PRECISION HOLE-MAKING ON COMPOSITE PANEL-EFFECT TO PRODUCTIVITY AND QUALITY

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Declaration

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Abstrak

Menebuk merupakan proses mericih mengunakan satu alat penebuk dengan menekankan penebuk ke atas bahan kerja untuk menghasilkan lubang. Kebiasaannya, penebuk akan menebuk bahan kerja melalui dai. Serpihan bahan kerja yang telah ditebuk akan terlekat pada dai. Antara kelebihan proses menebuk adalah proses yang lebih pantas, ketepatan dimensi, kemasan permukaan yang baik, yang menyumbang kepada kos yang rendah dan yang paling utama adalah proses ini lebih ekonomi untuk penghasilan lubang dalam kuantiti yang banyak. Proses menebuk adalah sama seperti penggerudiaan di mana kedua-dua proses dapat menghasilkan lubang yang berbntuk bulat pada bahan kerja. Walau bagaimanapun, proses menebuk jarang digunakan pada bahan panel komposit berbanding penggerudian. Hal ini kerana, bahan panel komposit mempunyai struktur dan ciri-ciri yang unik menyebabkan penghasilan lubang yang berkualiti rendah. Berbeza dengan proses penggerudian, di mana masalah kehausan pada mata alat dan kadar produktiviti yang rendah merupakan kelemahan proses penggerudian. Dalam projek ini, satu kajian melibatkan panel komposit telah dijalankan untuk mengkaji kesan teknik-teknik penghasilan lubang ke atas kualiti permukaan lubang yang terhasil dan produktiviti setiap teknik. Antara teknik-teknik yang digunakan dalam projek ini termasuklah, menebuk, penggerudian dan gabungan teknik menebuk dan penggerudian sebagai satu teknik campuran. Eksperimen telah dijalankan menggunakan ujian mesin universal (UTM) untuk teknik menebuk dan mesin konvensional penggilingan bagi teknik penggerudian. Imej-imej lubang yang dihasilkan kemudian diimbas dengan mengunakan perisian ImageJ. Dua kualiti aspek iaitu faktor keterasingan dan kekasaran permukaan bahan kerja telah telah diukur. Produktivi bagi setiap teknik akan diukur dengan mengambil kira masa untuk menyiapkan lubang berbentuk bulat pada bahan kerja. Hasil kajian menunjukkan teknik gabungan menebuk dan penggerudian tidak memberi kesan terhadap faktor keterasingan pada panel komposit tetapi bagi nilai kekasaran permukaaan, teknik ini telah mengurangkan nilai kekasaran permukaan lubang terhasil sebanyak 26.09 peratus berbanding teknik menebuk dan 19.6 peratus berbanding teknik penggerudian. Produktiviti untuk teknik ini adalah paling rendah kerana proses menghasilkan lubang melalui teknik gabungan ini telah mengambil masa yang lama berbanding teknik penggerudian dan teknik menebuk.

Abstract

Punching is a shearing process that uses a punch press to force a tool, called as puncher, through the workpiece to produce a hole. The punch often passes through the workpiece into a die. The scrap slug is produced from the hole during the punching process and deposited into the die. The advantages of punching process are high speed, good dimensional accuracy and surface finish, relatively low cost and most importantly it is economical for mass production. This method is similar with the drilling method where both operations can produce circular hole. However, the punching operation is rarely used in hole-making of composite panel material compared to drilling. This is due to the unique structure and properties of composite materials result in low quality of hole. In contrast, worn and low production rate are the disadvantages of drilling. In this work, an experiment was carried out on a composite panel to investigate the effect of hole making techniques on the surface quality and productivity. The hole making techniques are punching, drilling, and combination punching and drilling as a hybrid. Experiment was carried on using Universal testing Machine (UTM) for punching process and conventional milling machine for drilling process. The images of produced holes was captured and was analysed using ImageJ Software. Two quality aspect were measure, namely, delamination ratio and surface roughness. The productivity is measured in term of time taken to produce holes. The results show that the hybrid method of combining punching and drilling as a single process to create Ø10mm holes on composite panel has no significant effect on delamination factor but in term of surface roughness, this method has reduced the surface roughness value, R_a, by 26.09% compared to drilling technique. The productivity of hybrid method is the lowest since it has the highest processing time in hole-making process.

CHAPTER 1

Introduction

1.1 Background of the Study

Composite material have been used widely for various applications especially in aerospace industry due to the capability of providing required engineering properties such as high strength-to-weight and stiffness-to-weight ratios. In this project, the composite panel being studied is one type of the laminated composites. Composite laminates can be defined as combination of fibrous composite materials (fibers in a matrix) that are bonded together layer by layer to obtain required engineering properties including bending stiffness, strength, and in-plane stiffness. The individual layers consist of high-modulus, high-strength fibers in a polymetric, metallic, or ceramic matrix material. Most common fibers used include graphite, glass, boron, silicon carbide and typical matrix materials in use are epoxies, polyimides, aluminium, titanium and alumina. The general structure of laminated composite is shown in Figure 1.1.

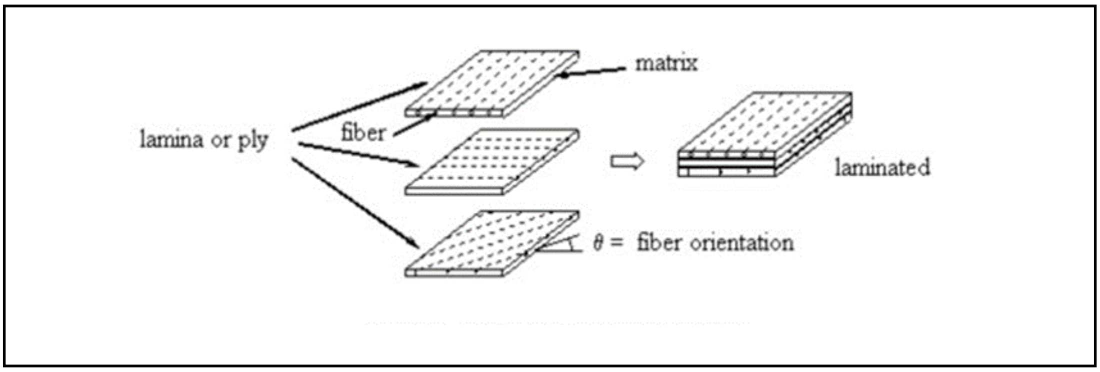


Figure 1.1: Laminated composite structure[1]

Generally, there are two type method for hole-making of composite panel namely drilling and punching. The common method of creating hole especially on composite panel is by drilling. Previous research has identified that drilling induced damage, such as spalling, delamination, edge chipping, fiber pull-out, crack formation, and excessive tool wear. A part from that, drilling is considered time consuming because the drilling tools need to be changed frequently for different size of hole and profile. In aircraft manufacturing industry, thousands of holes need to be produce hence time is important.

Other than drilling, punching is another method used to produce holes particularly on metal such as aluminium alloy and carbon steel. However, on composites, this approach is still new and only a few published works can be found related to this topic. Previous research has identified die clearance as one of the biggest influences on punching. The cut surface quality of the hole produced on composite panel by punching method is still unknown yet. In addition, the amount of practical work done is limited and relatively insufficient, thus, further research experiments are needed.

Although punch and drill are the common method in hole-making process, but both of the method have some differences in term of operation. A drill use a rotating bit, while a punch use a reciprocating male and female die and not involving any rotating mechanism. Drilling is one of the cutting process that use a drill bit to cut and enlarge a hole of circular cross-section and profiles in solid materials. The bit is pressed against the specimen and rotated at rates of hundreds to thousands of revolutions per minutes depends on the thickness of the specimen. Since punch doesn’t involve any rotating mechanism, it is extensively used in sheet metal processing due to the advantages including high strength, good dimensional accuracy and surface finish, relatively low cost and economical mass production for large quantity.

1.2 Problem statement

Typically hole on composite panel was made using drilling technique. One of the main problem with drilling is severe wear which requires frequent regrind and this may affect productivity of the operation and increase production cost and most importantly drilling is relatively slow. But holes produced from drilling are in good quality and low delamination level. Previous work found that punching is a potential and promising alternative to replace drilling in hole-making. Unfortunately, by punching, quality in terms complete shearing and neatness of the surface become the major issue. By combining these two techniques, may improve the quality and productivity of the hole making technique.

1.3 Objective

The objective of the project were:

1. To investigate the effect of combining punching and drilling technique on the surface quality of produced hole.
2. To study the effect of combining punching and drilling technique on the surface roughness of produced holes.
3. To compare the productivity of combining punching and drilling technique with the conventional drilling and conventional punching.

1.4 Scope of Work

In this work, composite panels were fabricated using hand lay-up process. Dedicated specimens were obtained and several holes were created on composite panel by three methods including punching method, drilling method and hybrid process which is combining both punching and drilling method using Universal Testing Machine (UTM) and Universal Milling Machine. The surface quality of the produced hole for each method will be measured based on delamination factors and surface roughness. A part from that, the productivity of each method will be measured and compared based on the time taken to produce several holes on composite panels.

CHAPTER 2

Literature Review

2.1 History and Background

In recent years, there were number of researches had been done to determine the quality of punching method and drilling method in hole-making process. However, almost all the involved material is typical sheet metal such as alloy, carbon steel, titanium alloy, magnesium and alloy. It shows that none of the involved material is consisted of a composite laminate structure panel especially for the punching method. A part from that, there is no research had been done on the effect of combining both method which is punching and drilling in hole-making process on composite panel. The literature reviews were performed by collecting various journals and articles from university library and free articles from internet. The study will be conducted through the use of an interaction analysis. Its goal is to increase the amount of knowledge regarding process influencing parameters of punching and drilling process. Any literature that related to punching and drilling process also was reviewed.

2.2 Punch Geometry

Previous study has identified die clearance as one of the major influences on punching. The die clearance can be determined based on Eq. (1), suggested by Da (1985) mentioned in research carried by H Y Chan (2015). The equation was introduced specifically for metals. Due to limited resources of machining on composite panels, the proposed equation can also be used on determining the die clearance in hole-making on composite panels[2].

$$\frac{c}{t} = K\sqrt{S}\ , \quad \ldots (1)$$

Where c is the single die clearance, t is the strip thickness, S is the material shearing strength and K is the clearance coefficient, whose scale is $K =$ 0.008-0.01. The shearing strength can be estimated using S = 0.7 UTS.

Experimental parameters of the hole-making process such as punch velocity, and blank holder pressure need to be determined before conducting the experiment. In the trimming experiment carried out by Hilditch and Hodgson (2005), a press that has maximum tonnage of

125 tonnes and punch velocity of ~0.1 m/s at the point of contact with the sheet. The stripper pressure used in the experiment was a constant value of approximately 1MPa[3]. Another trimming experiment carried out by Li (2000), using a press that has maximum tonnage of 20 tonnes and punch velocity of ~0.05 m/s at the point of contact with the sheet. The stripper pressure used in the experiment was a constant value of approximately 1MPa.

Iliescu et al. (2010) proposed a wear model based on thrust force and machining parameters for drilling CFRP. The suggested value for optimum cutting speed is 170 m/min with feed of 0.05 mm/rev. According to work presented by Miguel (2010), a 120° angle twist drill should be used for minimal delamination [4].

Leung et al. (2003) has proved that the shearing edge in fine-blanking can be influenced by various punch nose radii for tool geometry. Shearing edge quality can be measured and analysed using the relationship between the percentage of shearing area and the blanking punch nose radius. This relationship can be proved using Eq. (2), proposed by Leung et al.

$$K = \frac{S_g}{S}, \quad \dots (2)$$

Where S_g is the thickness of pure shear of the blanking edge and S is the thickness of the workpiece. From the Eq. (2), the best shearing edge quality will be obtained if the value of K is equal to 1.

2.3 Drilling Parameters

Based on the experiment of drilling of composite sandwich structures, carried out by Koran (2014), the results showed that has identified that the feed rate is the factor that has the greatest impact on delamination factor, followed by cutting speed and tool diameter, respectively. The experimental results showed that delamination factor increase with the increase of feed rate [5].

Eshetu (2014) conducted an experimental study of surface quality and damage when drilling unidirectional CFRP composites. Based on the result of different cutting parameters used in the study, better hole surface quality was obtained with a combination of higher cutting speed and lower feed rate. Lower value of surface roughness and delamination factor were obtained with a cutting speed of 4500rpm-6000rpm with feed rate of 64 µm/rev [6]. Figure 2.1 shows the typical holes produced by drilling process with different drilling parameters.

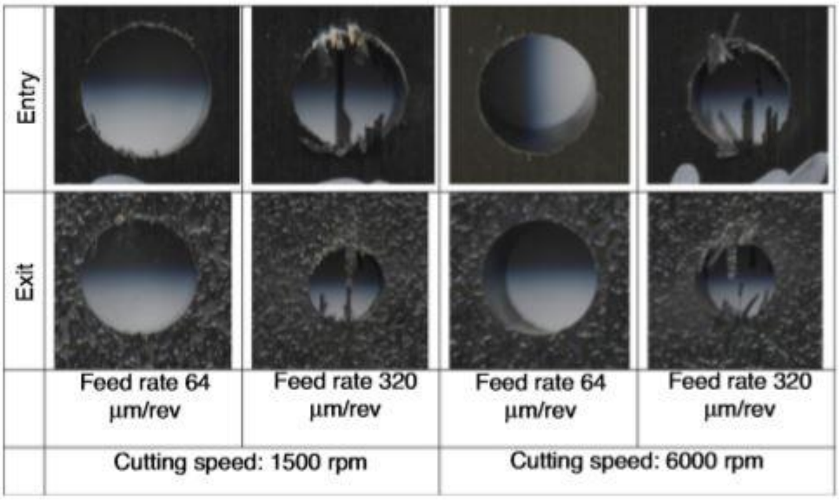


Figure 2.1: Typical Holes Produced by Drilling Process [6].

Azmi (2013) had described that the spindle speed range between 3000-5000rpm is truly represents the typical range of industrial application. He stated that higher speed rate which is more than 5000 rpm leads to rapid tool wear [7]. Kurt et al. had studied he role different coatings, point angles, cutting speeds, and feed rates on the hole quality (hole size, surface roughness, roundness, and radial deviation of produced hole) in drilling of Al 2024 alloy. They concluded that using low cutting speed and feed rate will result in the best quality of hole produced [8].

Tyagi et al. used Taguchi method and had studied the effects of machining parameters such as spindle speed, feed and depth of cut on the surface roughness and material removal rate (MRR). The results indicated that the spindle speed of drilling operation mainly effects the surface roughness and the effect of Mrr is associated to the feed rate [9].

Based on the previous work conducted by Naveen (2012), it was found that the damage around produced hole is predominant at higher feed rate in drilling of composite materials. They concluded that the high cutting speeds (40, 60, 80 rev/min) and lower feed rates (0.1, 0.2 mm/rev) are best suited for drilling FRP composite laminates [10].

2.4 Hole Quality

2.4.1 Top and Bottom Surface Diameter

Based on the experiment of precision punching on composite panels, carried out by Chan et al. (2015), the die clearances were according to actual industrial applications. A ruler is used for calibration where the images were capture and analysed using KLONK image measurement software. The cut surface quality was evaluated based on three aspects namely top surface diameter (Figure 2.2), bottom surface diameter (Figure 2.2), and incomplete shearing ratio.

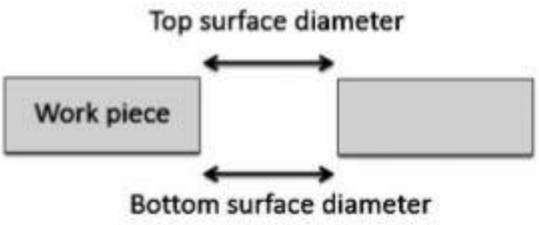
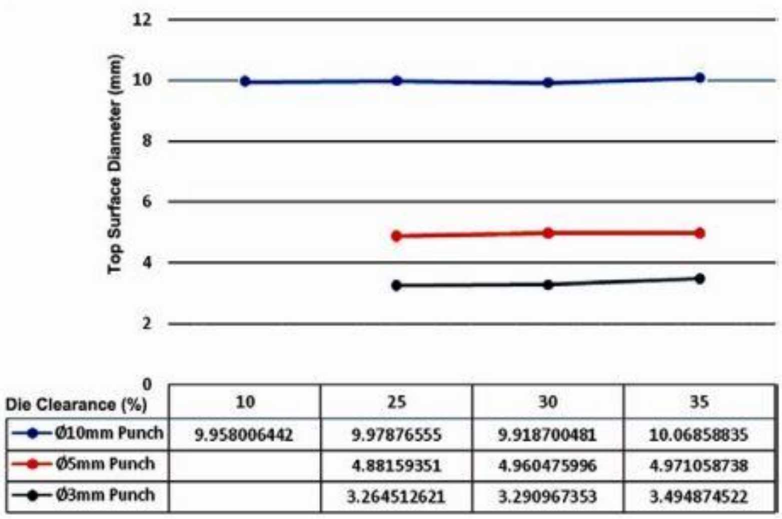


Figure 2.2: Schematic cross-sectional view of sheared material[2].

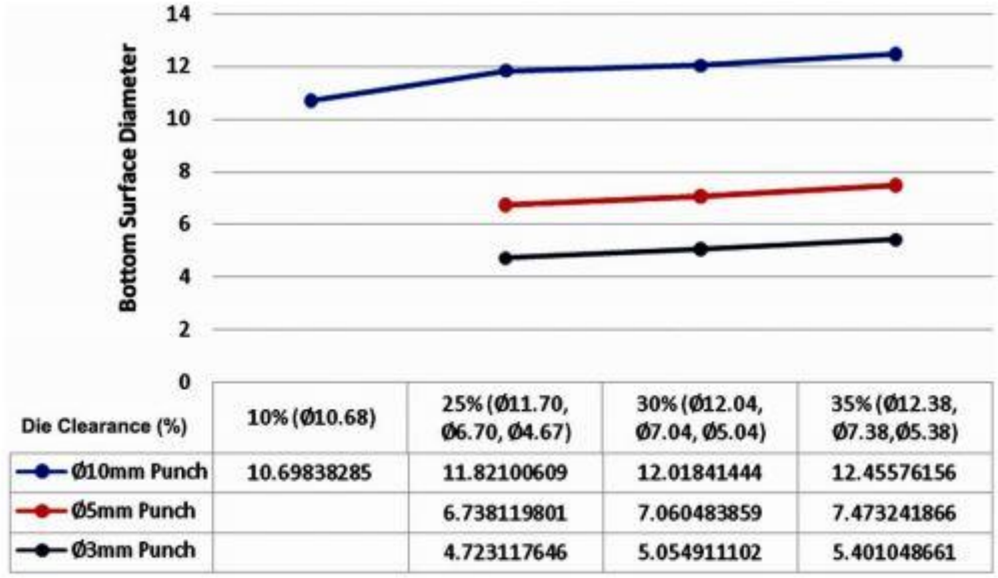
Based on the experiment, a total of 10 die sets with different punch diameters (3 mm, 5 mm, and 10 mm) and die clearance (25%, 30% and 35%) were used. The punch travel speed used is 5 mm/s on an Instron 3367 UTM. Three specimens were tested for each parameters set in the experiment. The experiment showed that die clearance does not affect the top surface diameter significantly based on the result obtained in Figure 2.3.



Die Clearance (%)	10	25	30	35
Ø10mm Punch	9.958006442	9.97876555	9.918700481	10.06858835
Ø5mm Punch		4.88159351	4.960475996	4.971058738
Ø3mm Punch		3.264512621	3.290967353	3.494874522

Figure 2.3: Effect of die clearance on top surface diameter[2]

The effect of the die clearance on the bottom surface diameter of all specimens increase as the die clearance (die diameters) expands showed in Figure 2.4.



Die Clearance (%)	10% (Ø10.68)	25% (Ø11.70, Ø6.70, Ø4.67)	30% (Ø12.04, Ø7.04, Ø5.04)	35% (Ø12.38, Ø7.38,Ø5.38)
Ø10mm Punch	10.69838285	11.82100609	12.01841444	12.45576156
Ø5mm Punch		6.738119801	7.060483859	7.473241866
Ø3mm Punch		4.723117646	5.054911102	5.401048661

Figure 2.4: Effect of die clearance on bottom surface diameter[2]

From the result obtained in the experiment, to produce Ø10 and Ø5 mm holes with favourable cut surface quality, the bottom die clearance value needed to be minimal since the bottom surface diameter of a hole tend to be close to the bottom die diameter. Chan proved that Eq. (3) can be applied to composite panels since the Ø3 mm puncher is bent after several punching as the ratio of the puncher diameter d to the material thickness t does not satisfy Eq. (3), recommended by Suchy [11].

$$\frac{d}{t} = 1.10\ minimum, \quad \ldots (3)$$

2.4.2 Hole Neatness

From the same study of precision punching of hole on composite panels conducted by Chan et al. (2015), the hole neatness is measured based on incomplete shearing calculated based on Eq. (4). The example of incomplete shearing was illustrated in Figure 2.6.

$$Ratio\ of\ incomplete\ shearing = \frac{A-A_C}{A}\ , \quad \dots (4)$$

To measure the incomplete shearing showed in Figure 2.5, the perimeter of the surface diameter of the hole was illustrated manually. The value of the illustrated area was generated automatically by operating software. The area value was regarded as hole area (A) showed in Figure 2.6. (A_C) is the clean hole area illustrated in Figure 2.7 that can be generated automatically through operating software. The incomplete ratio will be calculated by using Eq. (4).

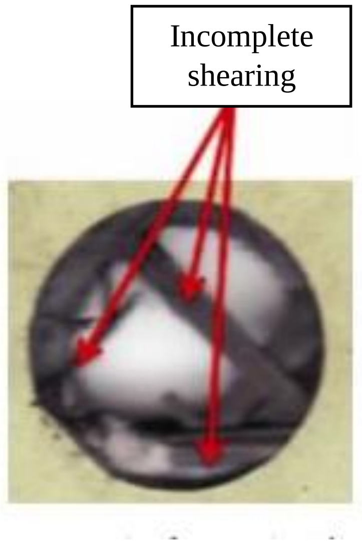


Figure 2.5: Example of incomplete shearing[2]

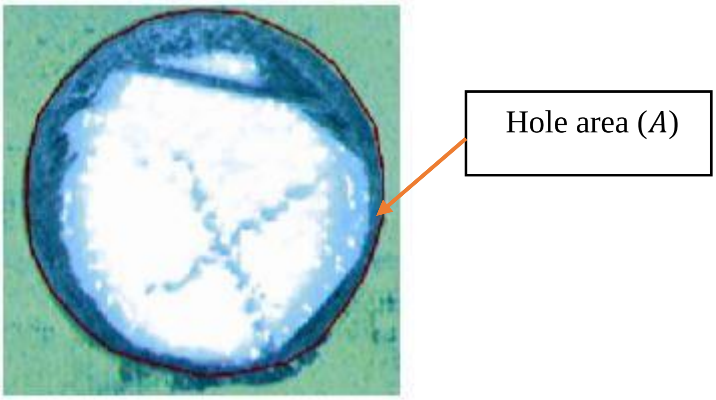


Figure 2.6: Hole area (A)[2]

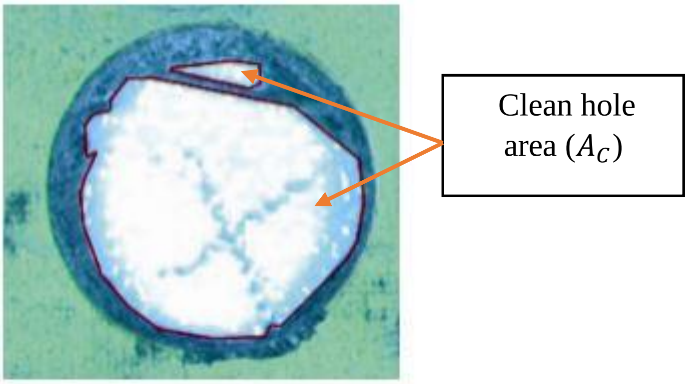


Figure 2.7: Clean hole area (A_C)[2]

2.4.3 Delamination Factor

Based on the research carried out by Chen, he presented a comparing factor called delamination factor (F_d), that enables the analysis and evaluation of delamination extent in laminated composites. Delamination factor was defined as the quotient between the maximum delaminated diameter (D_{max}) and the hole nominal diameter (D_o) as shown in Eq. (5).

$$Delamination\ factor, Fd = \frac{Dmax}{Do}\ , \quad \ldots (5)$$

The measurement of delamination factor are carried out based on the Figure 2.8. Figure 2.6 shows the measurement of the maximum delaminated and hole diameters.

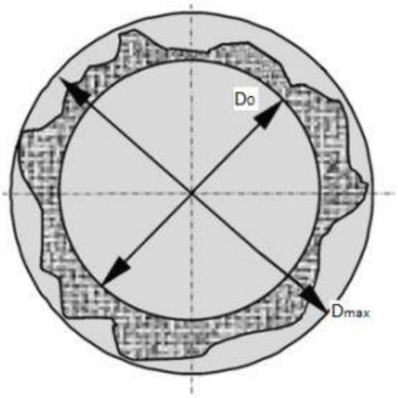


Figure 2.8: Measurement of the maximum delaminated and hole diameters[12]

Based on previous work by Miguel (2014), the assessment of delamination extension was evaluated through NDT. Some example of NDT are tool maker's microscope [13], ultrasound techniques [14], acoustic emission [15], enhanced radiography [16], C-Scan [17], or Computerized Tomography (CT) [18]. All of these methods are used to capture and obtain images representing the holes surrounding area that can be analysed and measured in term of areas and diameters. Figure 2.9 shows the damage evaluation using radiography, ultrasonic C-Scan (CT) and computerized tomography.

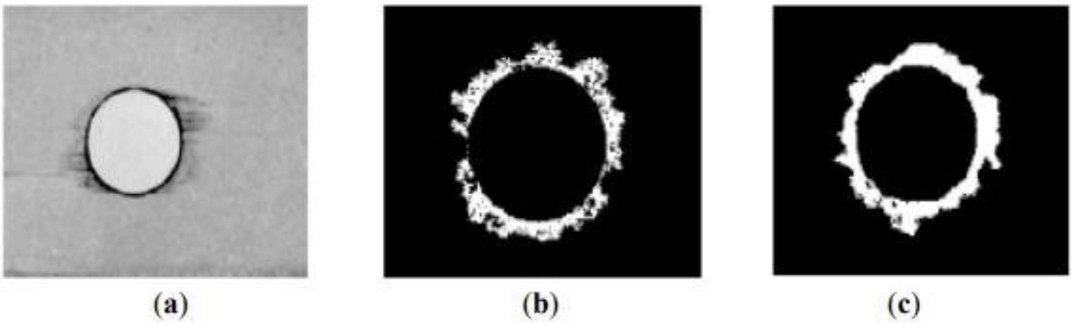


Figure 2.9: Damage evaluation: (a) radiography [16]; (b) ultrasonic C-Scan [14]; (c) computerized tomography [18].

Based on previous work carried out by Ghabezi (2014), the produced holes from drilling tecnique in composite was assessed based on two quality aspect including delamination factor (Fd) and uncut fiber factor (UCFF). Figure 2.10 shows the different sections for calculation of delamination factors.

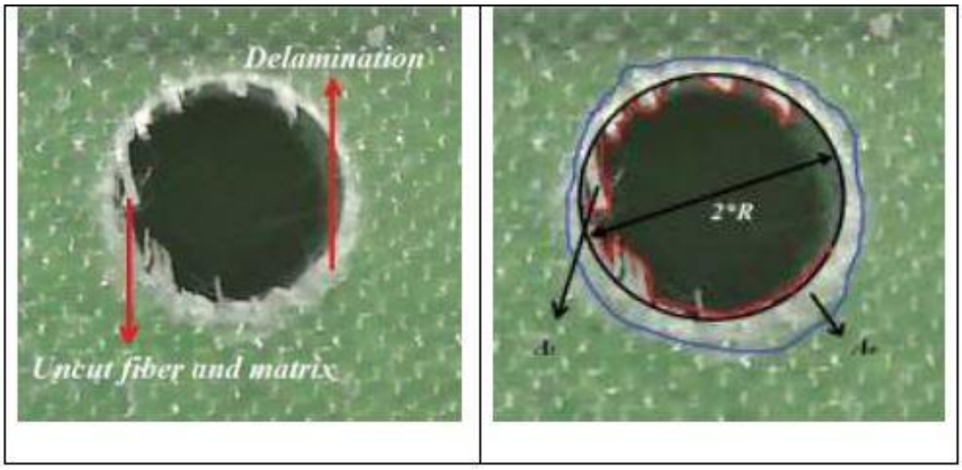


Figure 2.10: The different sections for calculation of F_d and UCFF [19].

Delamination factor and uncut fiber factor can be calculated based on Eq. (6) and Eq. (7). Where A_{Hole} is the diameter of the drill in mm^2, A_o is the area between circle of hole and maximum of the delamination zone in mm^2 [19].

$$Delamination\ factor, Fd = \frac{Ao}{AHOLE}\ , \quad \ldots (6)$$

$$Uncut\ fiber\ factor, UCFF = \frac{A1}{AHOLE}\ , \quad \ldots (7)$$

2.4.4 Surface Roughness

Wern (1993) conducted an experiment to study the surface structure of composite drilled holes. In this study, profilometry was used to study the textures of the surfaces. The results obtained indicate that the surface produced by drill b almost four times rougher than that produced by drill a when the feed rate is low. The surface roughness decreased with an increase in feed rate [20]. Based on previous work conducted by Kumar (2016), surface roughness of drilled holes on composite panels were measured using SJ-210 stylus type profilometer provided by (Mititoyo America Inc.) as shown in Figure 2.11.

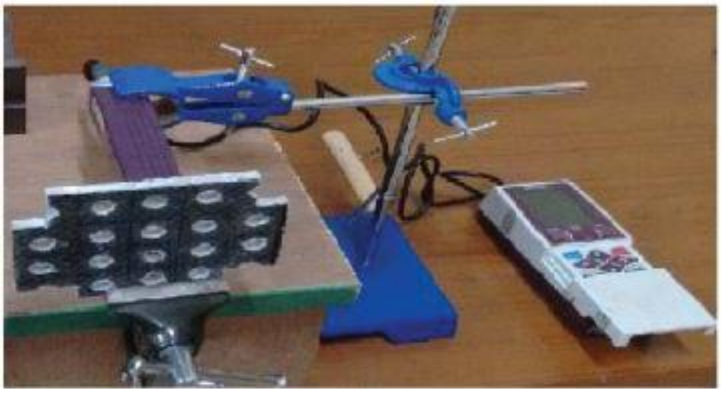


Figure 2.11: Setup for surface roughness measurement [21].

Surface roughness were measured at entry side and exit side of produced holes. For each hole, four measurement was taken at different cut section for entrance and exit. The analysis was conducted using the average value. For this work, cut-off length of 0.08 mm was chosen for surface roughness measurement at entrance and exit hole. The obtained result was concluded that surface roughness at entrance is more than at exit due to less damage appeared at exit.

Tan (2016) had investigate surface roughness analyses in drilling hybrid carbon/glass composite. In this work, the average arithmetic surface roughness, R_a, was chosen for surface quality response. The R_a value was measured using a Tokyo Seimitsu Handysurf (E-35A) surface measurer, shown in Figure 2.12. The results of surface roughness frequently depend on the deviation of the nominal surface with respect to the cutting surface [22].

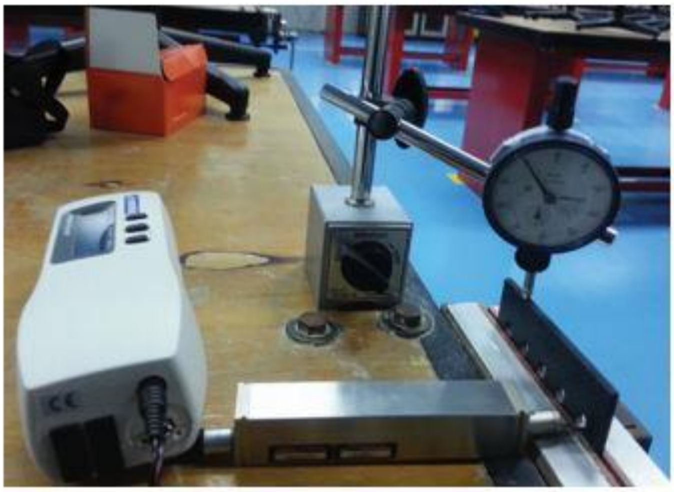
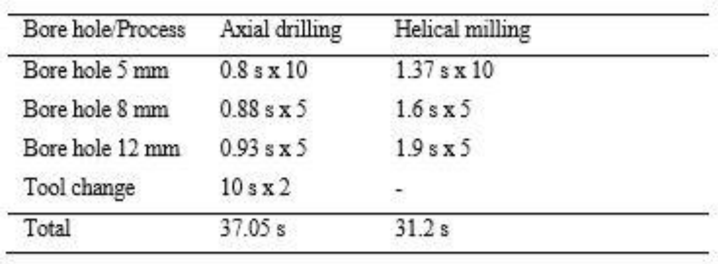


Figure 2.12: Surface Roughness Setup [23].

2.5 Processing Time

Based on previous study carried out by Uhlmann (2016), the processing time for axial drilling and helical milling were compared in term of economical point of view. in the experiment, 10 bore holes with diameter of 5 mm, 5 holes with diameter of 8 mm and 5 holes diameter of 12 mm are produced with axial drilling and helical milling techniques. The processing time for each technique were compared shown in Figure 2.13. Based on the results, the implementation of helical milling has reduced the processing time by 5.85 s even though the helical processes are slower compared to drilling due to obsolete tool changes.



Bore hole/Process	Axial drilling	Helical milling
Bore hole 5 mm	0.8 s x 10	1.37 s x 10
Bore hole 8 mm	0.88 s x 5	1.6 s x 5
Bore hole 12 mm	0.93 s x 5	1.9 s x 5
Tool change	10 s x 2	-
Total	37.05 s	31.2 s

Figure 2.13: Comparison of process times for axial drilling and helical milling [24].

CHAPTER 3

Methodology

3.1 Introduction

The methodology for this experiment consist of 4 stages. For stage 1, the focus is more on developing of technical knowledge on punching and drilling process and the properties of composite panel. Then, it was followed by stage 2 which was the preparation for experiment. In this stage, the fabrication of glass fiber composite panel was carried out. Composite panels with the dimension of 300 mm x 300 mm with thickness range of 2 mm to 2.5 mm was fabricated through hand lay-up technique. The fabricated panels is then being cut into three small panels with dimension of 270 mm x 90 mm. The diameter size of holes that need to be produced on the small panels is decided to be in the range of 5 mm to 10 mm. This value is suggested from various authors based on their research. The proper measuring technique and procedure to operate the machine also were studied in this stage. In stage 3, the experiment is carried out to produce holes on composite panels by using three different methods namely punching method, drilling method and hybrid process of combining punching and drilling method. The productivity and the quality of produced holes of three different methods will be studied and compared. Meanwhile, the image of produced holes are captured using a USB Microscope and the measurement were carried out using ImageJ software. In stage 4, the analysis of data collected from stage 3 will be performed and studied. The effect of hybrid process by combining punching and drilling method on hole-making process are studied. The methodology of this project have been summarized in Figure 3.1.

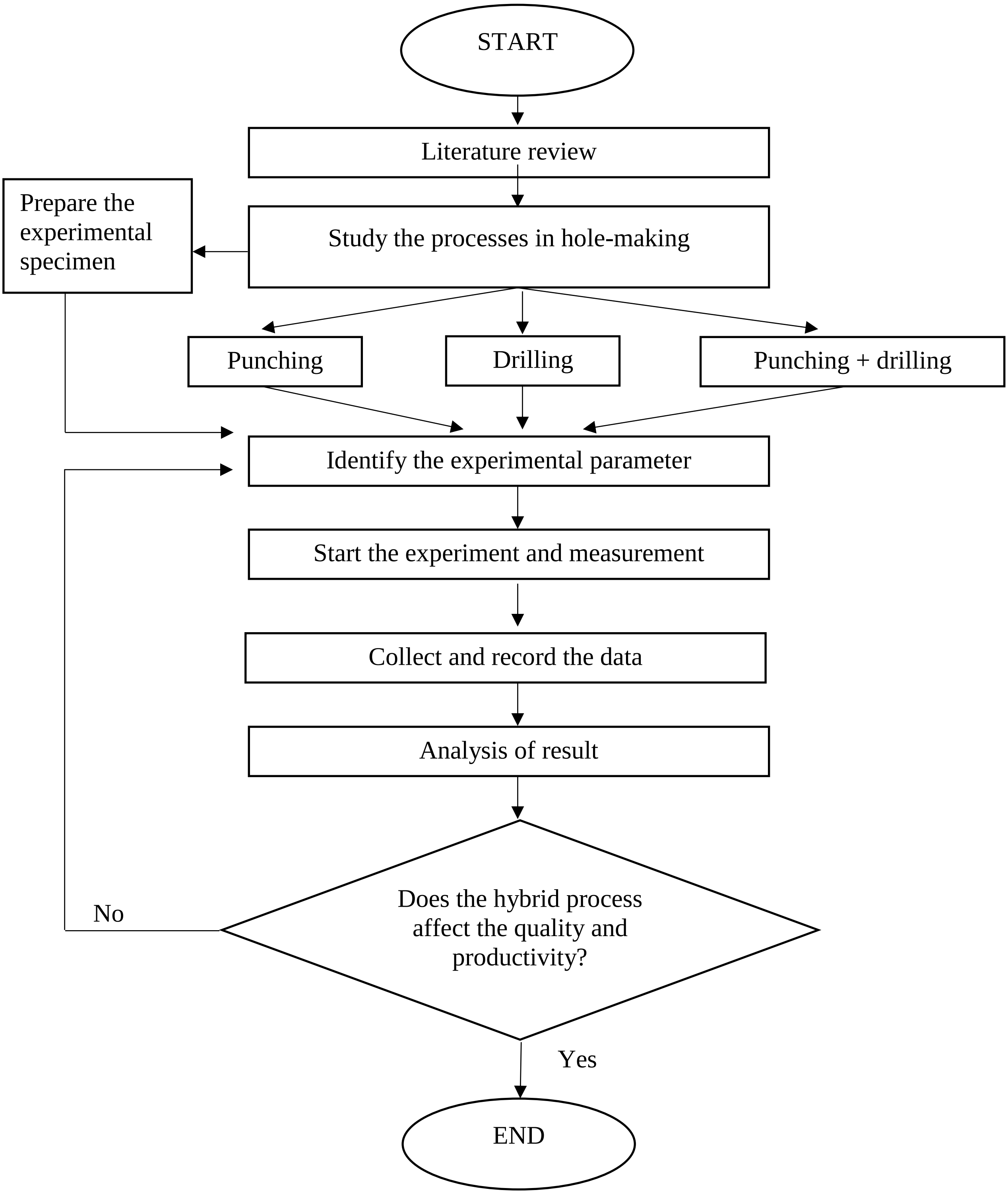


Figure 3.1: Flowchart of Experiment

3.2 Fabrication of Specimen

For this project, glass fiber reinforced composite (GFRC) panel was fabricated through hand lay-up technique. Generally, a mold must be used for making parts using hand lay-up process to obtain the desired shape. However in this project, a flat table is used to hold the flat shape of the layup as the composite panels being studied is one type of laminated composite. The first step of hand lay-up process is to mix the resin and the hardener. The resin used in this process is epoxy and the proportions are given by the supplier found on the containers of the hardener and resin. The portion is measured by weight with the ratio of 3:1 resin to hardener needed to ensure complete chemical reaction for maximum strength of the matrix. The weight of resin needed was estimated based on the weight of fibre glass. Composite panels of 300 mm x 300 mm was fabricated through hand lay-up technique and then being cut into three smaller panels (sample of experiment) with dimension of 270 mm x 90 mm shown in Figure 3.2. Nine samples were collected and five holes were produced for each of the sample as shown in Table 3.1. Marking process are conducted on each of the sample and details of specimen are described in Figure 3.3.

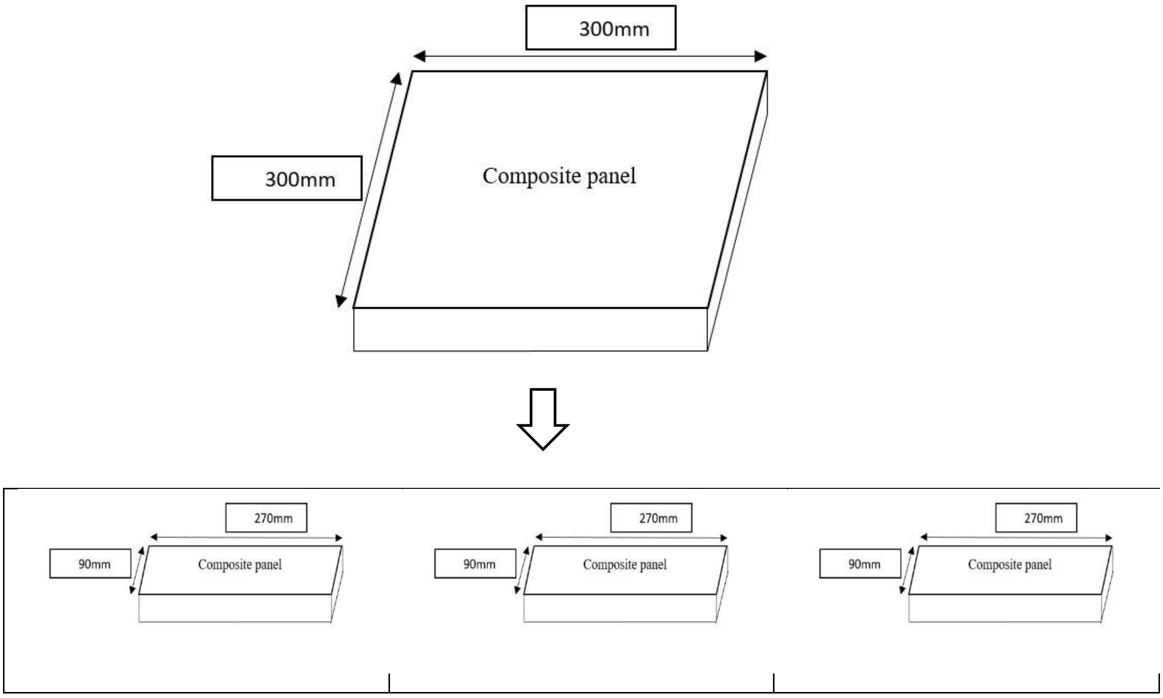


Figure 3.2: Preparation of specimen

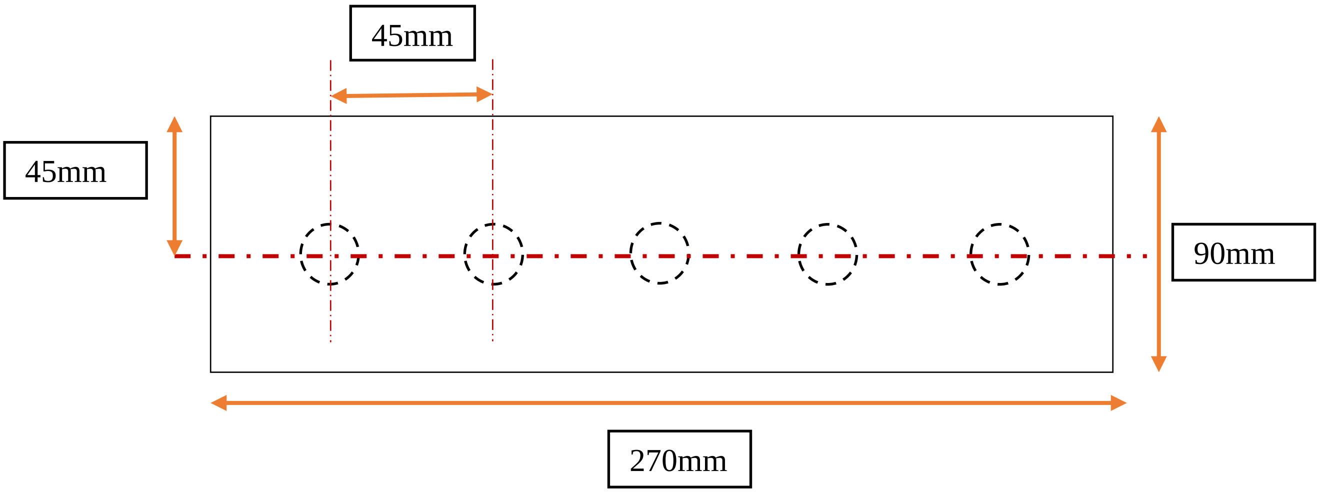


Figure 3.3: Marking process of specimens

Table 3.1: Details of samples

Method/Technique	Specimen (Panel)	Dimension	Thickness (mm)
Punching	A1	270mmx90mm	2.20
	A2	270mmx90mm	2.35
	A3	270mmx90mm	2.25
Drilling	B1	270mmx90mm	2.30
	B2	270mmx90mm	2.35
	B3	270mmx90mm	2.25
Hybrid process (Punching and Drilling)	C1	270mmx90mm	2.40
	C2	270mmx90mm	2.25
	C3	270mmx90mm	2.35

3.3 Methods in Hole-making

3.3.1 Method 1: Drilling

Several holes of Ø10 mm were produced on the composite panels using conventional drilling method as shown in Figure 3.1. The parameter are studied elsewhere and the experiment is conducted on composite panels. The productivity of the conventional drilling method are measured by recording the time taken to produce several holes of Ø10 mm. The quality of produced holes are evaluated and measured based on three quality aspects, namely, delamination factor, top and bottom surface diameter of produced hole, and surface roughness.

3.3.2 Method 2: Punching

Several holes of Ø10 mm were produced on composite panels using conventional punching. From recent studies, die clearance is identified as major influences on punching. For punching method, die clearance is determined based on equation proposed by Da (1985).

$$\frac{c}{t} = K\sqrt{S}$$

Where c is the single die clearance, t is the strip thickness, S is the material shearing strength, and K is the clearance coefficient, whose scale is K= 0.008-0.01. The shearing strength can be estimated using S=0.7 UTS. Hence a die set with 10mm punch diameter were selected for this experiment. The quality of produced holes will be measured based on three aspects namely delamination factors, top and bottom surface diameter of produced holes and surface roughness. The productivity of punching method will be measured based on the time taken to produce several holes on composite panels.

3.3.3 Method 3: Combination of Punching and Drilling Techniques

Several holes of Ø10 mm were produced on composite panels by using combination of punching and drilling method. Holes with diameter of Ø5 mm are created using punching method with punch diameter of Ø5 mm on the composite panels. Hybrid process is performed by creating holes using drilling method with diameter of Ø10 mm on the same centre and profile of the Ø5 mm produced holes.

3.4 Universal Testing Machine

For this work, Universal Testing Machine is used to perform punching method in hole-making process as it acted like a mechanical press to carry out the blanking process. The machine model used for this work is Instron – 3367 which is made by the Instron Corporation. The machine was designed to apply load on specimen through the moving crosshead, the drive system moves the crosshead up to apply a tensile load on the specimen, or down to apply a compressive load on the specimen. A load transducer or load cell is mounted in series with the specimen to measure the applied load. The load cell then converts the load into electrical signal so that the control system can measures and displays it. System performance of UTM machine are summarized in Table 3.2.

Table 3.2: System performance of Instron 3367 (Instron Corporation, 2004)

Parameter	**Specifications**
Testing type	Tension, compression, and through zero operation. Frame are also capable of limited cyclic testing.
Basic control	Closed loop position control
Load capacity (kN)	30
Minimum speed (mm/min)	0.005
Maximum speed (mm/min)	500
Maximum force at full speed (kN)	15
Maximum speed at full load (mm/min)	25
Return speed (mm/min)	600
Crosshead speed accuracy	±0.2% at steady state and no load
Position accuracy (extension)	Under no load condition, equal or less than ±0.02mm (0.0008in) or ±0.05% of displayed reading, whichever is greater
Position repeatability	±0.0015mm (0.00006in)
Load measurement accuracy	±0.5% of reading down to 1/100 of load cell capacity when using 2350 series load cells at 25°C
Strain measurement accuracy	±0.5% of reading down to 1/50 full scale with ASTM E83 class B or ISO 9531 class 0.5 extensometer
Crosshead position control resolution	0.054µm
Acceleration time, 0 to top speed (ms)	150
Emergency time (ms)	300

3.5 Conventional Milling Machine

Conventional milling machine is used to perform drilling method in-hole making process. Milling machine is used for this work to remove materials from a workpiece using rotary cutters. The specification of universal milling machine are tabulated in Table 3.3. A high speed steel CO 8% 4 flute end mill tool (Ø10mm) as shown in Figure 3.4 is used to perform drilling method in hole-making on composite panels. The parameters used to perform drilling method are studied elsewhere from previous journal.

Table 3.3: Specifications of Universal Milling Machine

Parameter	**Specifications**
Work table size	1100mmx40mm
Load capacity (kN)	30
Longitudinal travel	800mm
Cross travel	220mm
Vertical travel	400mm
Minimum spindle speed (rpm)	48
Maximum spindle speed (rpm)	1500
Minimum feed rate (mm/min)	0.11
Maximum feed rate (mm/min)	5.0
Rapid feeds (mm/min)	2.5

Figure 3.4: Ø10 mm high speed steel CO 8% 4 flute end mill tool.

3.6 Experimental Setup

3.1.6 Experimental Setup for Punching Method

A laboratory die rig was placed on an Instron - 3367 UTM as shown in Figure 3.5 with a punch travel speed of 5 mm/s which is 50% of the speed adopted in the industry (10 mm/s) and a tool punch was installed. The composite panel was clamped and precisely located as the punch will be travelled downward. Three samples are used for this punching method to produced five holes of Ø10 mm on each of the sample.

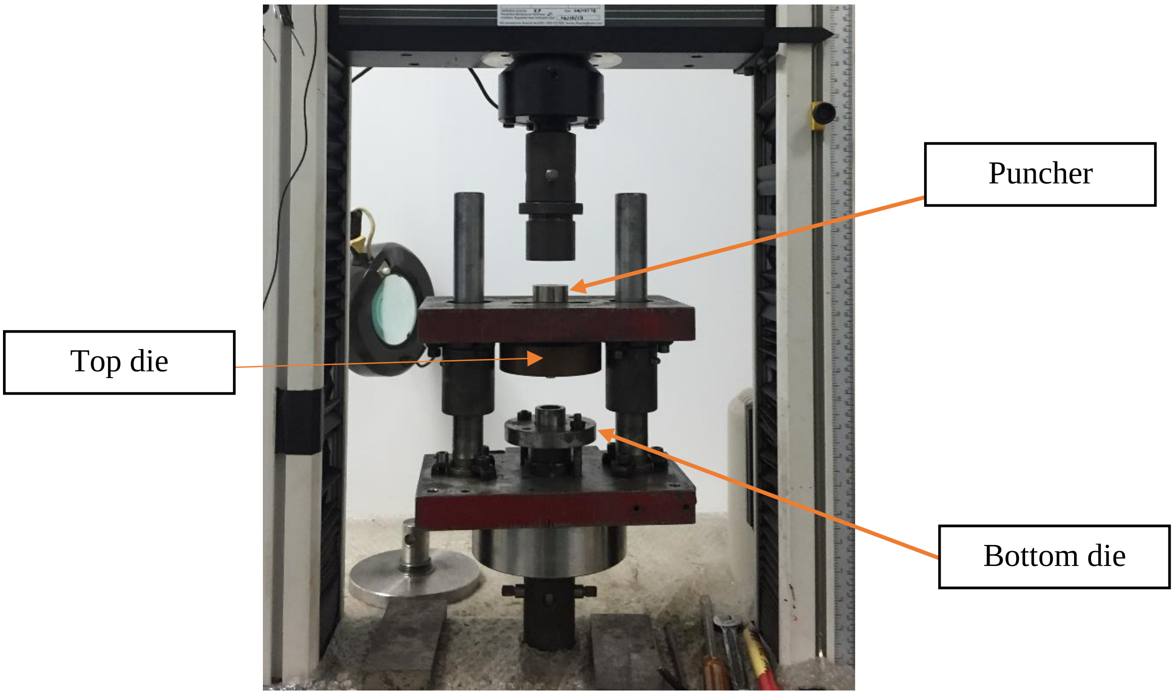


Figure 3.5: Experimental Setup of Punching

3.6.2 Experimental Setup for Drilling Method

Composite panel is clamped on the working table of the Conventional Milling Machine shown in Figure 3.6. Ø10 mm high speed steel CO 8% 4 flute end mill tool is used for the drilling method to produce Ø10 mm holes on the composite panel. The spindle speed of 1500 rpm and feed rate of 0.11 mm/min are decided to be the ideal parameters to perform this method. Three samples were used for this drilling method to produced five holes of Ø10 mm on each of the sample.

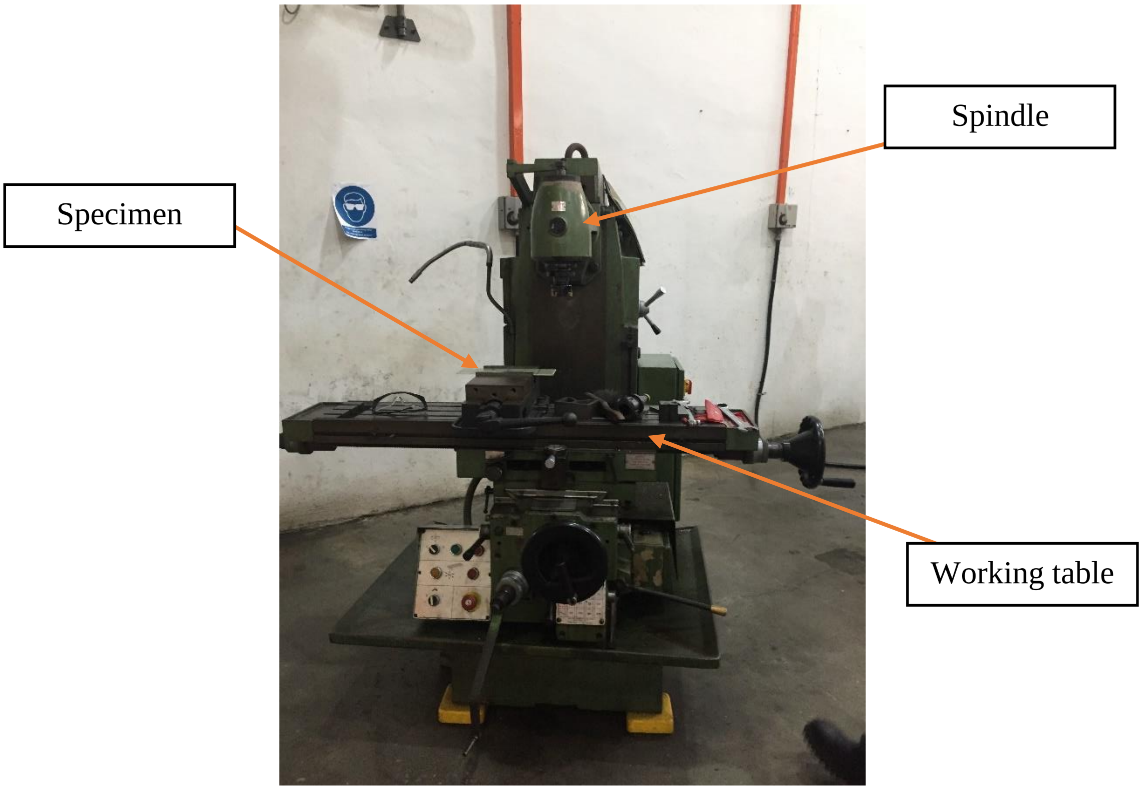


Figure 3.6: Conventional Milling Machine

3.6.3 Experimental setup of hybrid method

Hybrid method in hole-making of composite panel are performed by combining punching method and drilling method as a single process to produce Ø10 mm. Punching process was conducted first by producing Ø5 mm holes using UTM machine. The experimental setup followed the punching method except Ø5 mm punch tool is used for this experiment. Three samples were used for this hybrid method to produced five holes of Ø5 mm on each of the sample. The produced holes were drilled using Ø10 mm high speed steel CO 8% 4 flute end mill tool attached on the Universal Milling Machine.

3.7 Specimen Analysis

3.7.1 USB Microscope

The image of produced holes were captured using a USB microscope. An ordinary ruler is captured beside the holes to get accurate measurements. Figure 3.7 shows the setup of USB microscope.

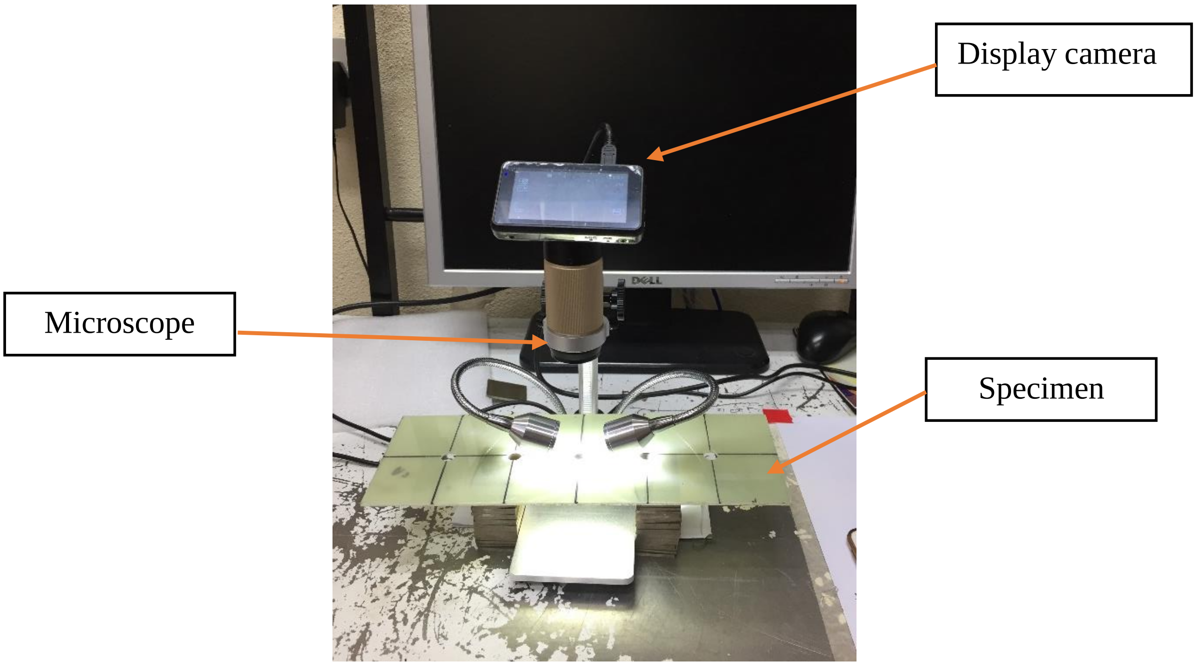


Figure 3.7: USB Microscope

3.7.2 ImageJ Software

The captured images from USB microscope were analysed using ImageJ software. This software can be used to get measurements such as areas, perimeters and lengths of selected surfaces of the images. Also, this software provides accurate and time-saving measurement and user-friendly. Area of produced holes can be measured by manually sketching the produced holes and analysed by ImageJ software to get the measurement. The maximum area and nominal area of produced holes were measured in this stage. The maximum diameter and nominal diameter were calculated elsewhere using the formula of area of circle. Figure 3.8 (a) and 3.8 (b) show the measurement of maximum diameter of produced holes using ImageJ software.