150 – 205.3552

= 12.2598 mm

Damage factor, F_d = D_d / D_o

= 12.2598 / 10

= 1.22598

Damage factor value for each sample is mentioned in the table below.

	Feed Rate (mm/rev)		
Spindle speed (rpm)	0.05	0.1	0.2
1000	A (F_d = 1.07435)	D(F_d = 1.14172)	G(F_d = 1.29214)
2000	B (F_d = 1.10515)	E(F_d = 1.15474)	H(F_d = 1.23048)
3000	C(F_d = 1.05968)	F(F_d = 1.05808)	I(F_d = 1.22598)

Table 4.1: Damage factor

From the results, there are 2 graphs that show the relationship of damage factor with the feed rate and damage factor with spindle speed. There are 3 lines with different color in a graph to show the differentiation of parameters used.

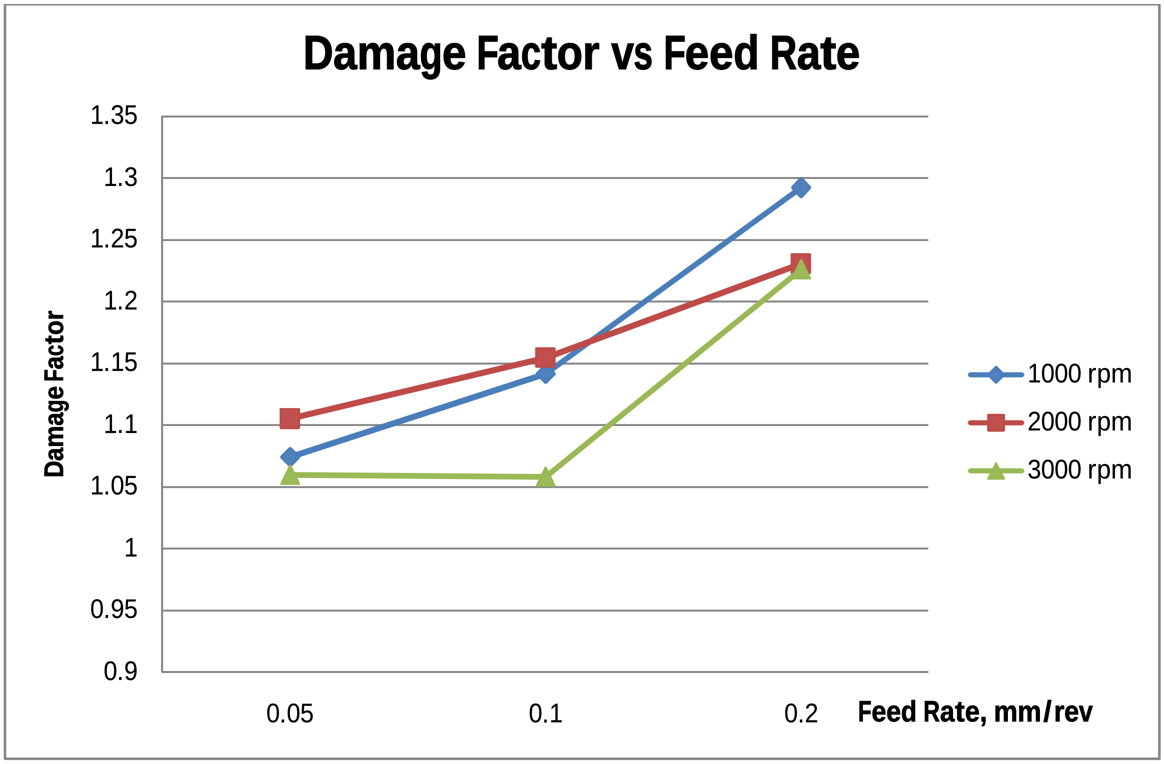


Figure 4.10: Effect of feed rate on damage factor

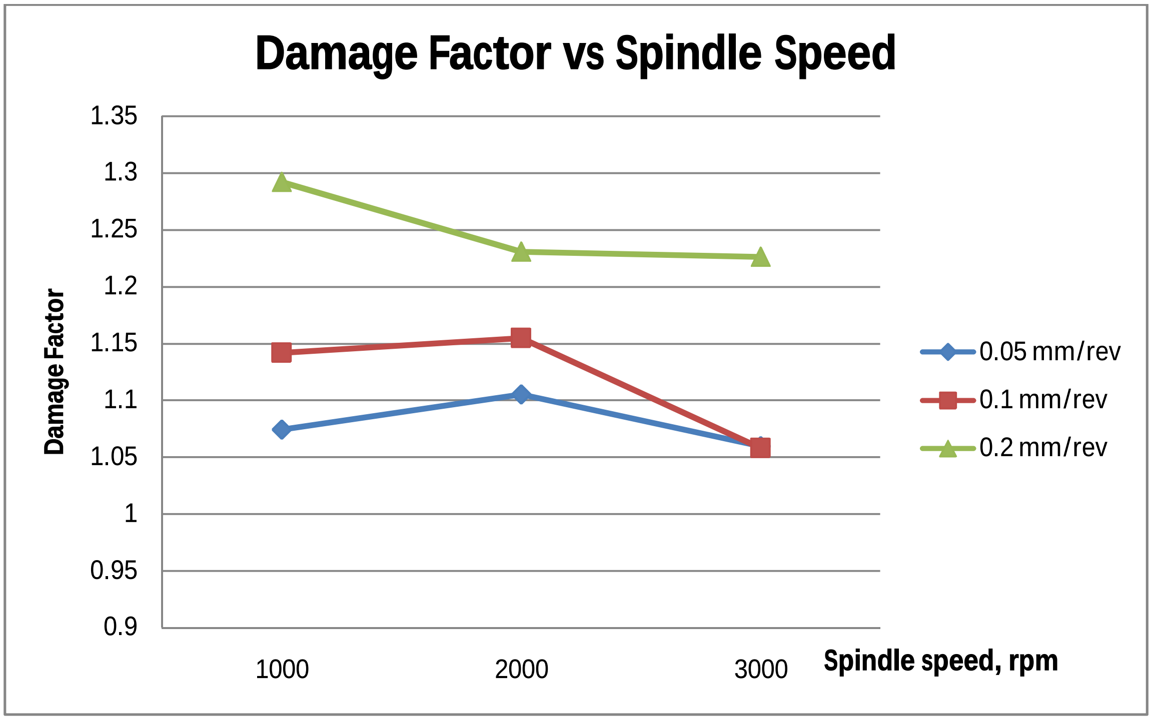


Figure 4.11: Effect of spindle speed on damage factor

In term of obtaining less damage factor, it can be observe from first graph where three samples that tested with different spindle speed on 0.05 mm/rev feed rate lead to low damage factor. Other than that, there is a significant with application of higher spindle speed with low feed rate lead to less damage factor was obtained for example in values pointed below at 3000 rpm, 0.05 mm/rev (sample C).

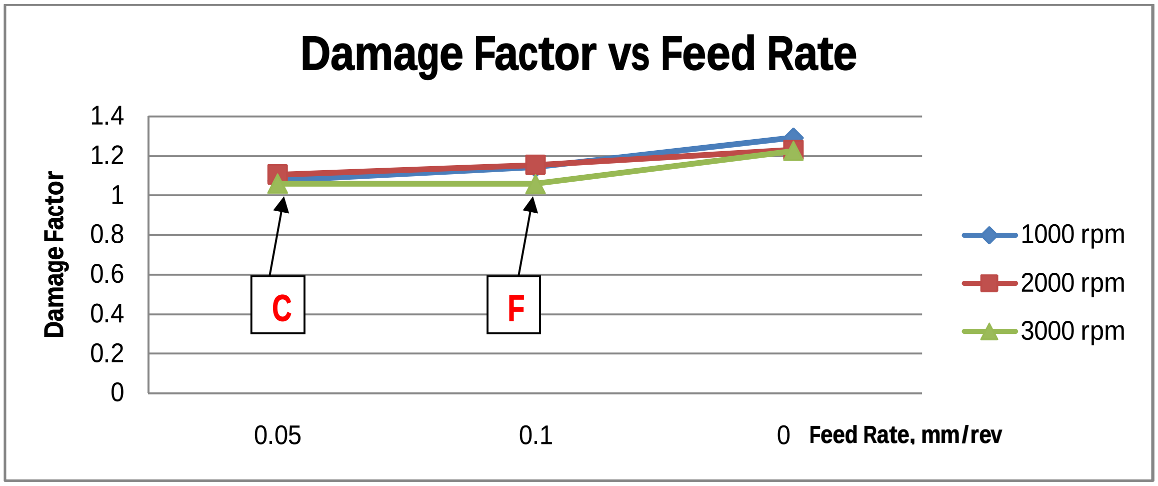


Figure 4.12: Less damage factor of samples C & F

It was observed that sample F (0.1 mm/rev, 3000 rpm) showed lesser damage factor than sample C (F_d = 1.05808). In industry, increasing feed rate will improve time consumption in drilling operation per composite panel. This got to be feasible result as sample F got higher feed rate than sample C.

In other results, damage increases with both cutting parameters, which means that composite damage is bigger for higher cutting speed together with higher feed rate. From few investigators (9, 11, 12, 13, 15), there are increasing thrust force with increasing feed rate but low spindle speed applied. Higher thrust force will lead to higher damage around drilled holes. This is proved from figure 4.1, on sample G (0.2 mm/rev, 1000 rpm), it is shown that damage factor is highest among nine samples at that graph which is 1.29214.

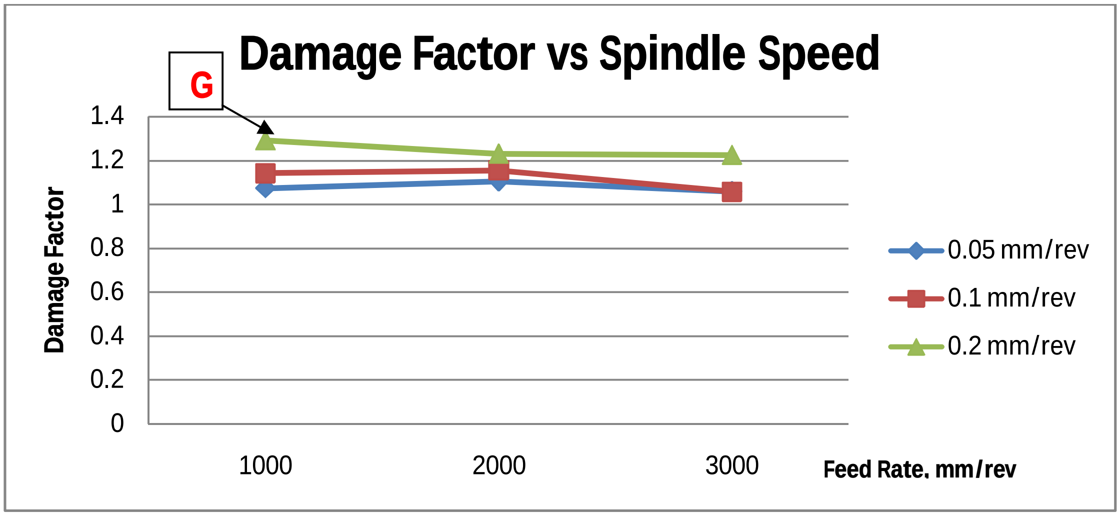


Figure 4.13: High damage factor of sample G

Correct combination of drilling parameters will allowed good drilled holes to be obtained. In this test, there is one result that would be feasible to apply which is from sample F where it produces less damage factor using high spindle speed and feed rate ability in term of time consumption for drilling process. Further research on the mechanical properties will be conducted to find out the suitability of the parameters in drilling GFRE and will be compared.

4.3 Tensile test

It was observed that there is substantial difference in thrust force and torque at various cutting conditions. This will result to difference of damage and thus, its strength was measured. Tensile test was conducted to determine tensile strength of drilled hole GFRE composite. It was measured with 100 kN load of Universal Testing Machine. There were 9 samples that have been tested. The graph showed load that can be applied to the sample until it fractured where the value is classified as its strength. Displayed below are results of nine samples which is graph of stress vs strain.

1. Sample A (1000 rpm, 0.05 mm/rev)
   Tensile strength = 7.072 kN

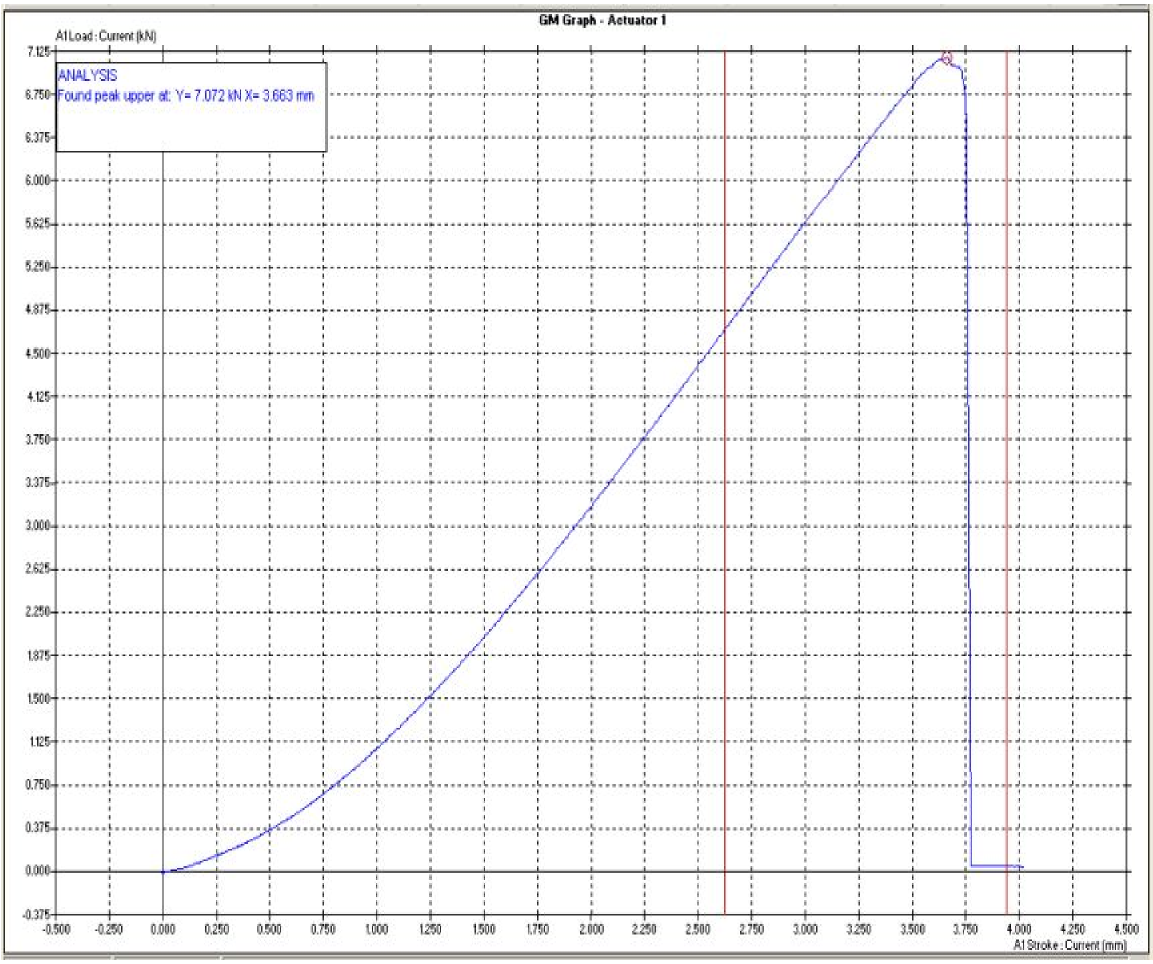


Figure 4.14: Sample A tensile strength

2. Sample B (2000 rpm, 0.05 mm/rev)

   Tensile strength = 5.744 kN

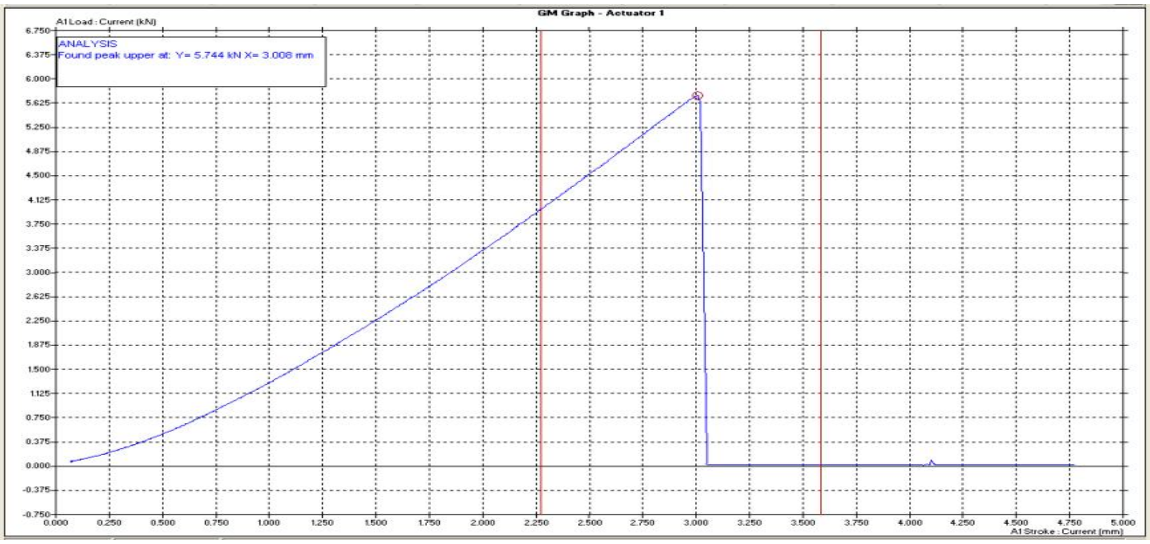


Figure 4.15: Sample B tensile strength

3. Sample C (3000 rpm, 0.05 mm/rev)

   Tensile srength = 7.389 kN

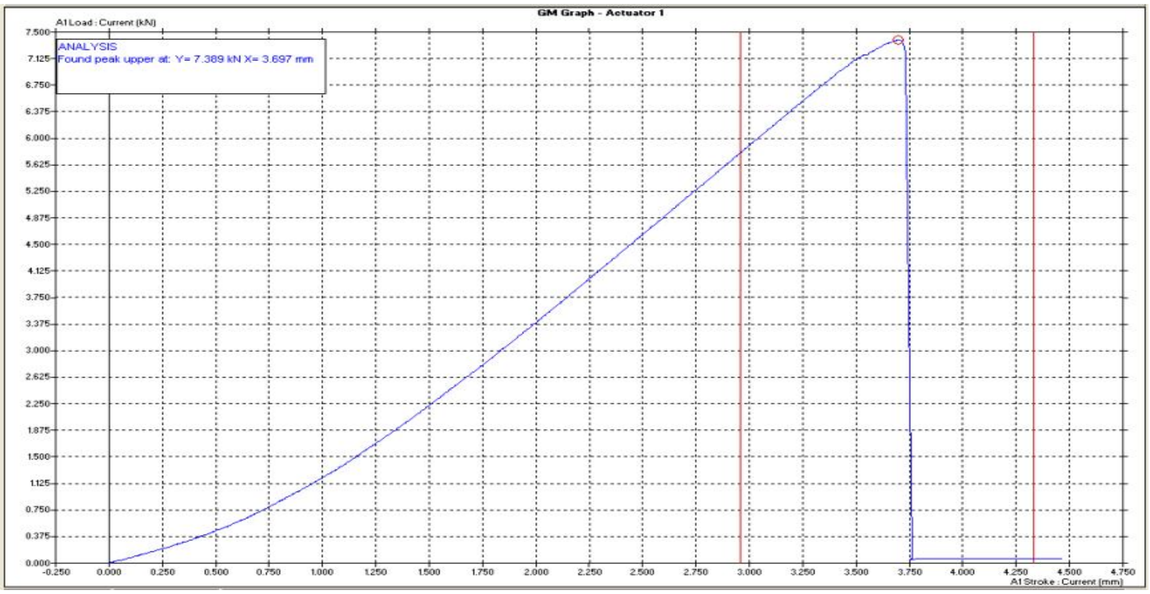


Figure 4.16: Sample C tensile strength

4. Sample D (1000 rpm, 0.1 mm/rev)

   Tensile strength = 5.368 kN

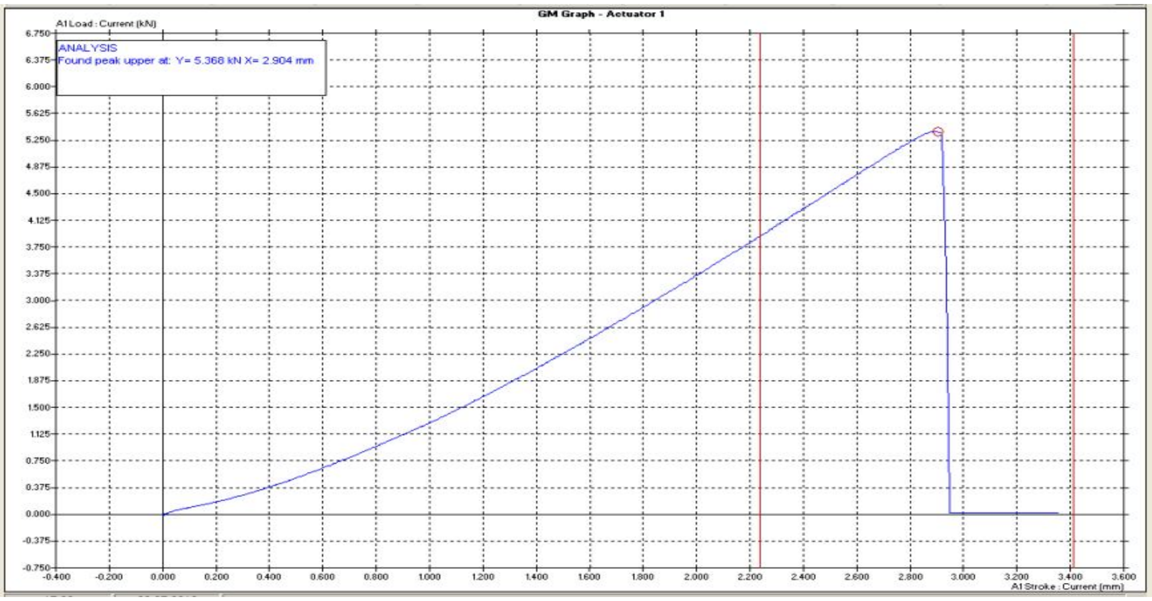


Figure 4.17: Sample D tensile strength

5. Sample E (2000 rpm, 0.1 mm/rev)

   Tensile strength = 5.306 kN

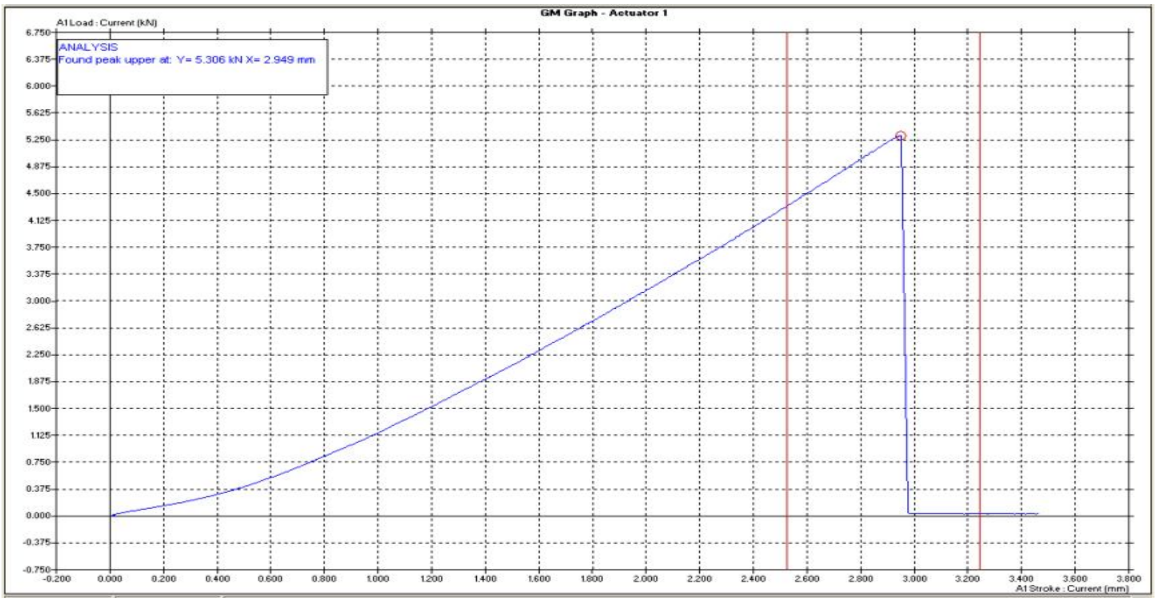


Figure 4.18: Sample E tensile strength

6. Sample F (3000 rpm, 0.1 mm/rev)

   Tensile strength = 8.10 kN

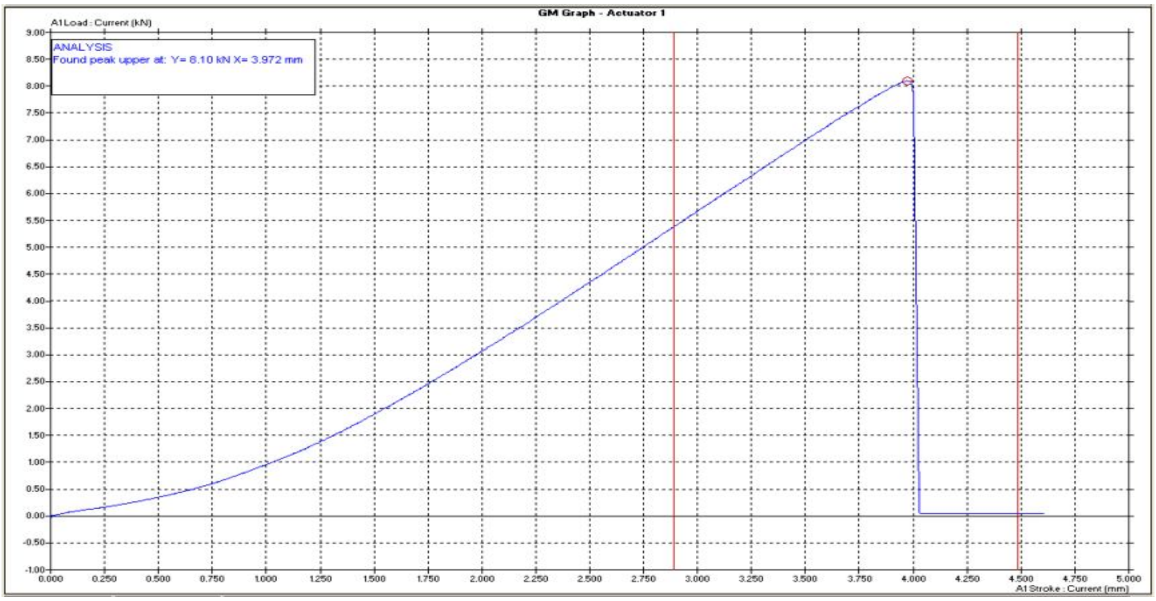


Figure 4.19: Sample F tensile strength

7. Sample G (1000 rpm, 0.2 mm/rev)

   Tensile strength = 4.362 kN

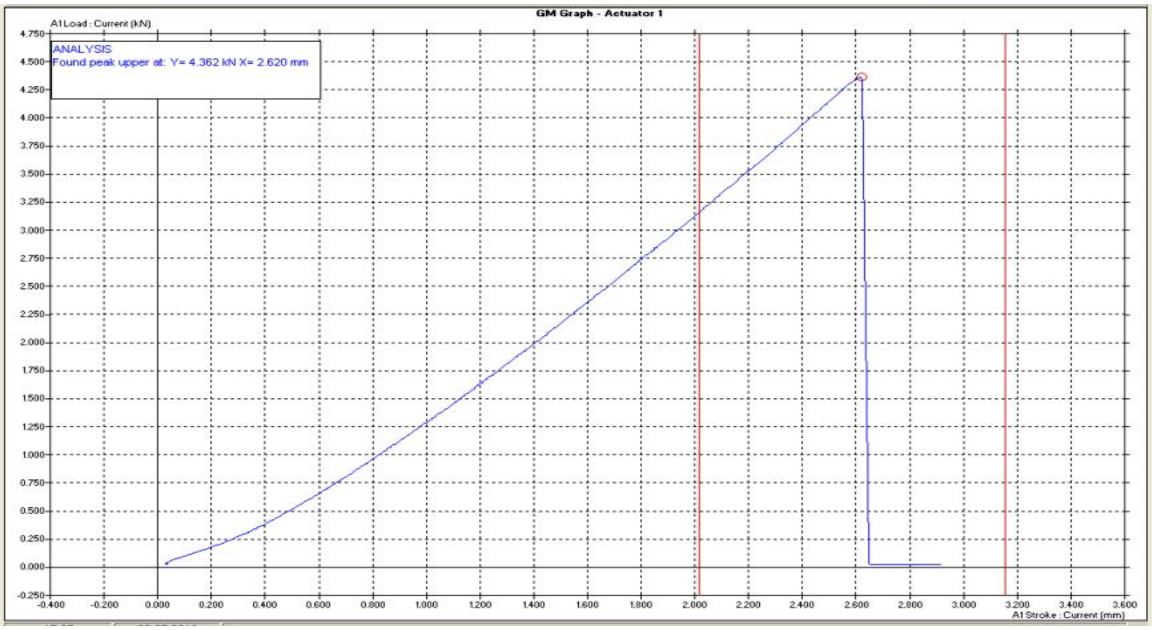


Figure 4.20: Sample G tensile strength

8. Sample H (2000 rpm, 0.2 mm/rev)

   Tensile strength = 5.131 kN

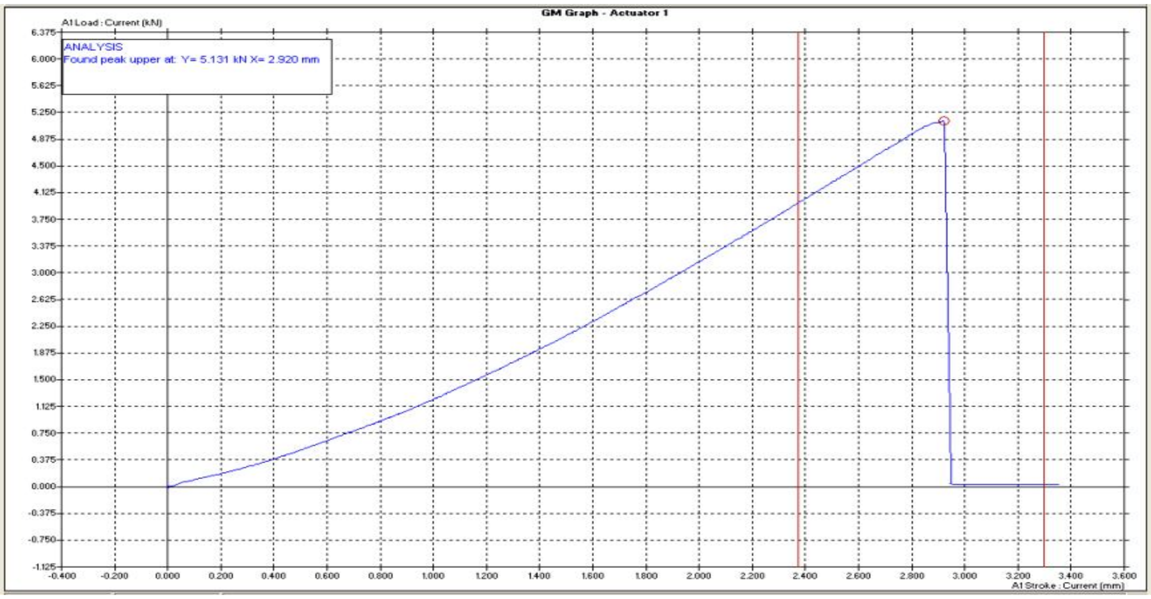


Figure 4.21: Sample H tensile strength

9. Sample I (3000 rpm, 0.2 mm/rev)

   Tensile strength = 5.240 kN

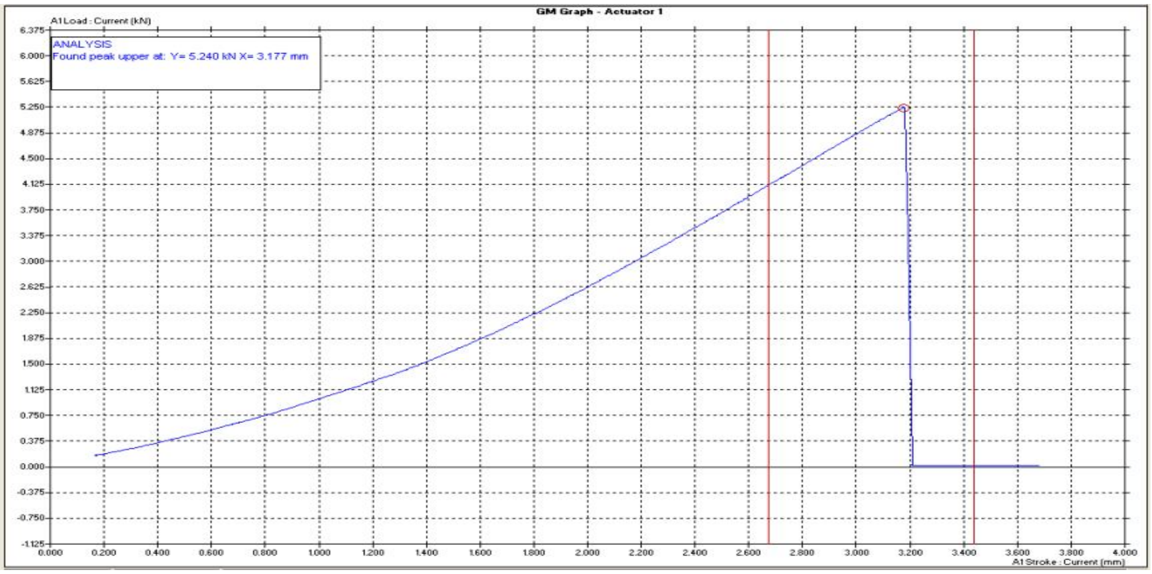


Figure 4.22: Sample I tensile strength

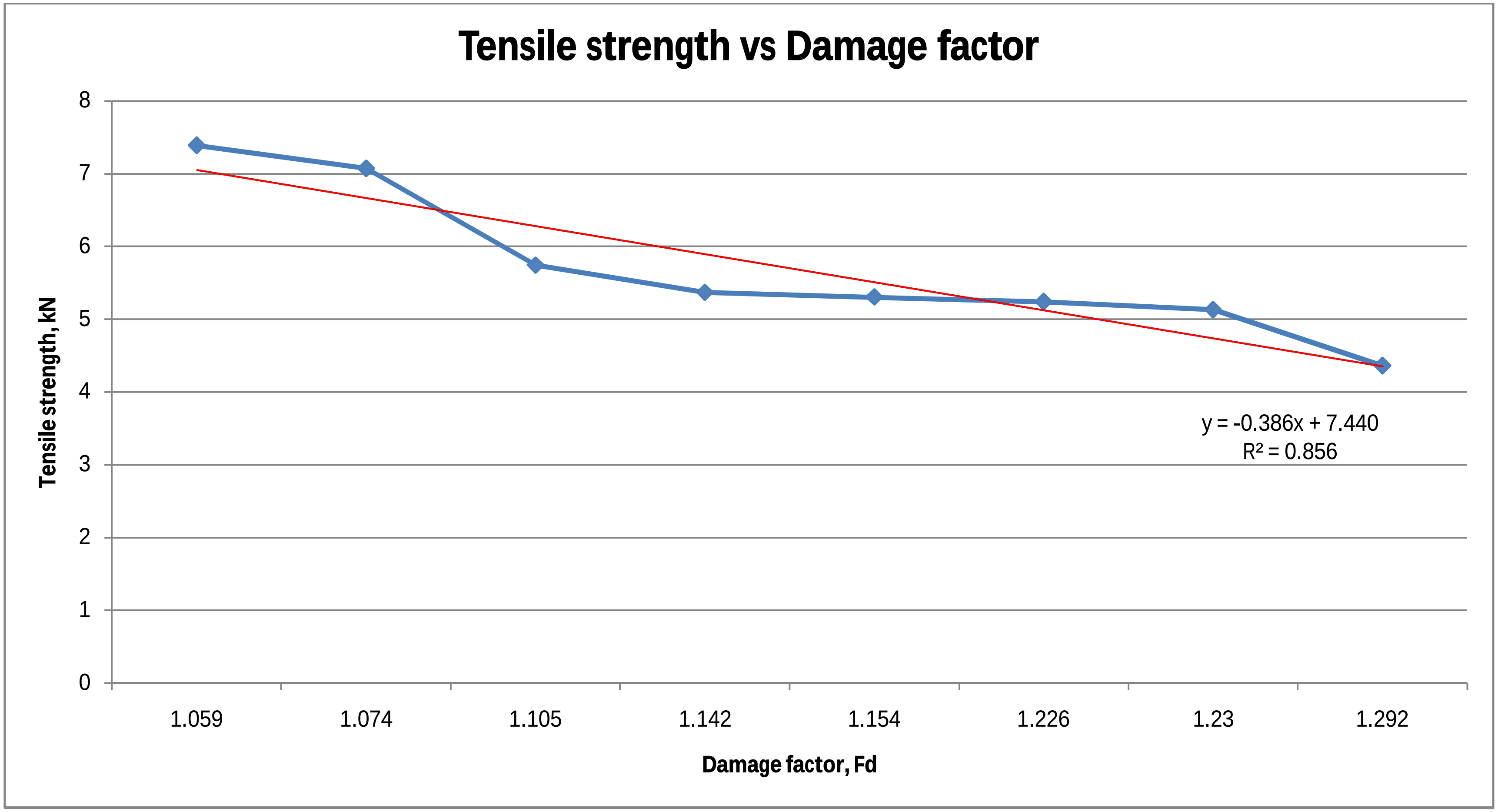


Figure 4.23: Effect of damage factor to tensile strength

All the results of tensile strength are simplified to the bar chart and each different value showed the effect of damage factor on its strength.

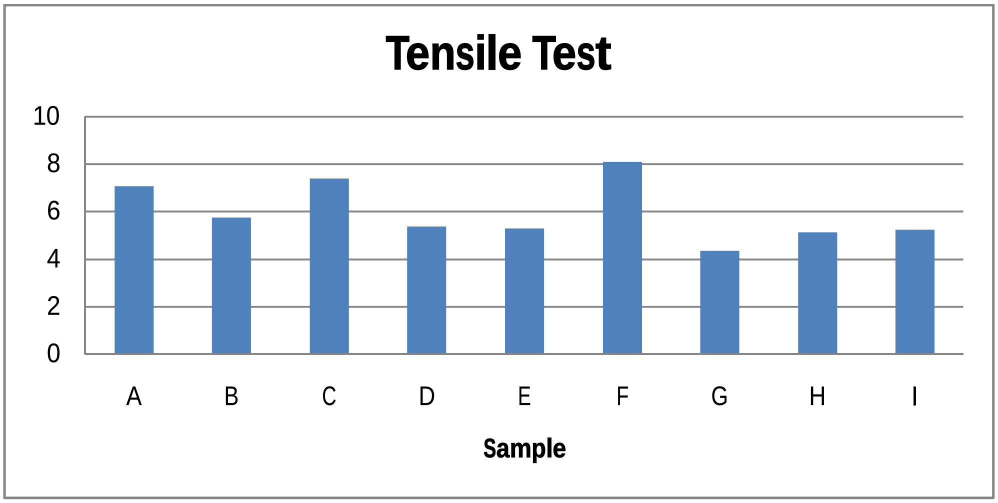


Figure 4.24: Bar chart for tensile strength of 9 drilled samples

It is observed from typical plot of tensile strength for damaged holes per part as shown in Fig. 4.24 where there exist an inverse relationship between the residual tensile strength and the damaged area around the drilled hole. At low speed-low feed combination ratio, damage area shows a minimum, whereas the resulting residual strength is maximized at this condition. From this study, highest strength was obtained from the sample F which got lowest damage factor. It gives the significance that less damage lead to high strength.

Besides that, the results clearly indicate that greater the damage the lower residual tensile strength will it be. From the Fig 4.24 graph, it can be seen that there are decreasing of 8.8% strength for sample F to sample C and goes to 46% decreasing of strength when compared to sample G which is high damage factor. From this study, it can be clearly said that damages generated could be detrimental to the mechanical behavior of the GFRE laminate. As a result, tensile strength will be inversely proportional with the damage factor. At high speed-low feed rate parameters, damage area shows minimum value but strength is maximum at this condition.

CHAPTER 5

CONCLUSION & RECOMMENDATIONS

5.1 Conclusion

Methodologies and techniques adopted in these studies are planned to be presented. The study reported here is limited to the domain of glass-fiber reinforced epoxy composite. Fiber volume fraction is the important part in the beginning of fabricating desired GFRE composite specimens. Measurement of damage factor was done by using 3D Non Contact Measuring System. Tensile strength of drilled sample was conducted by using Universal Testing Machine. Studies on the drilling induced defects and mechanical properties are going to be beneficial to composite industry especially for the CNC department of manufacturing composite parts. Understanding upon this subject will help in the decision of the best-suited parameters for drilling operations thus could save costs and time in composite repair and prolong the service life of the GFRE composite parts. There are many other parameters and analysis that can be focused on for example type of drill bits, surface roughness, thrust force and torque. Results obtained were following the expected results which is by high damage factor, low tensile strength would it be. In this study, important analyses obtained are:

1. Delamination existed around drilled holes occurred due to residual force of fibers at inside or outside the holes due to the thrust force from drilling process.
2. Damages occurred in this study are fiber pull out, delamination and fiber matrix debonding.
3. Thrust foce and torque cannot be analyzed due to unavailability of equipments which is drill tool dynamometer.
4. Type of drill point geometry also affected to the residual tensile strength.
5. Tensile strength shows increment with the decreasing damage factor.
6. Optimum drilling parameters in this study suit to the 0.1 mm/rev feed rate and 3000 rpm combination which showed highest strength and lowest damage factor.

5.2 Recommendations

In order to improve the project, few matters can be focused on for example laminate stacking sequence or ply orientation. It is important to be symmetry for unidirectional orientation. Other than that, drilling operation is not enough with using the clamp. Maybe a jig for the sample is needed to neglect any unwanted circumstances especially during drill enters or exits. It also could protect outer plies of the solid laminate. Hand layup process should be proceeding with the bagging process to obtained vacuum condition on the way to cure the sample to neglect appearances of voids. Fabrication process should be implemented in the clean room to obtain high quality of products.

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