UNIVERSITI MALAYSIA PAHANG

BORANG PENGESAHAN STATUS TESIS♦

JUDUL: **EXPERIMENTAL ANALYSIS ON DRILLING PROCESS OF CFRP COMPOSITE LAMINATES**

SESI PENGAJIAN: **2008/2009**

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EXPERIMENTAL ANALYSIS ON DRILLING PROCESS OF CFRP COMPOSITE LAMINATES

LATIFAH BINTI MD YUSOFF

A report submitted in partial fulfillment of the requirements
for the award of the degree of the degree of
Bachelor of Mechanical Engineering and Manufacturing

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

NOVEMBER 2008

SUPERVISOR’S DECLARATION

We hereby declare that we have checked this project report and in our opinion this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Manufacturing.

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Date : 14 NOVEMBER 2008

STUDENT'S DECLARATION

I hereby declare that the work in this report entitled "Experimental Design Analysis on Drilling Process of Composite Laminates" is the results of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

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ID Number : ME05029
Date : 14 NOVEMBER 2008

Dedicated to my beloved father, Md Yusoff bin Mamat,
mother, Rukaiyah binti Muhamad, sisters,
and
my supervisor, Mohd Azmir bin Mohd Azhari.

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ABSTRACT

The principal aim of this work is to optimize the drilling process of composite materials namely carbon fiber reinforced plastics (CFRP). Aspects of tool materials and machining parameters on their influence against the thrust force and delamination were investigated. The chosen machining parameters are feed rate and spindle speed. The optimization process was achieved by a method called General factorial. Through analysis function (ANOVA) the factorial model was found to be significant since the P value is 0.0116 which is less than 0.05. Type of tools is the most significant factor followed by spindle speed. The less significant factor is feed rate. The optimal parameters were SPF tool, 2000 rpm of spindle speed and 400 mm/min of feed rate. The optimization result shows that this method was reliable with desirability 0.815. It was found that the optimization process is achieved by Factorial Design.

ABSTRAK

Matlamat utama kajian ini adalah untuk mengoptimumkan hasil keputusan proses penggerudian bahan komposit khususnya pada gentian karbon bertelulang plastik (CFRP). Aspek seperti bahan penggerudi, parameter pemesinan dan kesannya kepada daya tujah dan delaminasi dikaji. Parameter yang dipilih ialah kadar pemotongan dan kelajuan spindel. Proses pengoptimalan dicapai dengan kaedah ’General Factorial’. Melalui fungsi penganalisaan (ANOVA) model faktorial didapati berkesan dengan nilai P ialah 0.0116 dimana ianya kurang daripada 0.05. jenis-jenis penggerudi adalah faktor yang paling memberi kesan diikuti dengan faktor kelajuan spindel. Faktor yang kurang berkesan ialah kadar pemotongan. Parameter yang optimum ialah penggerudi jenis SPF, kelajuan spindel 2000rpm dan kadar pemotongan 400 mm/min. Keputusan pengoptimalan telah menunjukkan bahawa kaedah ini adalah berkesan dengan kehendaknya 0.815. Ini telah menunjukkan bahawa process pengoptimalan adalah dicapai oleh ’Factorial Design’.

TABLE OF CONTENTS

CHAPTER 1 INTRODUCTION

CHAPTER 2 LITERATURE REVIEW

CHAPTER 3 METHODOLOGY

CHAPTER 4 RESULTS AND DISCUSSION

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CFRP	Carbon Fiber Reinforced Plastic
CNC	Computer Numerical Control
EDM	Electro Discharge Machining
MMC	Metal Matrix Composite
AFRP	Aramid Fiber Reinforced Plastic
SA	Simulated Annealing
PVD	Physical Vapour Deposition
SPF	Split Point Fiber
HSS	High Speed Steel
ANOVA	Analysis of Variance

CHAPTER 1

INTRODUCTION

1.1 Introduction

Fiber reinforced plastics have been widely used for manufacturing aircraft and spacecraft structural parts because of their particular mechanical and physical properties such as high strength to weight ratio [1]. Drilling of these composite materials, irrespective of the application area, can be considered a critical operation owing to their tendency to delaminate when subjected to mechanical stresses. The largest amount of money was spent on drills. Therefore, optimization of drilling process was extremely important for the manufacturing industry. With regard to the quality of machined component, the principal drawback was related to surface delamination. Among the defects caused by drilling, delamination appears to be most critical. Factors such as cutting parameters, end tool geometries/materials must be carefully selected in aiming to obtain the best performance on the drilling operation, i.e.: best hole quality. Therefore this paper aims to present an optimization process on drilling operation of carbon fiber reinforced plastics (CFRP).

1.2 Problem statement

While drilling was frequently used for the laminate composites, the drilling cause of delamination was a major concern. Therefore in this study, the drilling process on carbon fiber reinforced plastic (CFRP) was conducted by using CNC milling machine. CNC milling machine was used due to the fact that the normal drilling machine will not produce good drilling result. Some parameters were selected in order to study the quality of drilling process on CFRP. The control parameters are set to be the feed rate, spindle speed and type of cutting tool. It was decided to study the effect of these parameters on the delamination of CFRP and thrust force during drilling. For the function optimization, General Factorial was implemented in model formulation and analysis.

1.3 Objective

To study and optimize the drilling process of CFRP using General Factorial method.

1.4 Scope

A study was conducted to find the optimum parameters of drilling process on carbon fiber reinforced plastic (CFRP) composite. The optimization that used was General Factorial Optimization. The parameters studied are feed rate, spindle speed, and types of the tool material. The best parameters were selected from the studied parameters to minimize the effects of delamination and cutting force on drilling process.

1.5 Arrangement of report

1.5.1 Chapter 1

Chapter 1 was a brief review of the study that was conducted. It also outlines the objective, problem statement, scope of study and the flow chart of methodology for FYP.

1.5.2 Chapter 2

Chapter 2 gives a wholesome review about the research that has been done by others related to this study. Many journals have been shown here to obtain different views on the topic of study.

1.5.3 Chapter 3

Chapter 3 gives full details on ways how experiment was performed in this study. It shows how machine was conducted, equipments and the optimization method used.

1.5.4 Chapter 4

Chapter 4 gives the results that were outcomes from this study.

1.5.5 Chapter 5

Chapter 5 summarizes the whole study.

1.6 PLAN OF WORK

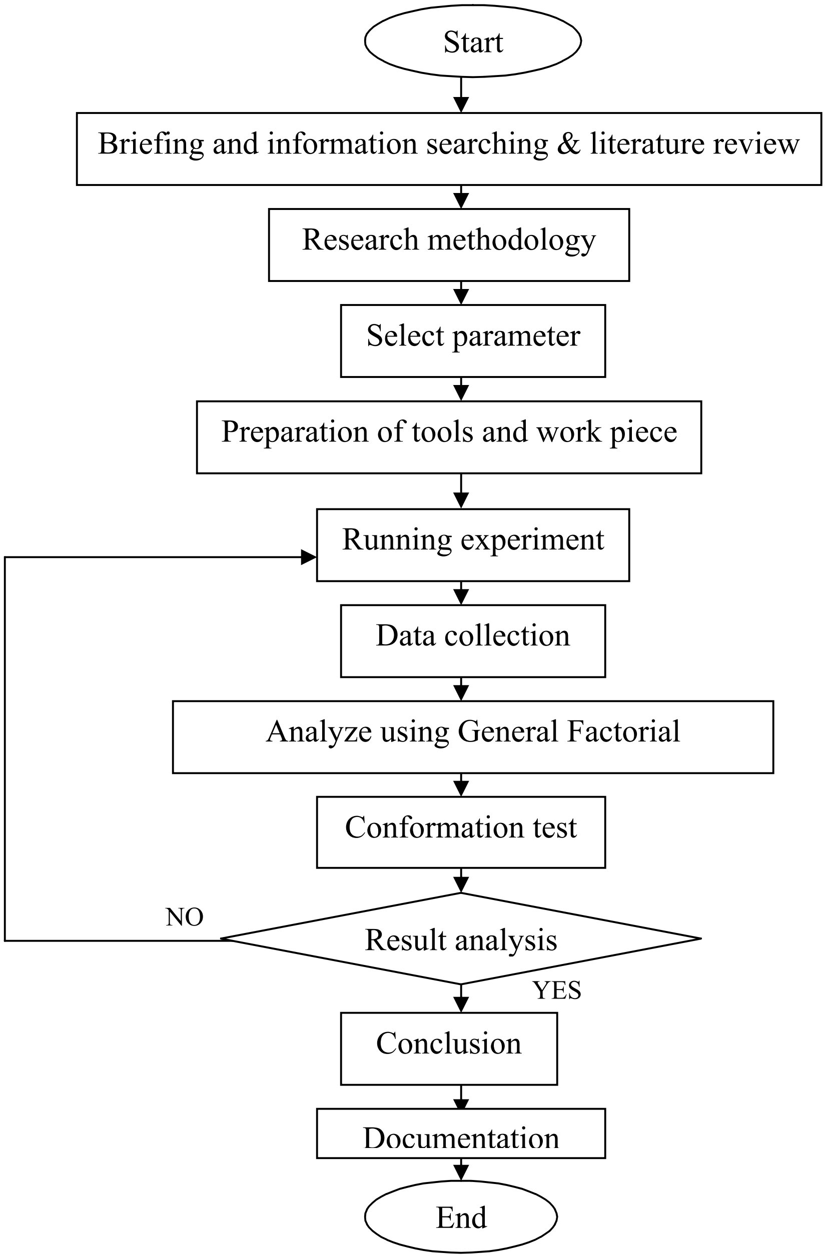
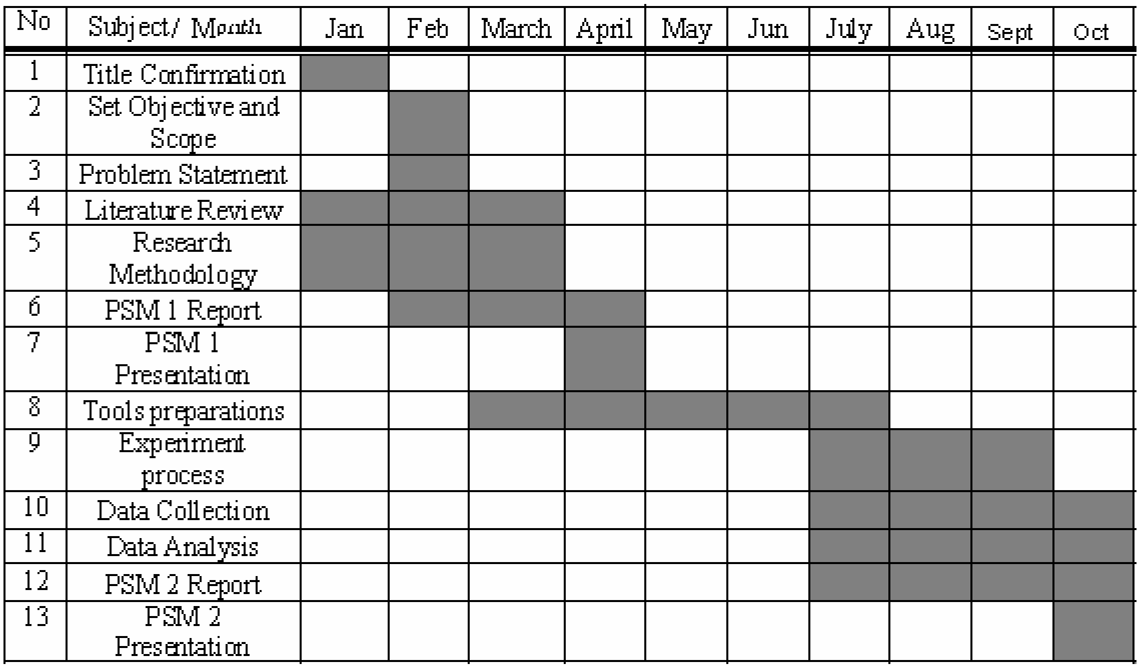


Figure 1.1: Methodology flow chart



No	Subject/ Month	Jan	Feb	March	April	May	Jun	July	Aug	Sept	Oct
1	Title Confirmation	■									
2	Set Objective and Scope		■								
3	Problem Statement		■								
4	Literature Review	■	■	■							
5	Research Methodology	■	■	■							
6	PSM 1 Report		■	■	■						
7	PSM 1 Presentation				■						
8	Tools preparations			■	■	■	■	■			
9	Experiment process							■	■	■	
10	Data Collection							■	■	■	■
11	Data Analysis							■	■	■	■
12	PSM 2 Report							■	■	■	■
13	PSM 2 Presentation										■

Table 1.1: plan of work for final year project

CHAPTER 2

LITERATURE RIVIEW

2.1 Introduction

A Composite in engineering sense is any materials that have been physically assembled to form one single bulk without physical blending to foam a homogeneous material [2]. There are two or more materials could be combined to take advantage of the good characteristics of each of the materials. Have two constituent materials in making a composite, there are matrix and reinforcement [3]. At least one portion of each type is required. The matrix was using to support the reinforcement materials by maintaining their relative positions. The reinforcements impart their special mechanical and physical properties to enhance the matrix properties. Advanced composites contain strong, stiff, engineering fibers embedded in a high performance matrix. The application of composite material was gained in high performance products. It can be seen in the founding of aerospace component like tails, wings, fuselages and propellers. Other uses also included boat, bicycle frames, fishing rods and storage tanks.

2.1.1 Aerospace materials (history of composites)

Aluminum played an essential role in aerospace history from its very inception. In the first flight of the Wright Flyer in 1903, the engine crankcase was made from aluminum alloy with 8% copper. This sets the stage for aluminiums' critical role in aircraft industry. In 1910 the alloy 2017-T4, was used in the construction of propellers and dirigibles, including the USS Shenandoah. During the 1940's alloy 7075-T651 was used on the B-29. It was not until the late 1960s' that the application of composite was used widespread in the aircraft industry. Composites are the most important materials to be adapted for aviation since then. Composites are materials that are combinations of two or more organic or inorganic components. Fiberglass is the most common composite material, and consists of glass fibers embedded in a resin matrix. Fiberglass was first used in the Boeing 707 passenger jet in the 1950s, where it comprised about two percent of the structure. By the 1960s, other composite materials became available, in particular boron fiber and graphite, embedded in epoxy resins. The U.S. Air Force and U.S. Navy began research into using these materials for aircraft control surfaces like ailerons and rudders. The first major military production use of boron fiber was for the horizontal stabilizers on the Navy's F-14 Tomcat interceptor. By 1981, the British Aerospace-McDonnell Douglas AV-8B Harrier flew with over 25 percent of its structure made of composite materials. Modern airliners use significant amounts of composites to achieve lighter weight. About ten percent of the structural weight of the Boeing 777, for instance, is composite material. Modern military aircraft, such as the F-22, use composites for at least a third of their structures, and some experts have predicted that future military aircraft will be more than two-thirds composite materials. Aluminium still remains a remarkably useful material for aircraft structures and metallurgists have worked hard to develop better aluminium alloys (a mixture of aluminium and other materials) [4].

2.1.2 Machining of composites

Because of the composite's structure of very strong fibers in a softer matrix, conventional machining techniques do not work effectively. Machining operation such as cutting and drilling are difficult to perform on composite with conventional tools and techniques because of their properties including anisotropy, low thermal conductivity and resistance of the reinforcement. Another, conventional machining may cause hazardous delaminating, splintering, and fraying and also due to heavy tool wear caused by the presence of the hard reinforcement. Because of the problem, several advances have been made in the machining of these materials. There has been growing interested in electro discharge machining (EDM) and laser cutting. Laser cutting was performed on all composite materials whereas EDM was only performed on conducting composite. W.S. Lau et al. [5] conducted a study of un-conventional machining of composite materials that is EDM and laser process. In their study, two types of polymer composites, (carbon fiber and reinforced liquid crystal polymer), one type of metal matrix composite (MMC) material and one type of conductive ceramic material were used. Their studies showed that laser process can produce a cleaner cut surface with less damage. Unconventional machining also can reduce the heavy tool wear caused by the presence of the hard ceramic reinforced. Since cemented carbide tools wear rapidly in conventional machining, diamond-impregnated tools may have to be used. To overcome the rapid tool wear experienced in conventional machining of some composites containing hard, abrasive, or refractive constituents, unconventional machining operations such as waterjets have been adopted. Waterjets are being used extensively to cut and machine these materials. The majority of waterjet systems used in aerospace are abrasive waterjet units. That is, an abrasive, usually garnet or aluminum-oxide grain is introduced into the high-pressure water stream. Some aerospace applications use water-only systems. Although the process is used for cutting many metals, the main applications are trimming and hole making in composite materials.

2.2 Drilling of composites

2.2.1 CNC drilling of composites

Computer Numerical Control (CNC) Drilling is commonly implemented for mass production. The drilling machine, however, is often a multi-function machining center that also mills and sometimes turns. The largest time sink for CNC drilling is with tool changes, so for speed, variation of hole diameters should be minimized. The fastest machines for drilling varying hole sizes have multiple spindles in turrets with drills of varying diameters already mounted for drilling. The appropriate drill is brought into position through movement of the turret, so that bits do not need to be removed and replaced. A turret-type CNC drilling machine is shown below. A variety of semi-automated drilling machines are also used. An example is a simple drill press which, on command, drills a hole of a set depth into a part set up beneath it. In order to be cost-effective, the appropriate type of CNC drilling machine needs to be applied to particular part geometry. For low-volume jobs, manual or semi-automated drilling may suffice. For hole patterns with large differences in sizes and high volume, a geared head is most appropriate. If holes are close to each other and high throughput is desired, a gearless head can locate spindles close together so that the hole pattern can be completed in one pass. CNC machining also can use water cutting for complex shapes where using a router would be too in-efficient. High pressure water cutting provided excellent results although if surface finish is required then solid carbide is the one to use. In CNC machining, diamond routing tools used to slot and machine heavy thicknesses. Diamond is essential in most Composite operations. N.S Mohan et al. [6] conducted a series of experiment using TRIAC VMC CNC machining center to machine the composite laminate specimens at various cutting parameter and material parameters. It is necessary to use CNC control to drill glass fiber reinforced plastic (GFRP) that have many excellent properties.

2.2.2 Cutting tools

Composite materials are used extensively as their higher specific properties of strength and stiffness. These materials are difficult to machine and because of that the selections of tools materials, specifications and types of tools have a big role in produce the best drilling product of composite. X.H Zheng et al. [7] conducted a research on the cutting performance of carbon nitride cutting tools. The C_3N_4 coated tools used in their experiments. Their studies showed that the anti-wear ability of a cutting tool increases sharply after C_3N_4 has been coated on HSS tool. A coated HSS drill also has some benefit after being reground. The tool life also prolonged after C_3N_4 has been coated on cemented carbide inserts, but is not so long as that of a C_3N_4 coated HSS tool.

In a studies about machining of composite material that a conducted by R.Teti [8], he used many types of drill material and performed it on difference types of composite. The results in the case of Glass Fiber Reinforced Plastics (GFRP) and Carbon Fiber Reinforced Plastics (CFRP) it is the cutting tool material that dominates the tools selection. Meanwhile for the Aramid Fiber Reinforced Plastic (AFRP), it is the tool geometry that dictates the choice of the cutting tool. Carbide tools, coated carbide tools and PCD tools yield good results in terms of tool wear and tool life during the machining of GFRP and CFRP. They also state that to guarantee that the fibers are severed in a clean cut, it is important to ensure very high cutting edge sharpness.

J.P Davim and Pedro Reis [9] conducted a study of delamination in drilling carbon fiber reinforced plastics using different type of drill material. Their studies showed that carbide drills exhibit an almost null wear land compared to HSS drills which presented a significant wear value. Their results also showed that the helical flute K10 drill, presents a better performance then helical flute HSS drill, i.e. the carbide drill is the better choice for drilling Carbon Fiber Reinforced Plastic (CFRP).

Piquet et al. [10] carried out a study on drilling thin carbon/epoxy laminates with two types of drills: a twist drill (4.8mm diameter, twist angle of 25◦, rake and clearance angles of 6◦) and a drill with special geometry (4.8mm diameter, three cutting edges, twist and rake angles of 0◦ and clearance angle of 6◦). Both drills presented a major cutting edge angle of 59◦, but the special drill had a minor cutting edge angle varying from 59◦ to 0◦. The results indicated a superior performance of the special geometry drill confirming that the principal cutting edge significantly affects the hole quality. According to their study, the smaller contact length between the special geometry drill and the hole resulted in less delamination.

Bhatnagar et al. [11] and Singh and Bhatnagar [12] carried out a comparative study aiming to evaluate the influence of the drill geometry on unidirectional laminates glass reinforced plastics. The results showed that the tool materials and geometries used to drill polymeric composites. He found that high-speed steel (HSS) and tungsten carbide (ISO grades K10 and K20) are equally used as tool materials, while polycrystalline diamond (PCD) is seldom tested. Matthew et al. [13] realized that superior hole quality is obtained when drilling with trepanning tools, compared to conventional twist drills, as long as a higher number of edges and a centre pilot drill are employed. Lachaud et al. [14] classified the damages of drilling polymeric composite materials into four categories: delamination at drill entry, geometric defects, temperature-related damages and delamination at drill exit. The tool geometry related damages are associated to the angle between fibres orientation and the cutting edge.

2.2.3 Drilling parameters

In the drilling of composite the quality of the cut surfaces is strongly dependent on the appropriate choice of drilling parameters. Aoyoma et al. [15] carried out an experimental work on glass reinforced plastic 1.6mm thick using a drill with 1mm of diameter, a cutting speed of 15.7m/min and a feed rate of 0.063 mm/rev. the authors found that the damage is larger when the angle between the cutting edge and fibre direction is 45^o. They also found an almost linear relationship between roughness (R_{max} value) and damage width.

In order to assess the mechanics of delamination under distinct work material supporting conditions (with and without backing), Capello [16] and Tsao and Hocheng [17] asserted that when drilling without backing the work material delamination takes place due to both a change of the feed rate value and the overload on the periphery of the cutting edges. These phenomena are caused by inflection of the work material followed by the release movement that happens when the chisel edge exits the work piece. The former author proposed a damping system able to reduce delamination by reducing the relative work piece-drill speed during the release stage without the need of backing.

For Ogawa et al. [18] in their study about investigation on cutting mechanism in small diameter drilling for GFRP found that feed rate is the most significant factor affecting the surface roughness of holes. Moreover, an increase in trust force results in inferior surface finish on the hole wall. Lin and Chen [19] investigated tool wear, when high speed drilling fiber reinforced plastics they found out that an increase in cutting speed leads to an increase in tool wear, which in turn provokes an elevation in trust force, which may impair the quality of the machined component. Chambers and Bishop [20] conducted a study the drilling of carbon fiber polymer matrix composites. They also investigated tool wear after drilling polymeric composites and asserted that it is rather difficult to obtain the surface quality required for an accurate assembly of structural components.

Khashaba [21] in his study about delamination in drilling GFR-thermoset composites investigated that the machining of GFRP composites produced using distinct matrix materials (epoxy and polyesters resins) and reinforcing shapes (chopped, cross winding continuous winding and woven). The authors reported that in contrast to other reinforcing shapes, when drilling the cross winding composite a gradual decrease in thrust force was observed at the drill exit, resulting in a surface without delamination. When machining the woven composite with different matrix materials, the author concluded that the matrix had negligible effect on thrust force; however, torque was higher when drilling the polyester composite. Increasing cutting speed resulted in lower thrust force and torque due to the higher temperatures produced by the increase in heat generation associated with the low coefficient of thermal conduction together with the low transition temperature of plastics.

Davim et al. [22] conducted an experimental study of drilling glass fiber reinforced plastics (GFRP). Authors studied the behavior of two cemented tungsten carbide drills with distinct geometries (“Stub Length” and “Brad & Spur”) when machining a glass fiber reinforced plastics. The results indicated that the thrust force increased with feed rate, however, lower values were recorded when using the Brad & Spur drill. From the study, the authors also found the effect of the cutting speed on both thrust force and torque was negligible within the cutting range tested.

Similar work was carried out by El-Sonbaty et al. [23] in their study of factors affecting the machinability of GFR/epoxy composites. Authors who tested the same work material using five cutting speeds ranging from 5.5 to 46.5 m/min and three feed rates (0.05-0.1 and 0.23 mm/rev). The authors found that there is a delay between the response for thrust force and torque, after which the former reaches a maximum value. From this point the thrust value is reduced (probably due to the softening of the matrix caused by friction) and the torque increases due to the fact that the last fibres are not shared, but entangled in the drill. They also noticed that the effect of cutting speed on thrust force is negligible, whereas torque increases with cutting speed. Surface roughness was not significantly affected by both cutting speed and feed rate.

2.3 Optimization methods

2.3.1 Simulated annealing

A technique to find a good solution to an optimization problem by trying random variations of the current solution. A worse variation is accepted as the new solution with a probability that decreases as the computation proceeds. The slower the cooling schedule, or rate of decrease, the more likely the algorithm is to find an optimal or near-optimal solution. Chen et al. [24] have used the combination of pattern search (PS) and simulated annealing for solving optimization problems. Their research about an optimization algorithm based on the simulated annealing (SA) algorithm and the Hooke-Jeeves pattern search (PS) is developed for optimization of multi-pass turning operations.

2.3.2 Taghuchi

Dr. Taguchi of Nippon Telephones and Telegraph Company, Japan has developed a method based on “ORTHOGONAL ARRAY” experiments which gives much reduced “variance” for the experiment with “optimum settings “of control parameters. E.Ugo et al. [25] carried out an experimental an approach for development of damage-free drilling of carbon fiber reinforced thermosets. The authors found that the results generated from the Taguchi method are used for constructing process maps for the machinability of carbon fiber reinforced epoxy composites. These maps are effective tools can be used for robust process design.

2.3.3 Genetic algorithm

This method used in computing to find exact or approximate solutions to optimization and search problems.Genetic algorithms are original systems based on the supposed functioning of the Living. The method is very different from classical optimization algorithms. A genetic algorithm was used to solve multi-pass turning optimization problems by Onwubolu et al. [26].They have shown that genetic algorithm-based approach outperforms the simulated annealing based approach

2.3.4 Factorial design

Factorial design is used when there are several factors that have multiple levels. P.G. Paterakis et al. [28] carried out an experiment that is Evaluation and simultaneous optimization of some pellets characteristics using a 33 factorial design and the desirability function. They found that Factorial design is a useful tool in order to characterize multivariable processes. It gives the possibility to separate the important factors from those, which are not, and identifying any possible interactions between them.

2.4 New trend in machining of composites

2.4.1 Deep drilling trend

Deep drilling trends are advanced and emerging drillstring technologies. New materials and designs open the way forward for ultra-deep drilling. Drilling ultra-deep wells places significant requirements on the drillstring. Lengthy drillstrings lead to high tensile loads, which lead to slip-crushing, hoisting issues and drill pipe collapse capacity concerns at the blowout preventer. BOP shear rams may also have difficulty cutting today's high-strength, high toughness drill pipe. BHA connection failures pose greater risk and cost at ultra-deep well depths. Industry's move toward UDD has led to increased consideration of non-steel drill pipe. Three advanced materials are included in this discussion: carbon fiber composites, titanium and aluminum. These have been studied and each has been employed in drillstrings with varying degrees of frequency and success. Presently, CDP is about three times the cost of conventional steel drill pipe. As the technology improves, this differential may decrease [27].

2.4.2 New drill bit technology

A new generation of durable, lightweight materials that can withstand the difficult conditions encountered during deep drilling while delivering superior performance will play a key role in reducing costs and increasing rate of penetration. Lighter weight drillstring components will extend the depth rating of conventional drilling rigs, currently limited by the weight of suspended drillstring they are designed handle. This could reduce the need to build new large rigs to meet increased depth requirements. Innovations in metallurgy and plastics technology and in the development of composite materials, show great potential for being adapted for drilling applications. For example, the recently developed composite carbon fiber-epoxy resins have been manufactured into lightweight drill pipe. Future research must be devoted to developing durable, inexpensive coatings and application processes that will extend the life of critical parts and reduce the amount of downtime spent on maintenance and replacement [27].

CHAPTER 3

METHODOLOGY

3.1 Introduction

The methodology used in this study is to obtain the optimum result for drilling process on carbon fiber reinforced plastic (CFRP) by using an appropriate optimization method. The data was collected are thrust force during the drilling process and delamination of the drilled hole on the composite.

Drilling of these composite materials, irrespective of the application area, can be considered a critical operation owing to their tendency to delaminate when subjected to mechanical stresses. Thus it is important to know the parameters that will give optimum drilling result on CFRP. Therefore the best parameters (feed rate, spindle speed and types of tool) to give the optimum drilling performance (thrust force and delamination) can be predicted by General Factorial design. The summary of the research methodology is shown in figure 3.1

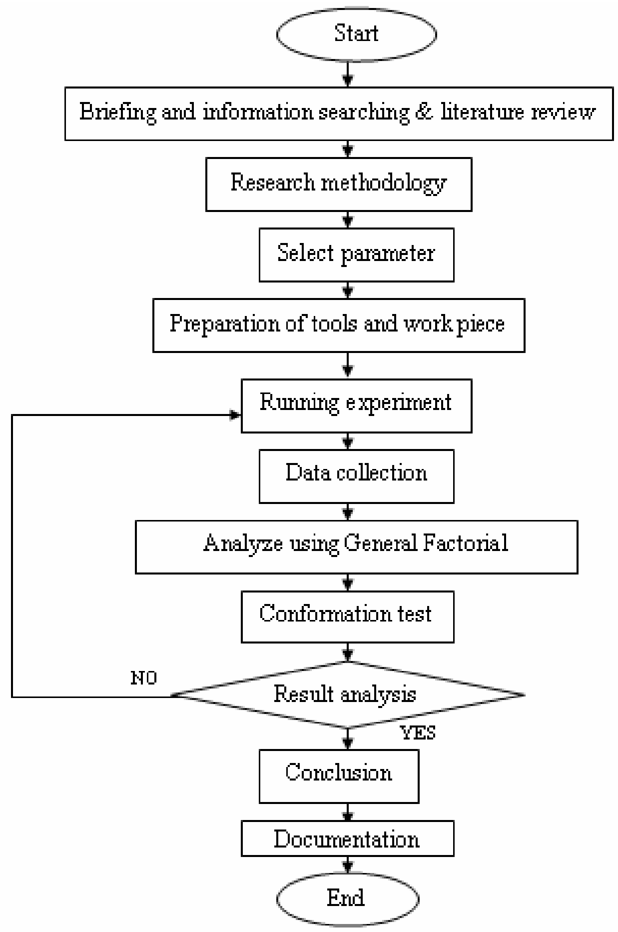


Figure 3.1: summary of research methodology

3.2 Material

The composites used for the tests were carbon fiber reinforced plastic (CFRP) named unidirectional and woven graphite and glass cloth faced aramid honeycomb core floor panel stock, BMS 4-20, an aircraft material. This composite is a very strong, light and expensive composite material or fiber reinforced plastic. The composite material is commonly referred to by the name of its reinforcing fibers (carbon fiber). The plastic is most often epoxy, but other plastics, such as polyester, vinyl ester or nylon, are also sometimes used.

The fiber used in this study is made of medium-density core, with faces approximately 0.015 inch thick. The dimension of the sample that is used is 165mm x 100mm. The material has an areal weight of 0.64 lb/sq ft max. A long beam load of 230 lb, and a deflection of 0.85 inch. Panel shear is recorded to be 585 lb, insert shear of 840 lb, impact strength of 35 lb and a stabilized core compression of 1600 lb/sq in.

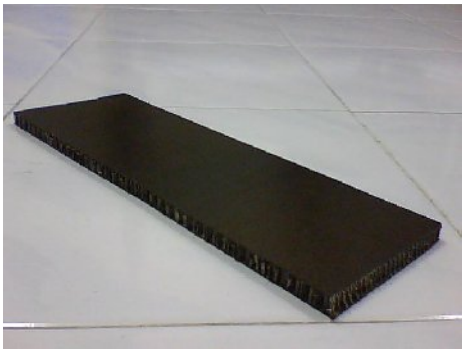


Figure 3.2: Carbon fiber reinforced plastic (CFRP)

3.2.1 Properties of material

Table 3.1: properties of the CFRP

Properties	Areal weight (Lb/sq ft max)	Thickness (Inch, range)	Long beam bending [load] (lb)	Long beam bending [deflection] (lb)	Panel shear (lb/inch)	Impact strength (in – lbs)	Stabilized core compression (lb/sq in)
Values	0.64	0.39-0.41	230	0.85	585	35	1600

Source: BOEING Material specifications (2007)

3.2.2 Fabrication of material

This material was produced by many methods. One method of producing graphite-epoxy parts is by layering sheets of carbon fiber cloth into a mold in the shape of the final product. The alignment and weave of the cloth fibers is chosen to optimize the strength and stiffness properties of the resulting material. The mold is then filled with epoxy and is heated or air cured. The resulting part is very corrosion-resistant, stiff, and strong for its weight. Parts used in less critical areas manufactured by draping cloth over a mold, with epoxy either preimpregnated into the fibers (also known as prepreg), or "painted" over it. High performance parts using single molds are often vacuum bagged and/or autoclave cured, because even small air bubbles in the material will reduce strength.

The process in which most carbon fiber reinforced plastic is made varies, depending on the piece being created, the finish (outside gloss) required, and how many of this particular piece are going to be produced. For simple pieces of which relatively few copies are needed, (1–2 per day) a vacuum bag can be used. A fiberglass or aluminum mold is polished, waxed, and has a release agent applied before the fabric and resin are applied and the vacuum is pulled and set aside to allow the piece to cure (harden).

There are two ways to apply the resin to the fabric in a vacuum mold. One is called a wet layup, where the two-part resin is mixed and applied before being laid in the mold and placed in the bag. The other is a resin induction system, where the dry fabric and mold are placed inside the bag while the vacuum pulls the resin through a small tube into the bag, then through a tube with holes or something similar to evenly spread the resin throughout the fabric. Wire loom works perfectly for a tube that requires holes inside the bag.

Both of these methods of applying resin require hand work to spread the resin evenly for a glossy finish with very small pin-holes. A third method of constructing composite materials is known as a dry layup. Here, the carbon fiber material is already impregnated with resin (prepreg) and is applied to the mold in a similar fashion to adhesive film. The assembly is then placed in a vacuum to cure. The dry layup method has the least amount of resin waste and can achieve lighter constructions than wet layup. Also, because larger amounts of resin are more difficult to bleed out with wet layup methods, prepreg parts generally have fewer pinholes. Pinhole elimination with minimal resin amounts generally requires the use of autoclave pressures to purge the residual gases out.

A quicker method uses a compression mold. This is a two-piece (male and female) mold usually made out of fiberglass or aluminum that is bolted together with the fabric and resin between the two. The benefit is that, once it is bolted together, it is relatively clean and can be moved around or stored without a vacuum until after curing. However, in this study, material is obtained from the suppliers of BOEING materials. Therefore material fabrication was not necessary in this study.

3.3 Machine

Figure 3.3: CNC milling machine that used in this study

In this study, CNC machine used to drill the composite. The abbreviation CNC stands for computer numerical control, and refers specifically to a computer "controller" that reads G-code instructions and drives a machine tool, a powered mechanical device typically used to fabricate components by the selective removal of material. CNC does numerically directed interpolation of a cutting tool in the work envelope of a machine. The operating parameters of the CNC can be altered via a software load program. The machine that will be used in this study is named CNC MILLING (FANUC). The model is FANUC ROBODRILL (T14 iFEe). It is a 3 axis machine which means it could move in 3 axes namely X, Y and Z. Maximum spindle speed that could be accepted by this machine is 10 000 rpm. The range of feed rate is 1 to 30,000mm/min. This CNC milling machine could accommodate up to 14 tools with a maximum tool diameter of 80mm and maximum tool length of 250mm. The work piece table could withstand a maximum load of 250kg. This machine is manufactured in Japan.

3.4 Experimental Setup

3.4.1 Experimental Planning

In this study General Factorial design will be implemented to find the optimal parameters in the drilling process. General factorial is a branch of Factorial design that is a simple and important statistic tool. For the function optimization, General Factorial is implemented in model formulation and analysis. For more than two factors, a 2^k factorial experiment can be recursively designed from a 2^{k-1} factorial experiment by replicating the 2^{k-1} experiment, assigning the first replicate to the first (or low) level of the new factor, and the second replicate to the second (or high) level. For this study, there are three factors with three levels. This framework can be generalized to, *e.g.*, designing three replicates for three level factors, etc.

A factorial experiment allows for estimation of experimental error in two ways. The experiment can be replicated, or the sparsity-of-effects principle can often be exploited. Replication is more common for small experiments and is a very reliable way of assessing experimental error. When the number of factors is large (typically more than about 5 factors, but this does vary by application), replication of the design can become operationally difficult. In these cases, it is common to only run a single replicate of the design, and to assume that factor interactions of more than a certain order (say, between three or more factors) are negligible. Under this assumption, estimates of such high order interactions are estimates of an exact zero, thus really an estimate of experimental error.

For this study, Design-Expert software was used to implement General Factorial for the purpose of analysis and optimization. By using this software, it will set up a design on multiple categorical factors. As with any statistical experiment, the experimental runs in a factorial experiment should be randomized to reduce the impact that bias could have on the experimental results. In practice, this can be a large operational challenge. By using the software, General factorial allows to have factors that each has a different number of levels. It creates an experiment that includes all possible combination of factor level in this study.

Part two of this software shows how to convert truly continuous factors, such as feed rate and spindle speed for this case. All factors should be categorical rather than numeric. Categoric factors can either be specified as nominal or ordinal. This specification determines the type of mathematical contrasts that are used. Ordinal will generate orthogonal contrast that can be used to define the linear, quadratic, etc.

- Use nominal if the categoric levels are simply names or labels. In this case, it doesn't matter which one is first or second and the nominal factor is tools
- Use ordinal if the levels represent an ordered relationship. An example of ordinal is low, medium and high or slow and fast. In this case, the ordinal factors are feed rate and spindle speed.

A factorial experiment can be analyzed using ANOVA or regression analysis. It is relatively easy to estimate the main effect for a factor. These tips are just for the key elements in the ANOVA report.

- Model P-value

  Look at the Model p-value - it should be less than 0.05 to be strongly significant. Between 0.05 and 0.10 is marginally significant - use subject matter knowledge to decide if the effect is worth pursuing or not.

- Term p-values

  Confirm that each of the terms has a p-value less than 0.05 or at least less than 0.10. If a term is not significant, then it should be removed from the model UNLESS it is needed to satisfy hierarchy (i.e. it is a parent term of a significant interaction.)

- Block term

  If the Block mean square value is 3-4x greater than the Residual Mean Square, then it would generally be considered a large effect.

- R-squared values

  Look at the adjusted and predicted R-squared values. If this is a response surface design you want to use for modeling the design space, then the R-squared values should be rather high (perhaps above 0.60, but this is not a "set in stone" rule.)

  If this is a factorial design you are using to simply identify the significant factors, then it really doesn't matter what the value is. The significant factors are still significant, even if the polynomial isn't perfect.

- Curvature

  If you have a curvature term and it is significant, then the middle of the design space is not linear. Predictions in the middle of the design space will not be correct. You may consider augmenting this design to estimate higher-order terms such as quadratic.

- Lack of fit

  If you have a lack of fit term and it is significant, this means that the polynomial model is not fitting all of the design points well. You may need a higher order model, or perhaps a transformation. Look for outliers. Or, sometimes a polynomial just can't describe the system very well.

3.4.2 Experimental procedure

To design the experiments, the following steps are to be implemented: the selection of the appropriate optimization method for drilling process of fiber reinforced plastics composite (CFRP), select parameters to study and preparation of tools and work piece. The essential steps in this study include identifying factors that are to be included in the study and determining the factor levels. Size of the cutting tools in this drilling process will be fixed for all set of experiments. The control parameters are set to be the feed rate, spindle speed or RPM and type of cutting tool. In this study it has been decided that carbide tools will be chosen to drill holes on the CFRP. There have three different types of carbide tools will be used to study the variation on hole quality on CFRP. Type of drill material with two main categories which is solid carbide and coated carbide tools mainly. It was decided to study the effect of these parameters on the delamination of CFRP and trust force during drilling. The range of the input parameters was fixed as given in Table 3.2.

Table 3.2: Machining parameters and their levels for each type of different types of carbide tools

Machining parameter	Level 1	Level 2	Level 3
Spindle speed (rpm)	2000	5000	8000
Feed Rate (mm/min)	200	400	600

The composites used for the tests were carbon fiber reinforced plastic (CFRP) named unidirectional and woven fiberglass faced aramid honeycomb core floor panel stock. The dimension of the sample that is used is 165mm x 100m. A computer numerical control (CNC) milling machine will use for the drilling experiments. Figure 3.4 shows a schematic of the drill exit delamination. CNC codes written for drilling holes on the planned positions and with the required experimental conditions.

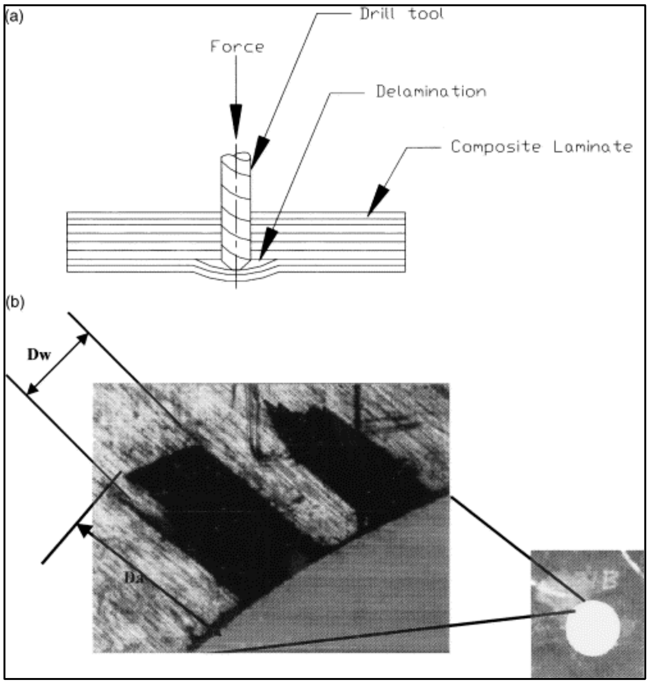


Figure 3.4: Schematic of drill exit delamination. (b) Damage caused by abusive drilling in carbon fiber reinforced plastic (CFRP).

To detect the force on the drilling process, a dynamometer named Kistler was used. A specially designed fixture was bolted onto the three-component strain gage based dynamometer (Kistler). The fixture used to eliminate generation of moment and concentrates thrust force in the *z*-direction during drilling. To firmly secure the work piece on the device, direct clamping were used to mount it on the device. Figure 3.5 shows the Kistler piezoelectric dynamometer.

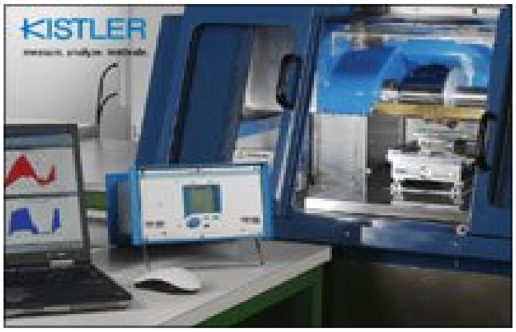


Figure 3.5: The Kistler Piezoelectric Dynamometer with Charge Amplifiers 5070A

To start a drilling process the necessary control parameters was fed in the simulator so as to run the machine without hassle. The values of RPM and feed rate ranges as shown in table 3.3.

Table 3.3: DOE of the experiment

Tool	Spindle Speed (rpm)	Exp#	Feed Rate (mm/min)
SPF	2000	01	200
		02	400
		03	600
	5000	04	200
		05	400
		06	600
	8000	07	200
		08	400
		09	600
PVD	2000	10	200
		11	400
		12	600
	5000	13	200
		14	400
		15	600
	8000	16	200
		17	400
		18	600
K20	2000	19	200
		20	400
		21	600
	5000	22	200
		23	400
		24	600
	8000	25	200
		26	400
		27	600

Each experiment conducted thrice with prior respect to the three types of tools used. In total 27 holes was drilled on the composite irrespective of RPM, feed rate and tool material. At the same time, thrust force readings will be generated on DynoWare 2825A (special software equipped with the piezo electric dynamometer). Figure 3.6 shows the Kistler multi channel charge amplifier with piezoelectric dynamometer that fixed on the CNC milling machine.

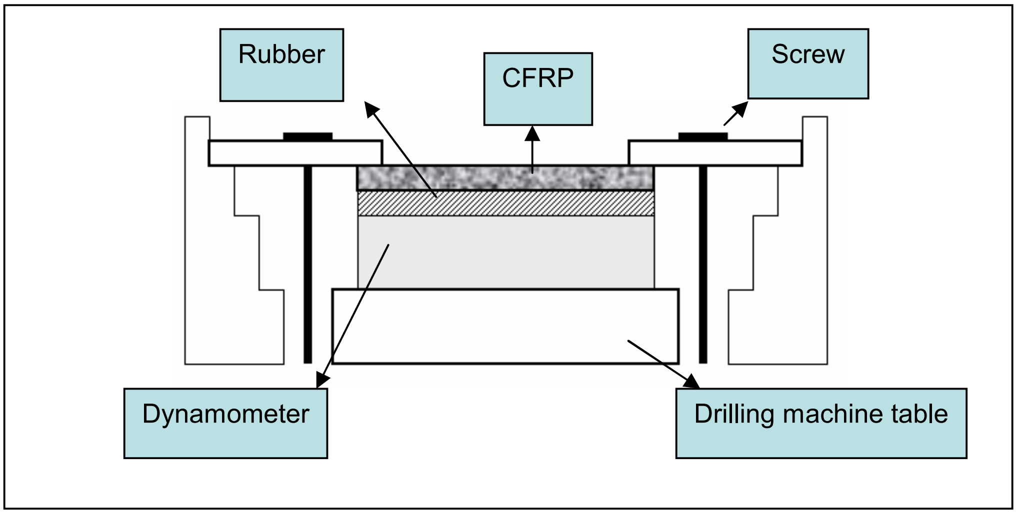


Figure 3.6: Experimental set-up to measure the thrust forces and torque.

The delamination will be measured with the metallurgical microscope, Meiji Techno IM7000 inverted metallograph series. The IM7000 delivers an excellent performance-to-cost ratio because it has the features and versatility that one would expect to find in more expensive instruments. The IM7000 has an integrated front mounted camera port with adapters available for 35mm, CCD, CMOS and other cameras. Each microscope head has the eye tubes inclined at 30 degrees with the left eye tube having graduated diopter settings. The inter pupillary distance on the viewing heads is adjustable between 53mm - 75mm.The IM7000 metallurgical microscope is equipped with a JENOPTIK CT3 PROGRES digital camera. This will enable the caption of the sample work piece for further study.

The digital microscope camera ProgRes® CT3 allows for quick and precise setting of specimen and microscope, and hence provides comfortable operation. The integrated CMOS sensor is absolutely resistant against blooming and shows superior performance in imaging highlights. The camera is configured with standard interfaces such as C-Mount and IEEE 1394 Firewire. Figure 3.7 shows the microscope equipped with the digital camera.

Figure 3.7: The microscope equipped with the digital camera

CHAPTER 4

RESULTS AND DICUSSION

4.1 Introduction

This chapter shows all the results obtained from this study. Tables of results, graphs, and figures are included. Detailed explanation of graphs and figures are also provided. The data is collected starting with the drilling results on CFRP focused on the thrust force and delamination. The optimization method usage and interpretation of its results are obtained based on detailed study of the usage of the software involved. In this case the Design Expert 7.1, statistical software which user friendly and reliable. Lastly, the results will be test with a conformation test and percentage errors of results are obtained.

4.2 Drilling Results

4.2.1 Results of thrust force

In order to obtain the result of thrust force of drilling process on CFRP, a dynamometer named Kistler is used. This equipment equipped with special software named Dyno Ware 2825A. During the drilling process, thrust force readings will be generated on DynoWare 2825A.

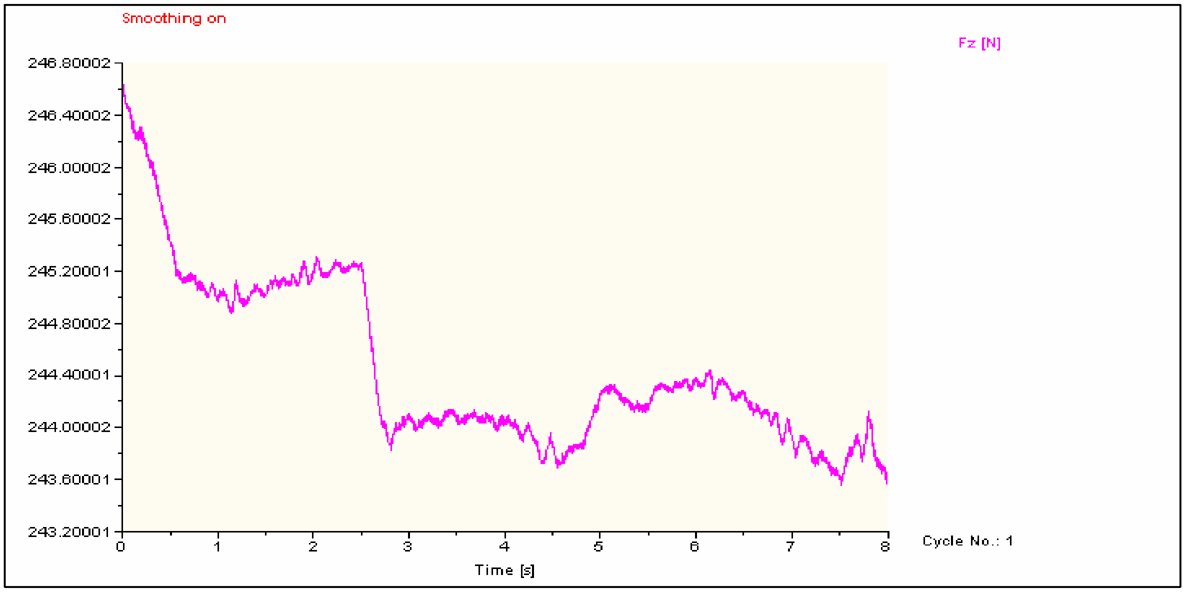


Figure 4.1: Typical graph of thrust force generated from kistler.

Figure 4.1 shows typical graphs that generated from kistler to obtain the thrust force result during the drilling process on CFRP. Basically the entire holes have the same type of graph. From the graph, we can obtain the highest value of thrust force during the drilling process on the hole. The highest value of thrust force for this hole is 247.00N. Individual graph generated from kistler for 27 hole can be found on appendix A.

4.2.2 Result of delamination

During the drilling process on the composite, certain application area have tendency to delaminate. The delamination will be measured with the metallurgical microscope, Meiji Techno IM7000 inverted metallograph series.

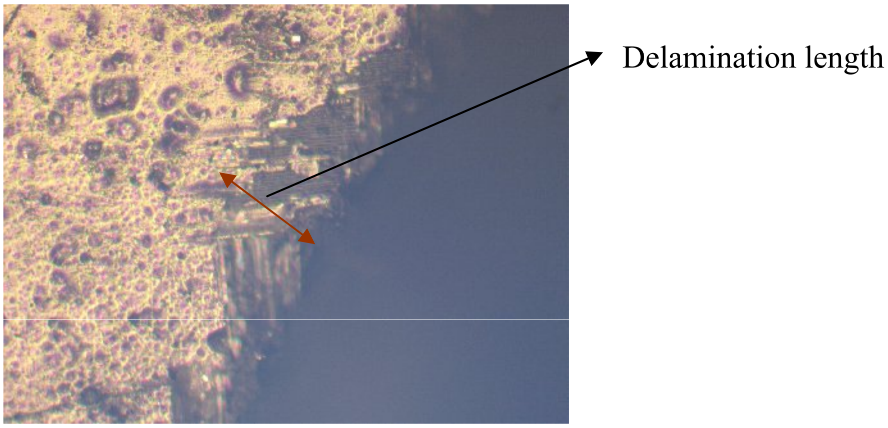


Figure 4.2: typical figure of delamination on CFRP

Figure 4.2 shows a typical figure of delamination on CFRP. Basically the entire holes have the same type of delamination. The figure was obtained by using a metallurgical microscope. The microscope was equipped with the digital camera and the length of delamination can be measured by using an icon that have in the software. Individual figure of delamination for 27 hole can be found on appendix B.

4.2.3 Thrust force and delamination results

Table 4.1: Design experiment layout and the responses

Tool	Spindle Speed (rpm)	Exp#	Feed Rate (mm/min)	Thrust Force, Fz (N)	Delamination (mm)
SPF	2000	01	200	239.84	0.9638
		02	400	244.13	0.4485
		03	600	241.52	0.9839
	5000	04	200	244.67	1.1304
		05	400	244.9	0.5903
		06	600	245.58	1.1743
	8000	07	200	247	1.0476
		08	400	247.22	1.1687
		09	600	249.08	0.5981
PVD	2000	10	200	239.75	1.5343
		11	400	248.2	0.9032
		12	600	249.7	0.8717
	5000	13	200	250.03	0.6119
		14	400	249.11	0.8681
		15	600	250.77	0.9803
	8000	16	200	249.33	0.5840
		17	400	251.52	1.0017
		18	600	248.93	0.6450
K20	2000	19	200	250.41	0.7234
		20	400	252.03	0.9540
		21	600	249.15	0.7089
	5000	22	200	249.76	0.6251
		23	400	247.49	0.8740
		24	600	247.07	0.7566
	8000	25	200	249.17	1.3100
		26	400	245.97	1.1327
		27	600	245.18	0.9191

The drilling results displayed by table 4.1 after doing the process of drilling on CFRP followed the DOE (design of experiment) table. Based on table 4.1, many conclusions can be concluded. It could be seen that the thrust force constant increase regardless the tools differs. There also shows uprate in thrust force with the increase of spindle speed and feed rate. The highest recorded thrust force would be 252.03 N for the tool K20 with the spindle speed of 2000 rpm and feed rate of 400mm/min. while the lowest thrust force recorded is 239.75N for the tool PVD with the spindle speed of 2000 rpm and feed rate of 200mm/min. For the delamination, the result shows that the highest value is 1.5343mm for the PVD tool with 2000 rpm of spindle speed and 200mm/min of feed rate. While the lowest value of delamination is 0.4485mm for SPF tool with spindle speed of 2000rpm and feed rate of 400 mm/min.

4. 3 Analysis of graphs

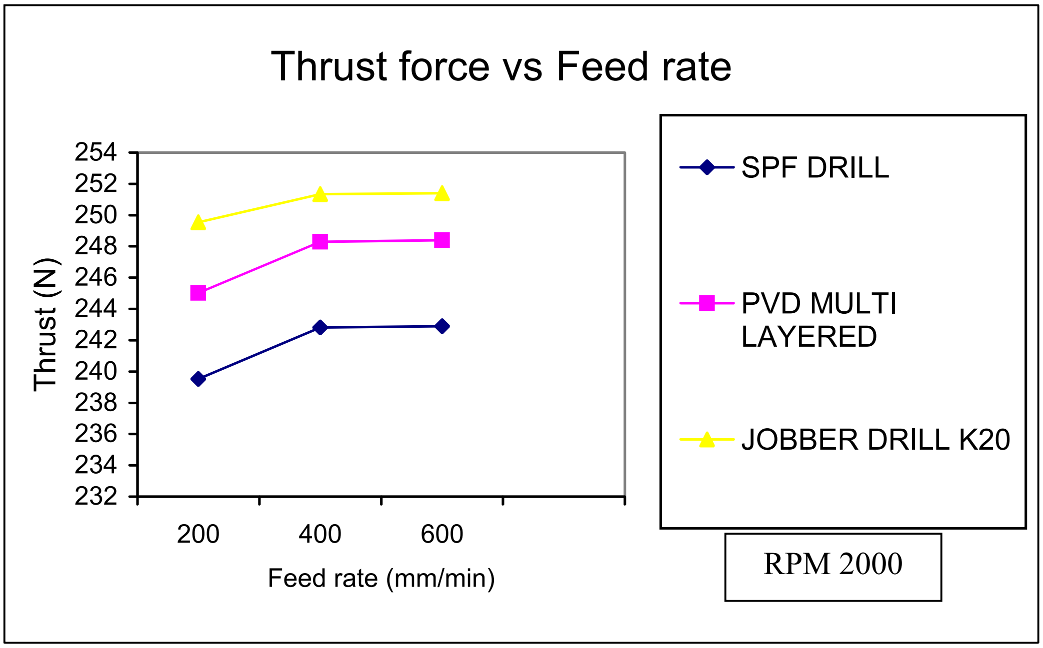


Figure 4.3: Thrust force versus feed rate for 2000 rpm

Figure 4.3 is one graph of thrust force versus feed rate for all three different types of tools, that is SPF drill, PVD multi layered, and Jobber DRILL k20. This is the result of drilling process on CFRP under 3 level of feed rate, which is 200mm/min, 400 mm/min, and 600 mm/min. This graph shows a clearer view of the variation of the thrust force under the same RPM which in this case is 2000 rpm. From the graph it could be clearly observed that the SPF drill produces the least thrust force among the other two drills, which are PVD and K20. The thrust force values recorded for SPF drill here were 239.84N, 244.13N, and 241.25N for the feed rate of 200, 400 and 600 mm/min respectively. While for the PVD drill, the thrust force recorded are 239.75N, 248.20N, and 249.70N for the feed rate of 200, 400 and 600 mm/min respectively and lastly for K20, the thrust force values recorded are 250.41N, 252.03N, and 249.76N for the feed rate of 200, 400 and 600mm/min respectively.

Although, the thrust force was supposed to increase linearly with the feed rate regardless of the tool, this discrepancy could be due to certain errors during experimental. Have two other graphs that shows thrust force versus feed rate that is drawn for different cutting speed which is 5000rpm and 8000rpm. The graphs also shown similarly with the graph above whereby, the SPF Drill produce the least value of thrust force compared to the other tools and the thrust force increases with feed rate for all the tools. The SPF drill shows the best drilling result among the other tools for overall cases whereby it produce the lowest thrust force. From the literature review it was proven that the thrust force increased with feed [22]

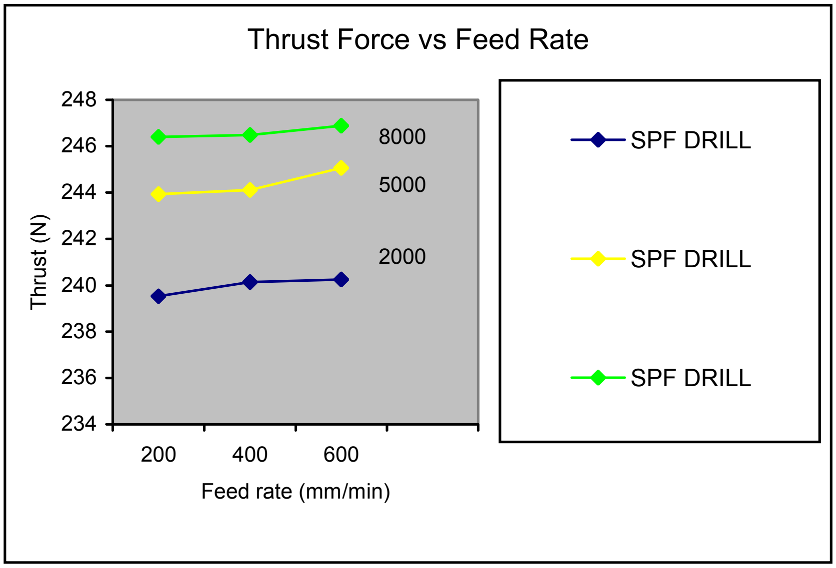


Figure 4.4: Thrust force versus feed rate using SPF tool

Figure 4.4 shows the result of thrust force versus feed rate for all levels of spindle speed by using three types of tools. From the graph, it could be seen that SPF drill has been proven to give lowest thrust force compared to the other two tools. The graph shows the thrust force that generated in three different level of spindle speed which is 2000rpm, 5000rpm and 8000rpm. As mentioned earlier, based on literature review the thrust force generated will definitely increased with feed [22]. Thrust force was elevated as feed rate was increased due to the elevation in the shear area.

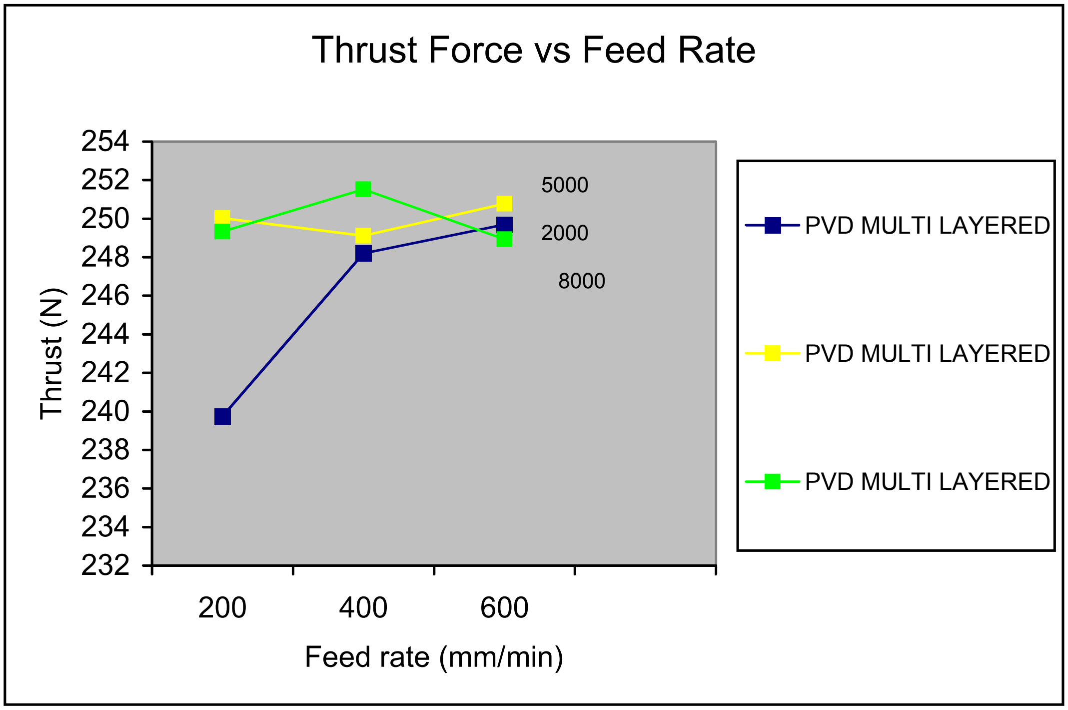


Figure 4.5: Thrust force versus feed rate using PVD tool

Figure 4.5 presented the data of thrust force that generated by the PVD multi layered drill. From the graph, only the thrust force generated during the 2000 RPM followed the rule stated which is that the thrust force increases with feed rate. For the spindle speed of 5000 RPM a slight error is detected whereby the thrust force generated at a feed rate of 200mm/min which is 250.03 N is higher compared to the thrust force generated at a feed rate of 400mm/min which is 249.11N. It is also slight error detected at the spindle speed of 8000rpm. The highest value of spindle speed at this spindle speed is at 400mm/min which is 251.52 N

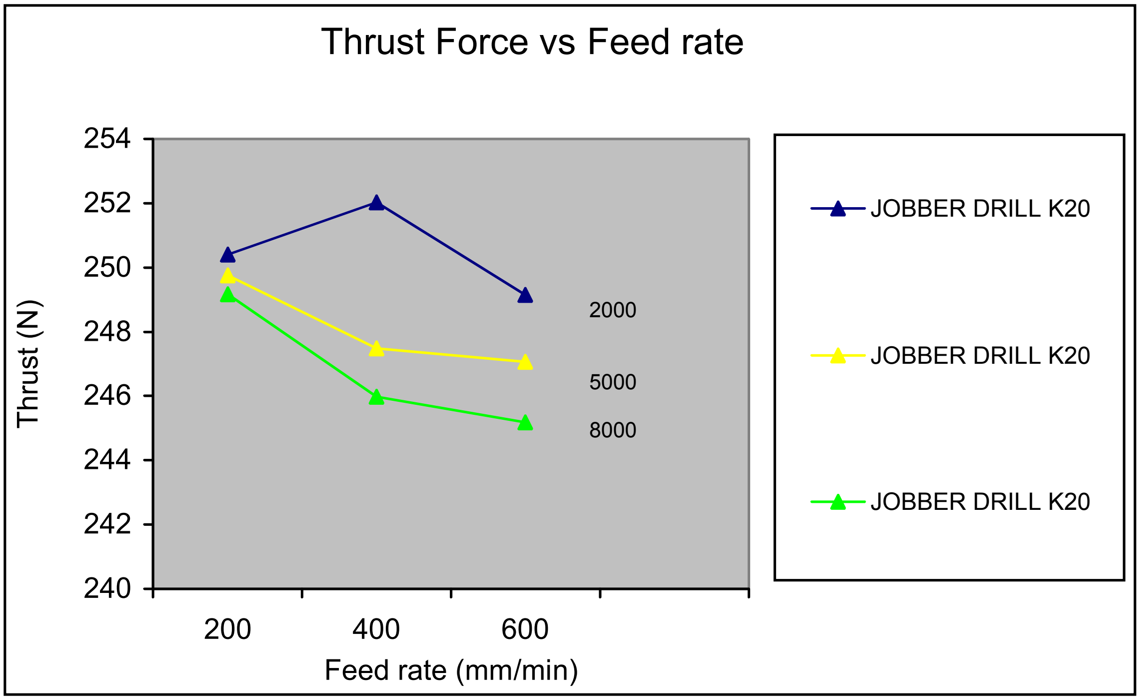


Figure 4.6: Thrust force versus feed rate using Jobber drill K20 tool

Figure 4.6 presented the data of thrust force that generated by the Jobber drill K20 tool. From here, it can be observed that the all three graphs obtained is slightly askew for example for the spindle speed of 2000 rpm a slight error is detected whereby the thrust force generated at a feed rate of 400mm/min which is 252.03 N is higher compared to the thrust force generated at a feed rate of 600mm/min which is 249.15N. It is also slight error detected at the spindle speed of 5000rpm and 8000rpm, whereby the thrust force generated at a feed rate of 200mm/min is higher compared to the thrust force generated at a feed rate of 400mm/min and 600mm/min. This marginal error may due to certain unavoidable circumstances.

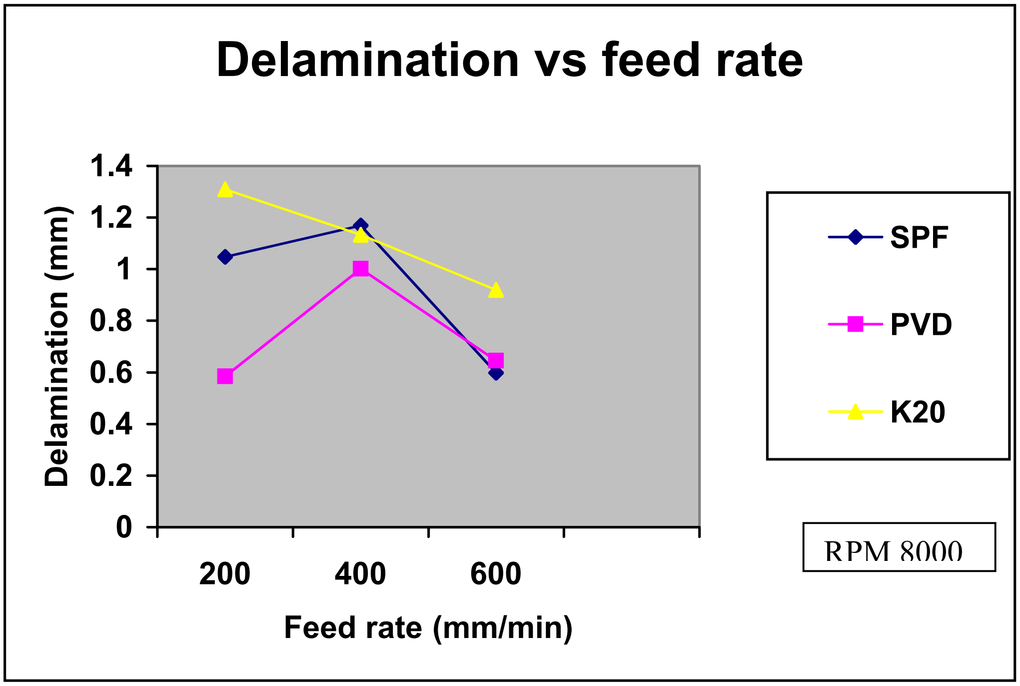


Figure 4.7: delamination versus feed rate for 2000 rpm

Figure 4.7 is one graph of delamination of hole on CFRP versus feed rate for all three different types of tools, that is SPF drill, PVD multi layered, and Jobber DRILL k20. This is the result of drilling process on CFRP under 3 level of feed rate, which is 200mm/min, 400 mm/min, and 600 mm/min. This graph shows a clearer view of the variation of the delamination under the same RPM which in this case is 8000 rpm. According to the literature review, the delamination will decrease with an increasing cutting speed and a lower feed rate. From the graph, only the delamination resulted by K20 drill followed the rule. For the other two graphs which are resulted by SPF and PVD drills, it is totally opposite from the previous studies. This may due to certain unavoidable circumstances that cause of limitation of the machine to measures the delamination on CFRP.

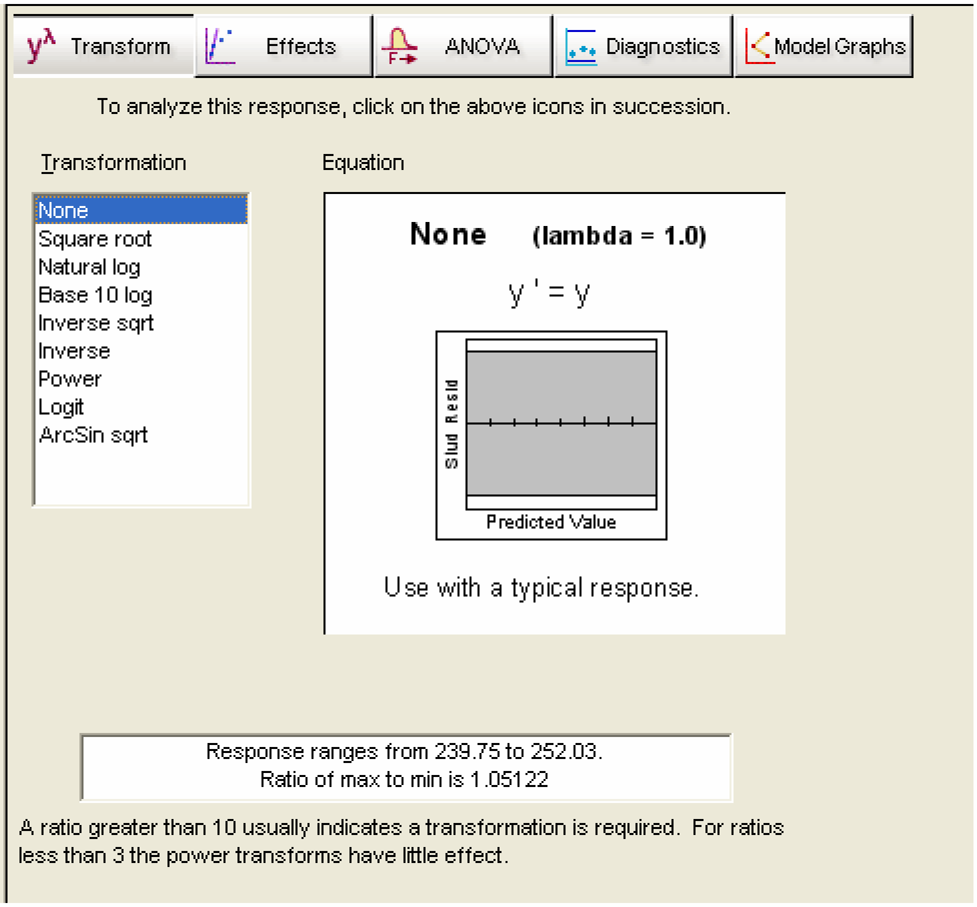
4.4 Analyze and optimize the results

For this study, Design-Expert software was used to implement General Factorial for the purpose of analysis and optimization. By using the software, General factorial allows to have factors that each has a different number of levels. It creates an experiment that includes all possible combination of factor level in this study.

Table 4.2: Design layout in standard order with response data entered

Std	Run	Block	Factor 1 A:tools material	Factor 2 B:spindle speed rpm	Factor 3 C:feed rate mm/min	Response 1 thrust force N	Response 2 delamination mm
1	11	Block 1	spf	2000	200	239.84	0.9638
2	14	Block 1	pvd	2000	200	239.75	1.5343
3	4	Block 1	K20	2000	200	250.41	0.7234
4	15	Block 1	spf	2000	200	244.67	1.1304
5	27	Block 1	pvd	2000	200	250.03	0.6119
6	25	Block 1	K20	2000	200	249.76	0.6251
7	1	Block 1	spf	2000	200	247	1.0476
8	20	Block 1	pvd	2000	200	249.33	0.584
9	6	Block 1	K20	2000	200	249.17	1.31
10	5	Block 1	spf	2000	200	244.13	0.4485
11	26	Block 1	pvd	2000	200	248.2	0.9032
12	2	Block 1	K20	2000	200	252.03	0.954
13	24	Block 1	spf	2000	200	244.9	0.5903
14	13	Block 1	pvd	2000	200	249.11	0.8681
15	7	Block 1	K20	2000	200	247.49	0.874
16	23	Block 1	spf	2000	200	247.22	1.1687
17	16	Block 1	pvd	2000	200	251.52	1.0017
18	17	Block 1	K20	2000	200	245.97	1.1327
19	22	Block 1	spf	2000	200	241.52	0.9839
20	9	Block 1	pvd	2000	200	249.7	0.8717
21	8	Block 1	K20	2000	200	249.15	0.7089
22	10	Block 1	spf	2000	200	245.58	1.1743
23	3	Block 1	pvd	2000	200	250.77	0.9803
24	18	Block 1	K20	2000	200	247.07	0.7566
25	19	Block 1	spf	2000	200	249.08	0.5981
26	12	Block 1	pvd	2000	200	248.93	0.645
27	21	Block 1	K20	2000	200	245.18	0.9191

Table 4.2 show the design layout in standard order with response data entered in Design Expert software. This table was generated after we enter the factor names, units, number of levels, and a name for each level. There have three design parameters identify as factors that could be entered which are tools, cutting speed and feed rate. For the response, there have two response could be entered that is thrust force and delamination.



To analyze this response, click on the above icons in succession.

None (lambda = 1.0)

y ' = y

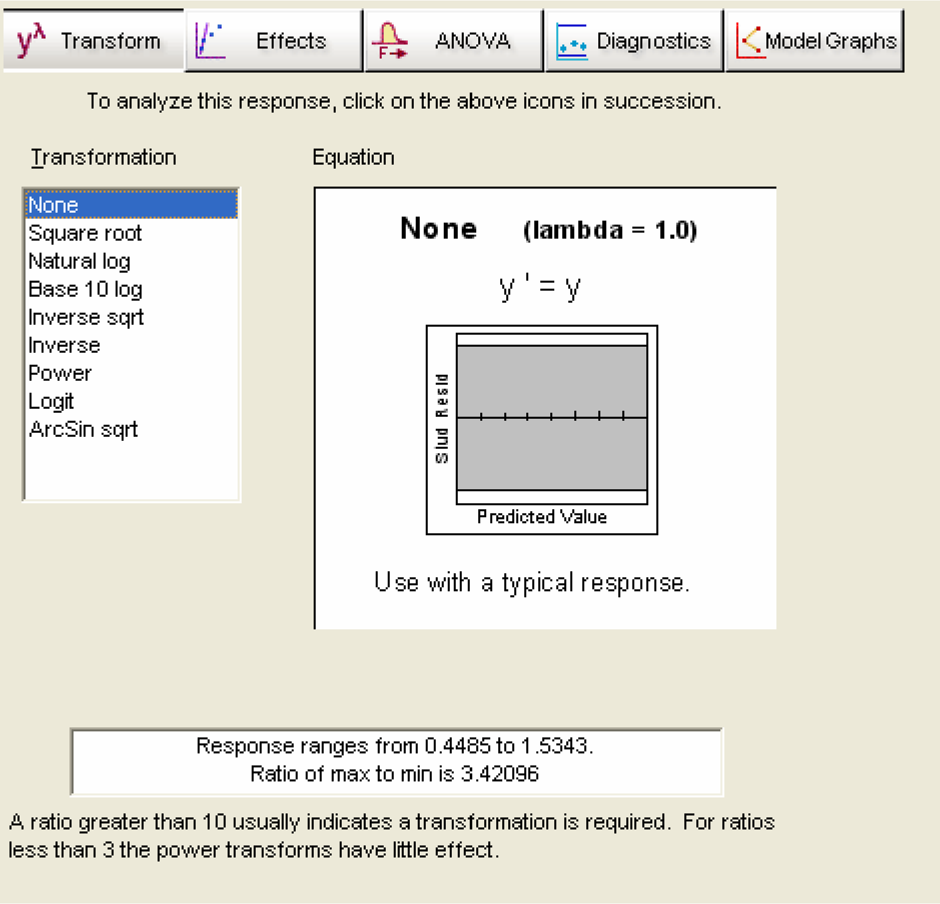
Use with a typical response.

Response ranges from 239.75 to 252.03.
Ratio of max to min is 1.05122

A ratio greater than 10 usually indicates a transformation is required. For ratios less than 3 the power transforms have little effect.

Figure 4.8: Transformation of the trust force result

The first step in the analysis of trust force result was shown in figure 4.8. That is the transformation of the thrust force result. The response ranges for thrust force are from 239.75N to 252.03N. While the ratio of the maximum value to minimum value is 1.05122.



To analyze this response, click on the above icons in succession.

None **(lambda = 1.0)**

$y' = y$

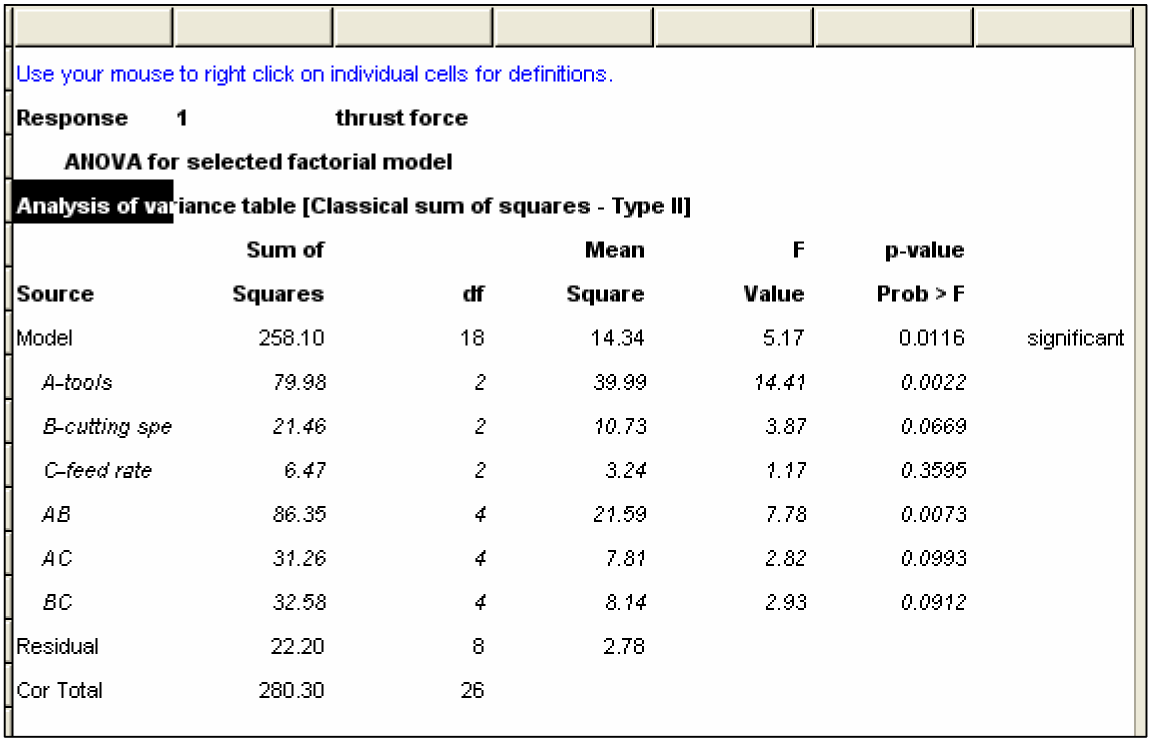
Use with a typical response.

Response ranges from 0.4485 to 1.5343.
Ratio of max to min is 3.42096

A ratio greater than 10 usually indicates a transformation is required. For ratios less than 3 the power transforms have little effect.

Figure 4.9: Transformation of delamination result

Figure 4.9 shows the first step in the analysis of delamination result. It is the transformation of the delamination result. The response ranges for delamination are from 0.4485mm to 1.5343mm. While the ratio of the maximum value to minimum value is 3.42096.



Use your mouse to right click on individual cells for definitions.

Response 1 thrust force

ANOVA for selected factorial model

Analysis of variance table [Classical sum of squares - Type II]

Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**	
Model	258.10	18	14.34	5.17	0.0116	significant
A-tools	*79.98*	*2*	*39.99*	*14.41*	*0.0022*	
B-cutting spe	*21.46*	*2*	*10.73*	*3.87*	*0.0669*	
C-feed rate	*6.47*	*2*	*3.24*	*1.17*	*0.3595*	
AB	*86.35*	*4*	*21.59*	*7.78*	*0.0073*	
AC	*31.26*	*4*	*7.81*	*2.82*	*0.0993*	
BC	*32.58*	*4*	*8.14*	*2.93*	*0.0912*	
Residual	22.20	8	2.78			
Cor Total	280.30	26				

Figure 4.10: Annotated ANOVA report

By using General Factorial, the experiment can be analyzed using ANOVA analysis. Figure 4.10 shows the result for ANOVA analysis for this study. The Model F-value of 5.17 implies the model is significant. There is only a 1.16% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, AB are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve the model.

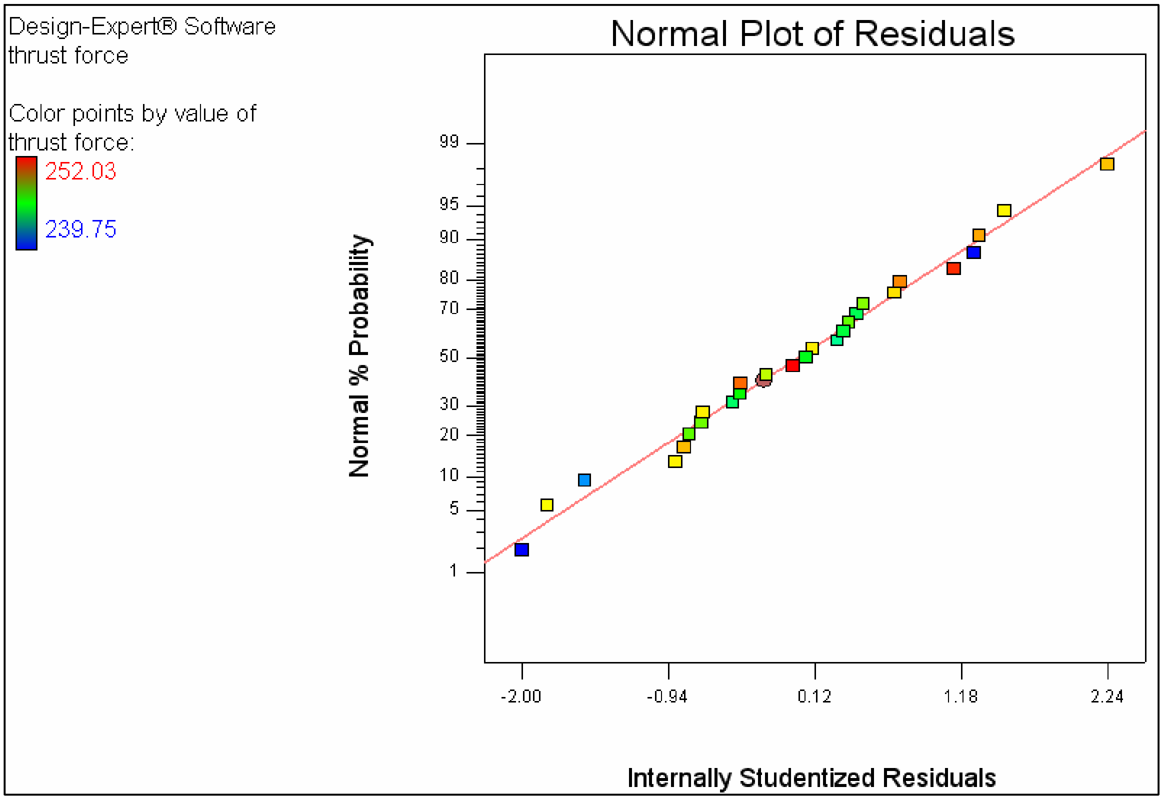
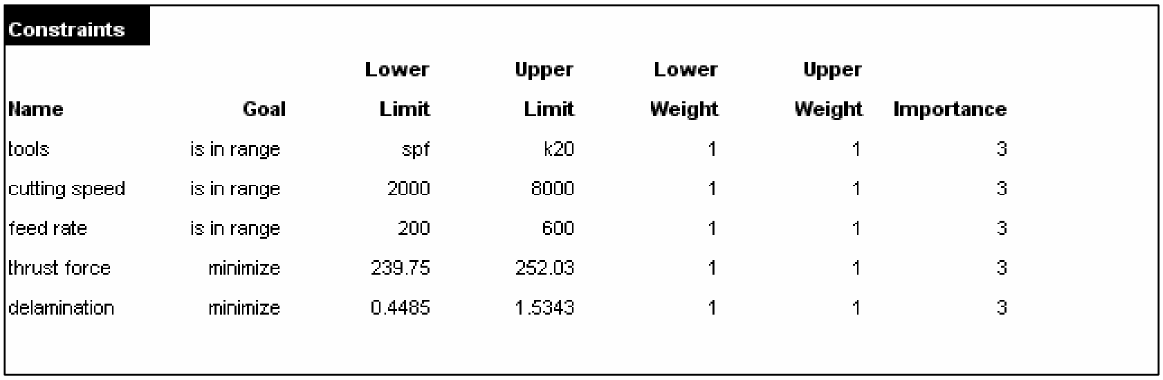


Figure 4.11: Normal plot of residuals

Figure 4.11 shows the normal plot of residuals. The normal probability plot indicates that the residuals follow a normal distribution, whereby in this case the points follow a straight line.

Table 4.3: the constraint of the parameters



Constraints

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
tools	is in range	spf	k20	1	1	3
cutting speed	is in range	2000	8000	1	1	3
feed rate	is in range	200	600	1	1	3
thrust force	minimize	239.75	252.03	1	1	3
delamination	minimize	0.4485	1.5343	1	1	3

Table 4.3 shows the constraint of the parameter in this study. This section summarizes the criterion that was set for this optimization run. For the tools factor, it was set as in range which is the lower limit is spf and the upper limit is K20. For the spindle speed factor also set as in the range which is the lower limit as 2000 rpm and upper limit as 8000rpm. Similarly with feed rate factor, it was also set up as in the range with the lower limit as 200mm/min and the upper limit as 600mm/min. for the purpose of optimization, the thrust force and delamination was set minimize as the goal. From the table there have shown the response weight for each parameter.This is the specified weight for the lower or upper limit. It can range from 0.1 to 10. A weight of 0.1 will put less emphasis on the limit, while a weight of 10 will put more emphasis on the limit. Besides that, there also have the importance value for each parameter which is meant the specified importance value for each response in relation to the other factors and responses. The default is +++ (three pluses). If it is more important to achieve one response than another, give the more important response a higher weight.

Table 4.4: Solutions for 27 combinations of categoric factor levels.

Solutions for 27 combinations of categoric factor levels

Number	Tools	Spindle speed	Feed rate	Thrust force	delamination	desirability	
1	spf	2000	400	243.877	0.4485	0.815	Selected
2	spf	5000	400	244.516	0.5903	0.729	
3	spf	2000	200	238.69	0.9638	0.725	
4	spf	2000	600	242.923	0.9839	0.613	
5	K20	8000	600	244.884	0.9191	0.574	
6	K20	5000	600	246.741	0.7566	0.555	
7	spf	8000	600	247.725	0.5981	0.550	
8	K20	5000	400	247.065	0.874	0.496	
9	pvd	8000	200	248.701	0.584	0.487	
10	pvd	5000	200	248.844	0.6119	0.469	
11	pvd	2000	600	247.672	0.8717	0.465	
12	spf	5000	200	245.102	1.1304	0.458	
13	spf	5000	600	245.532	1.1743	0.419	
14	pvd	2000	400	248.413	0.9032	0.414	
15	K20	8000	400	246.355	1.1327	0.413	
16	spf	8000	200	247.719	1.0476	0.397	
17	K20	2000	600	249.775	0.7089	0.374	
18	K20	2000	200	249.745	0.7234	0.373	
19	spf	8000	400	247.856	1.1687	0.338	
20	pvd	5000	400	249.919	0.8681	0.325	
21	K20	5000	200	250.514	0.6251	0.322	
22	pvd	8000	600	250.581	0.645	0.311	
23	pvd	8000	400	250.499	1.0017	0.247	
24	K20	8000	200	249.081	1.31	0.223	
25	pvd	5000	600	251.147	0.9803	0.191	

25 solutions found

Table 4.4 shows the solutions for 27 combinations of categoric factor levels. From the 27 experiments, 25 experiments are created that includes all possible combination of factors level. From the combination, the best solution will be selected according to the highest value of desirability. It could be seen that the highest value of desirability is 0.815. This value was yield from the combination of certain parameters which is SPF tools, spindle speed of 2000rpm, feed rate of 200mm/min, the thrust force of 243.877N and the delamination of 0.4485mm. Optimization is the process of making compromises between responses.

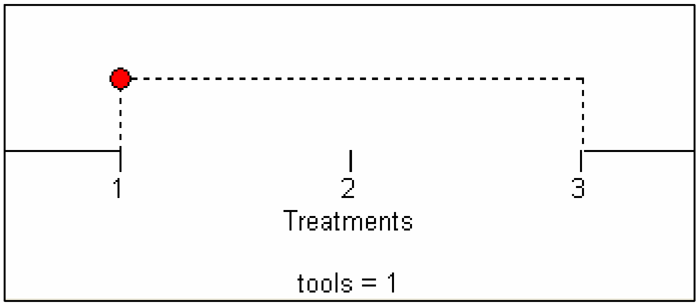


Figure 4.12: the ramps for tools factor

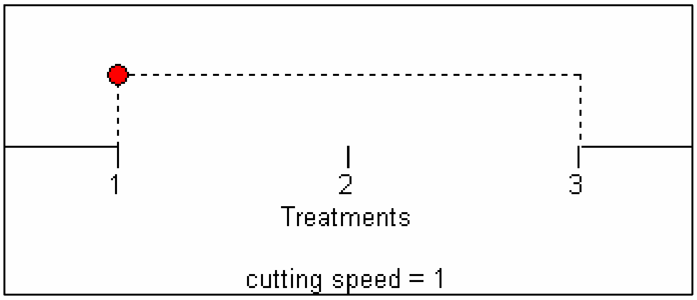


Figure 4.13: the ramps for spindle speed factor

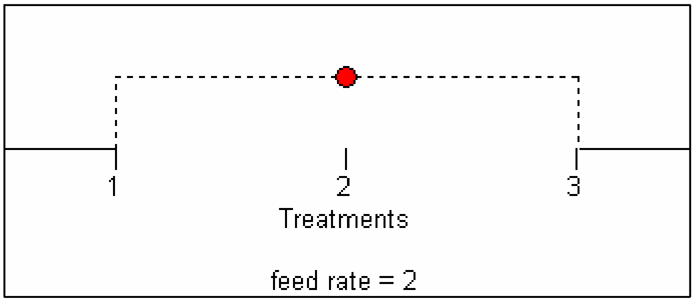


Figure 4.14: the ramps for feed rate factor

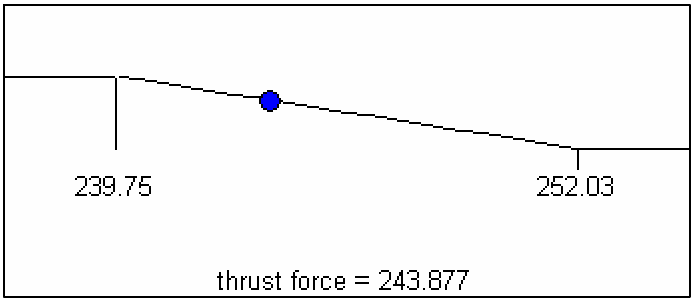


Figure 4.15: the ramps for thrust force factor

Figure 4.16: the ramps for delamination factor

Figure 4.12 to 4.16 shows the ramps which are indicated the level of parameter for the best solution after the optimization. From this it would be concluded that the best parameter for drilling process is SPF tools, spindle speed of 2000rpm, feed rate of 200mm/min. the combination of these three parameters produce the best compromises between response that is the thrust force of 243.877N and the delamination of 0.4485mm.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Introduction

This chapter is summarizes the whole study and recommendations about way to improve this study for next time. Several conclusions and recommendations based on the results and data analysis.

5.2 Conclusions

As a conclusion, the objectives of this study has been achieved which is to study and optimize the drilling process of CFRP focusing on thrust force and delamination on Carbon Fiber Reinforced Plastic (CFRP) by using General Factorial.

From the discussion in the previous chapter, the following conclusion can be draws are:

1. The optimal parameters that are chosen from the set of experiment are
   Tool: SPF
   Spindle Speed: 2000 rpm
   Feed Rate: 400 mm/min
   Thrust Force: 243.877 N
   Delamination: 0.4485 mm

2. The optimization process is achieved by Factorial Design and the method was proven reliable with desirability 0.815

3. The increase of feed rate and spindle speed will increase the thrust force and delamination of CFRP.

5.3 Recommendations

From the results that been obtained in the previous chapters, the following future works can be recommended are:

1. The feed rate should be selected carefully in order to reduce all kinds of damages seems the feed rate could be the most critical parameter in drilling process of composite.
2. Use of high cutting speed and low feed rate to minimize delamination on the drilling leads of composite.

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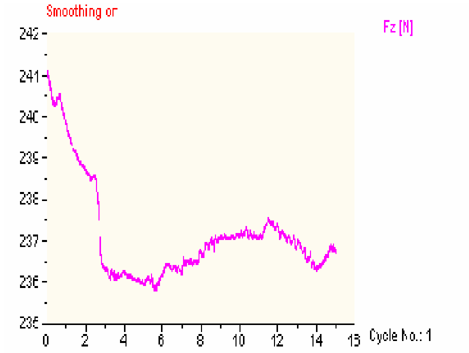
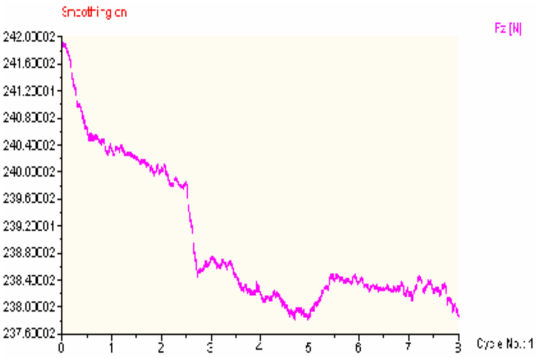
APPENDIX A

THRUST FORCE GRAPHS



Graph for hole 1

Graph for hole 2



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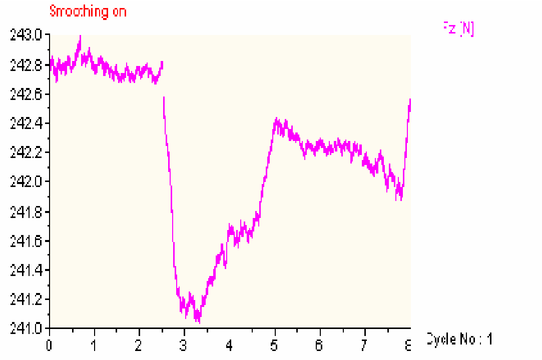

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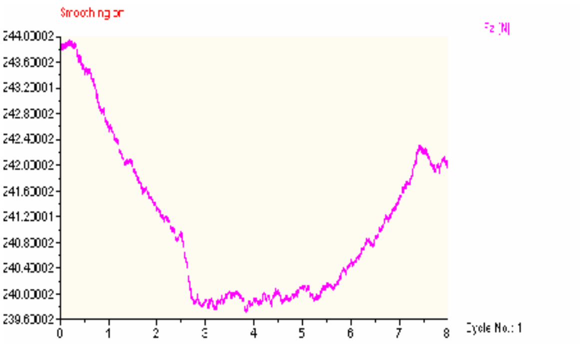
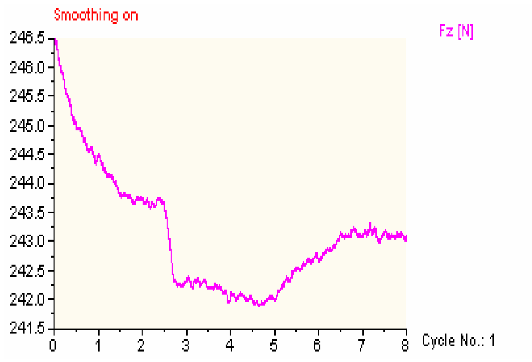
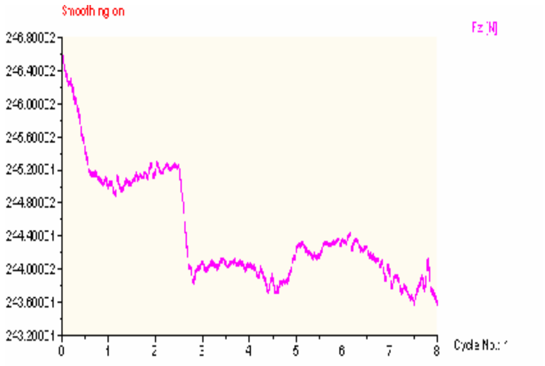


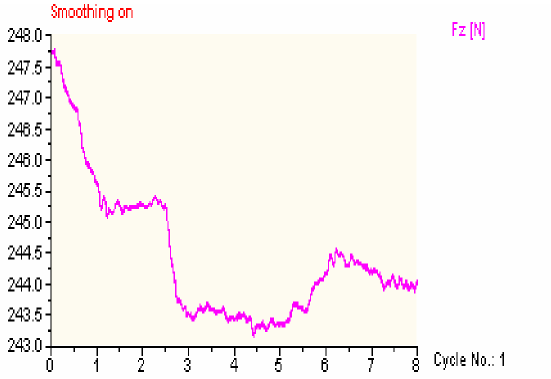
Graph for hole 5



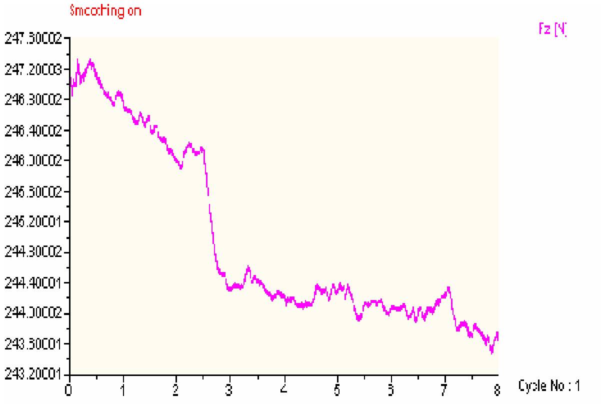
Graph for hole 6



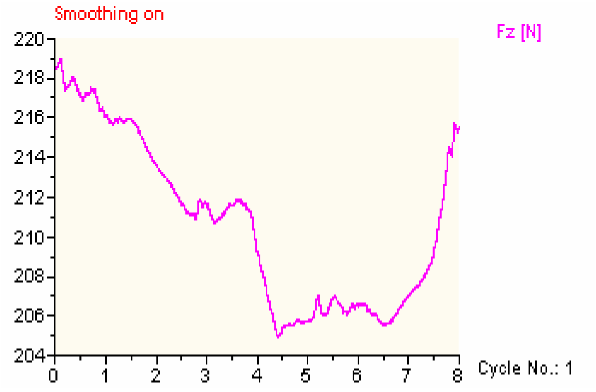
Graph for hole 7



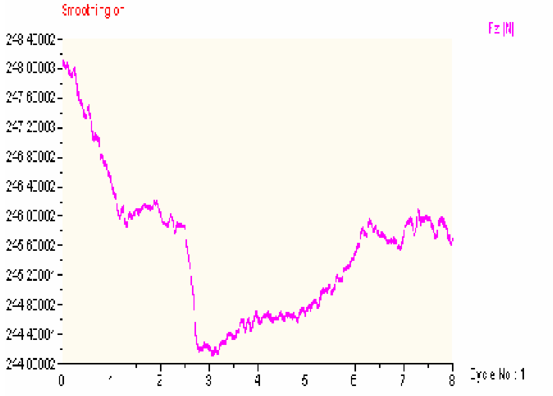
Graph for hole 8



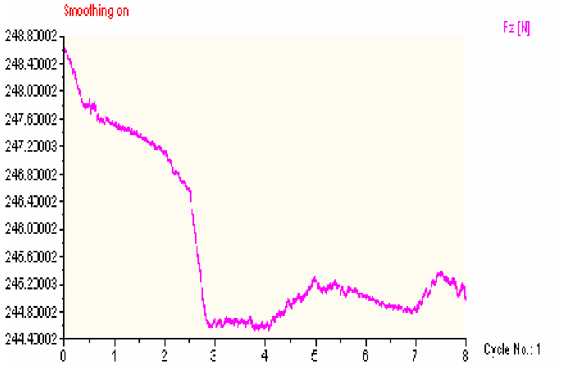
Graph for hole 9



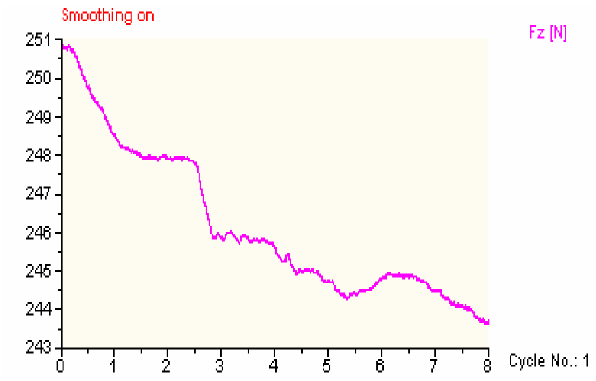
Graph for hole 10



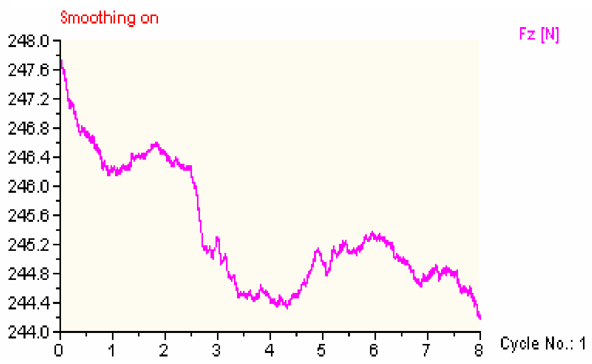
Graph for hole 11



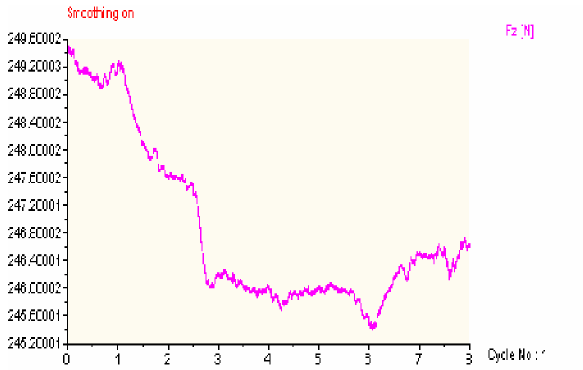
Graph for hole 12



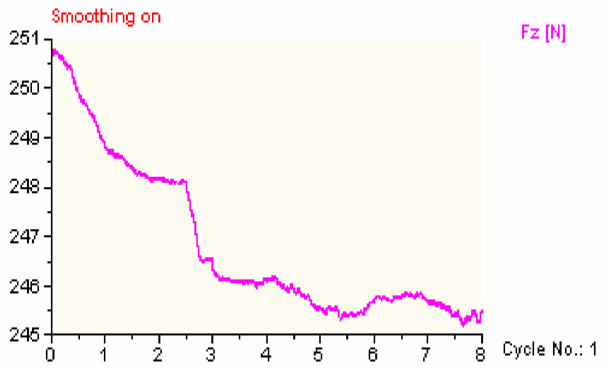
Graph for hole 13



Graph for hole 14



Graph for hole 15



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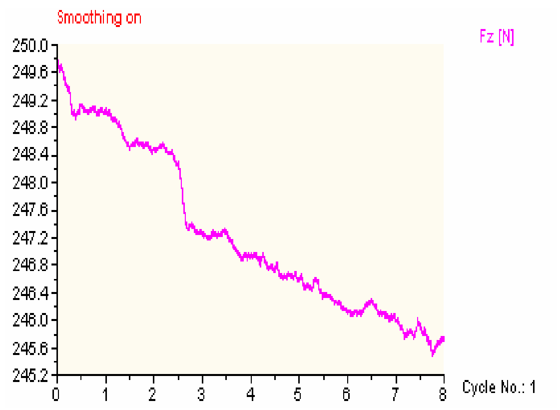
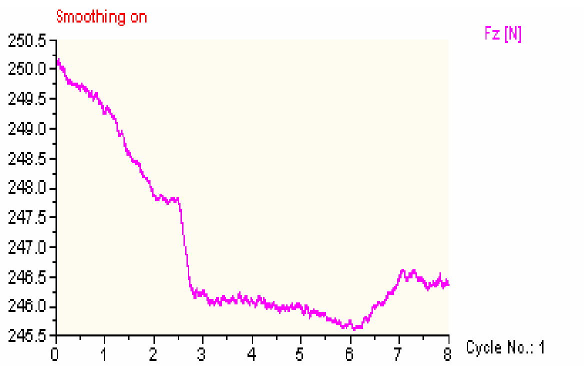


Graph for hole 17



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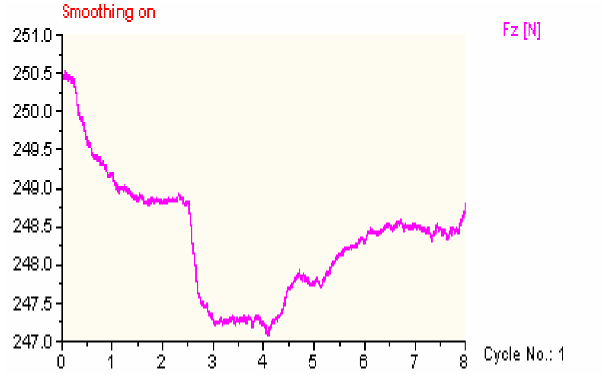
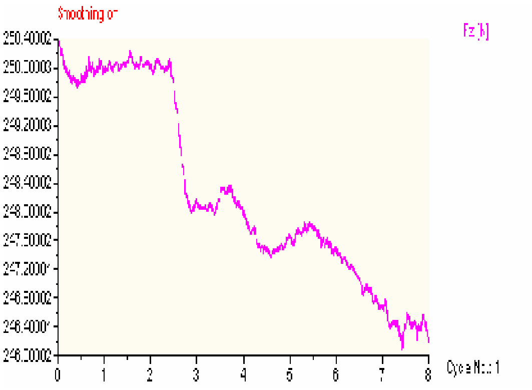
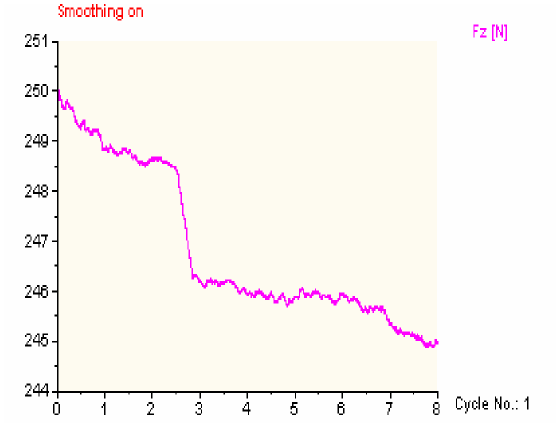


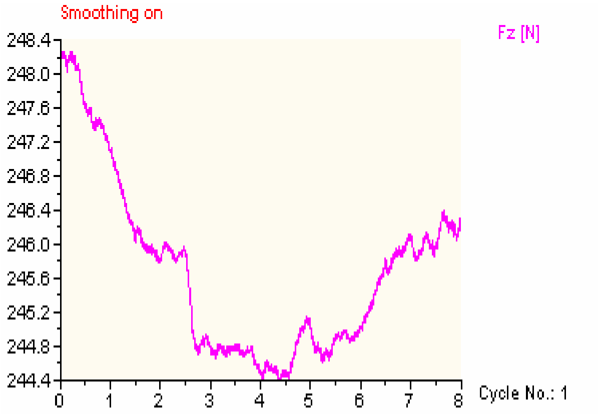
Graph for hole 19



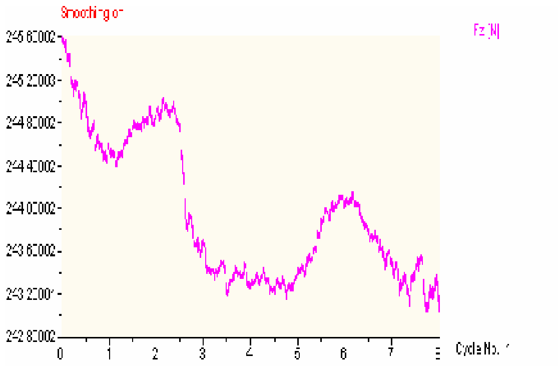
Graph for hole 20



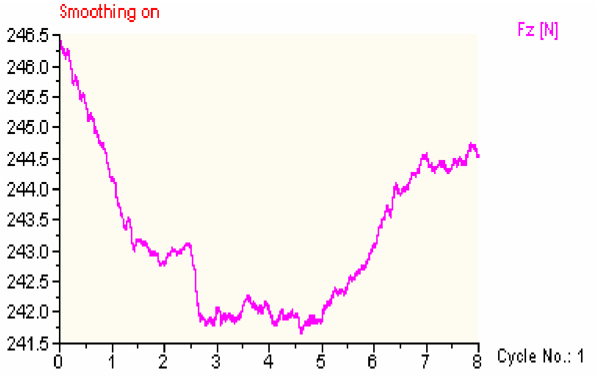
Graph for hole 21



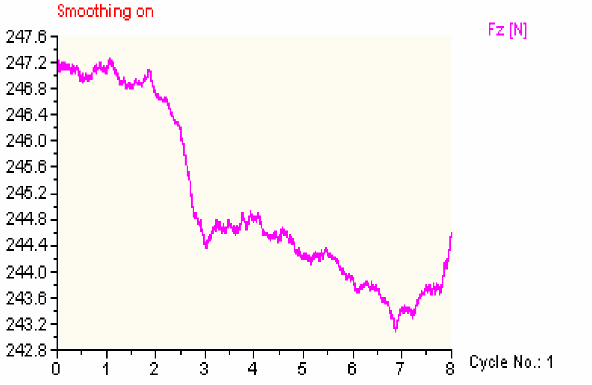
Graph for hole 22



Graph for hole 23

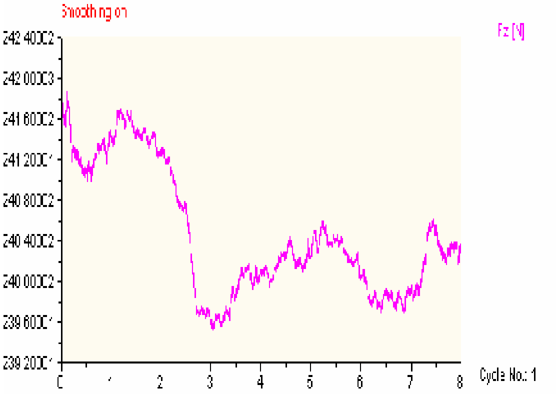


Graph for hole 24



Graph for hole 25

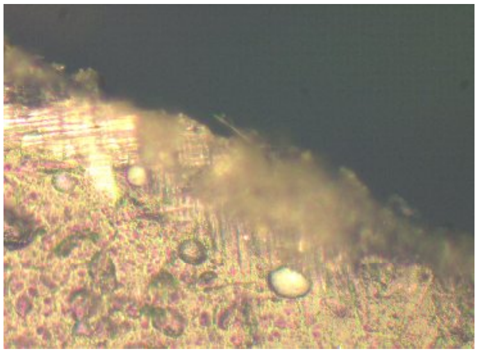
Graph for hole 26



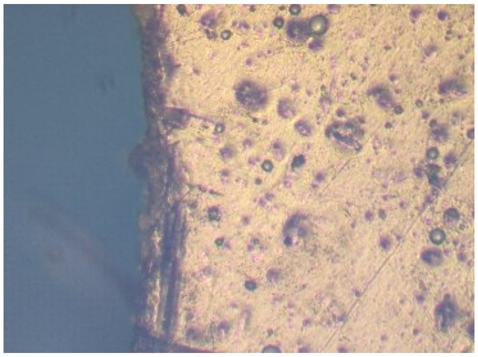
Graph for hole 27

APPENDIX B

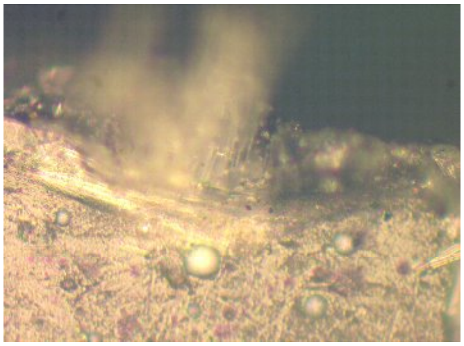
DELAMINATION OF HOLES



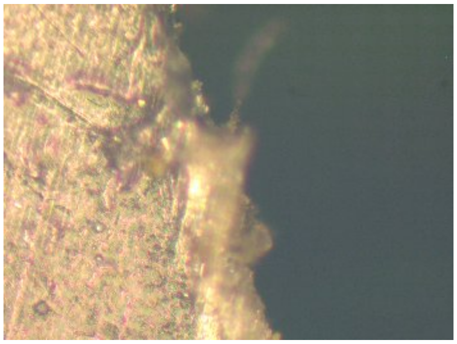
First hole



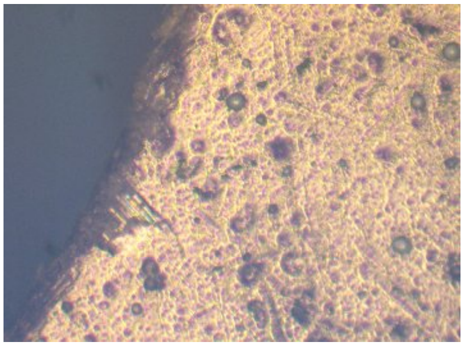
Second hole



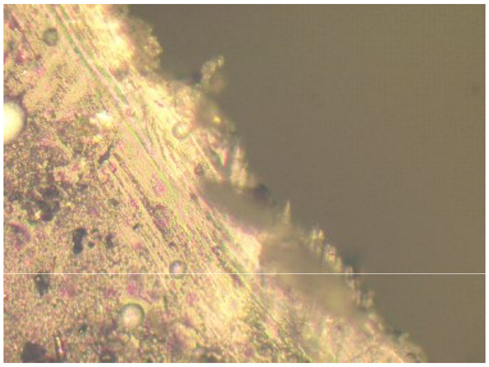
Third hole



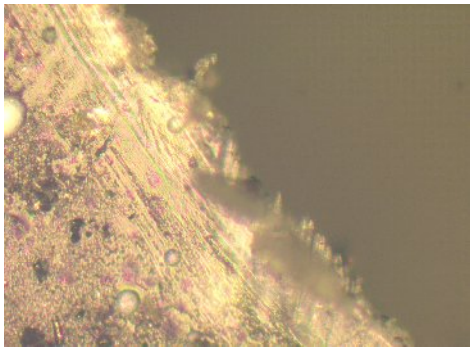
Fourth hole



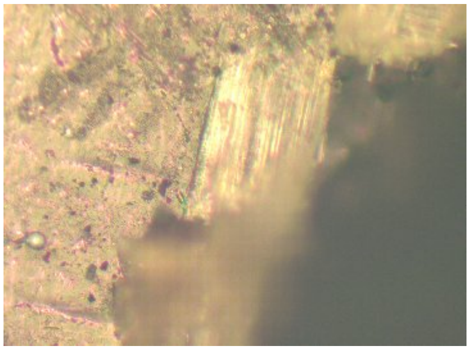
Fifth hole



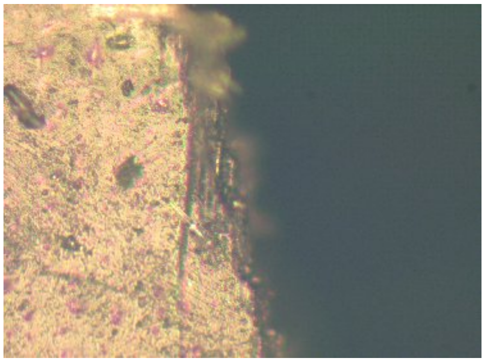
Sixth hole



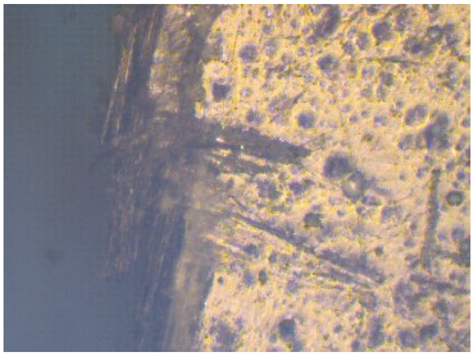
Seventh hole



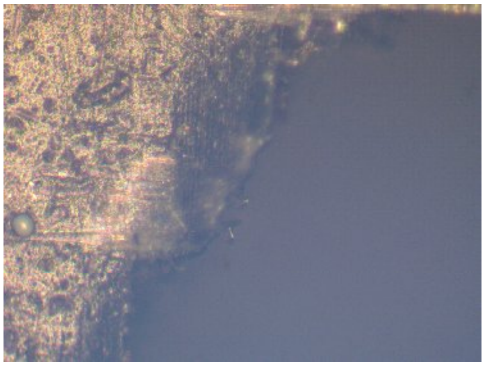
Eighth hole



Ninth hole

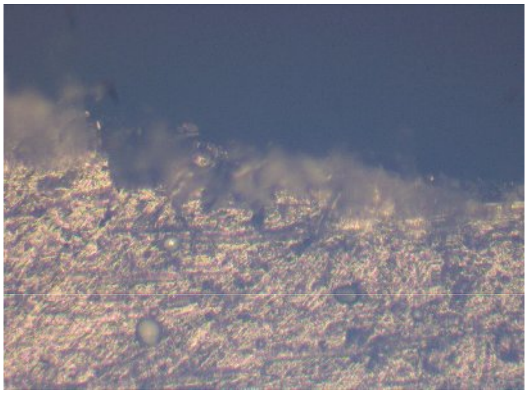


Tenth hole

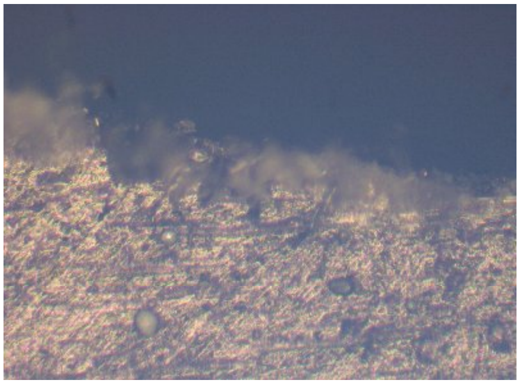


Eleventh hole

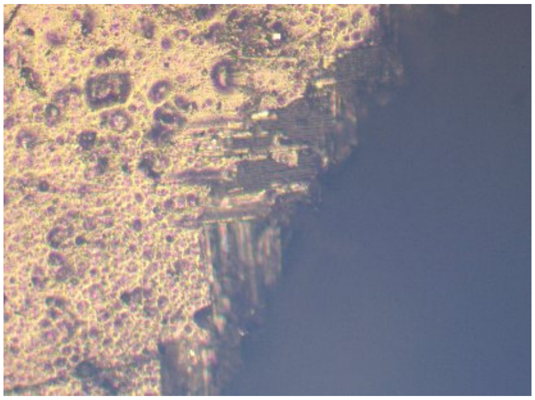
Twelfth hole



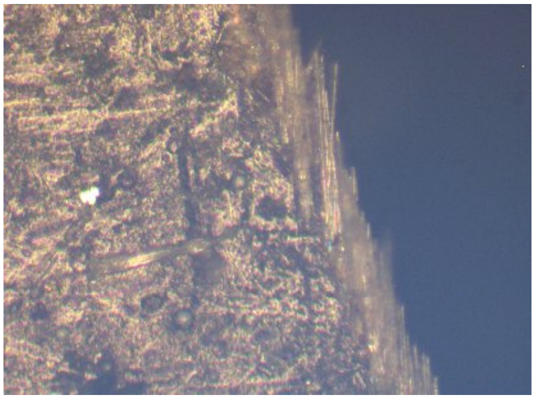
Thirteenth hole



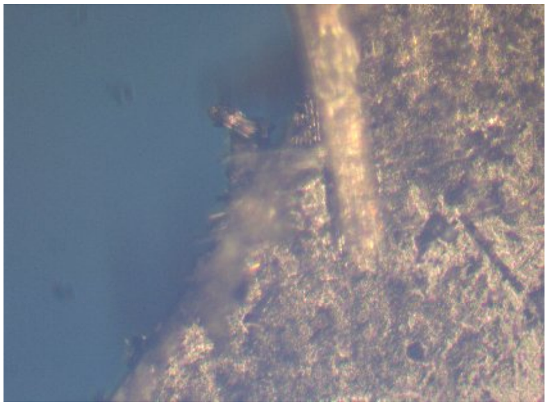
Fourteenth hole



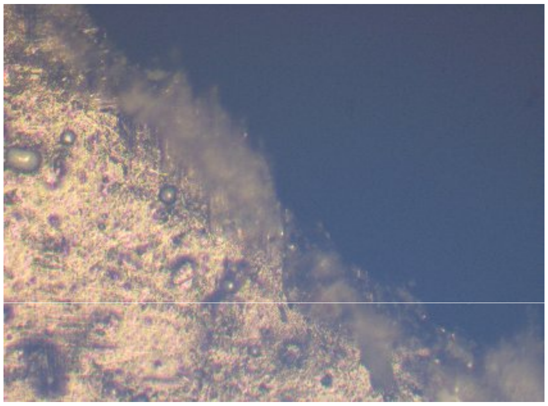
Fifteenth hole



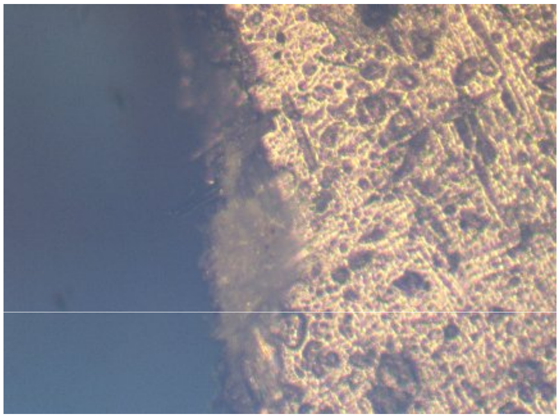
Sixteenth hole



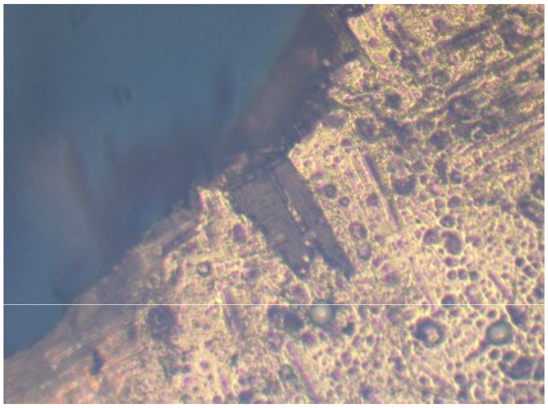
Seventeenth hole



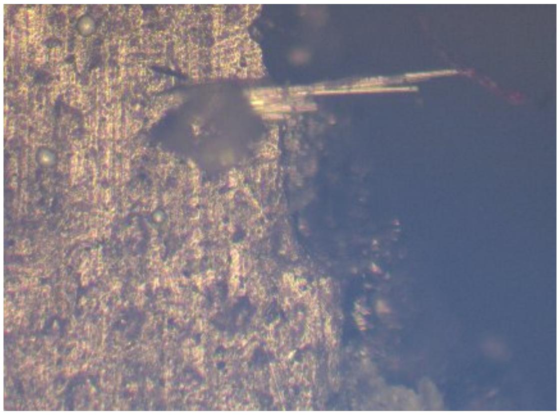
Eighteenth hole



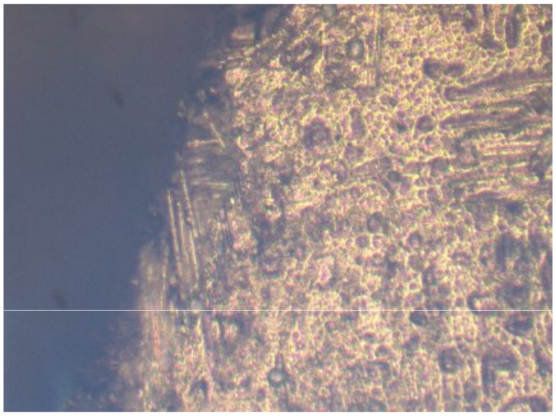
Nineteenth hole



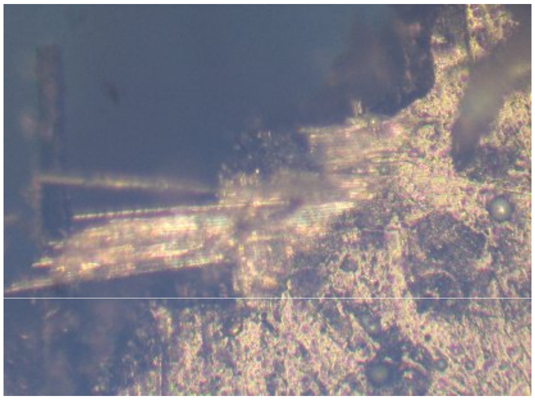
Twentieth hole



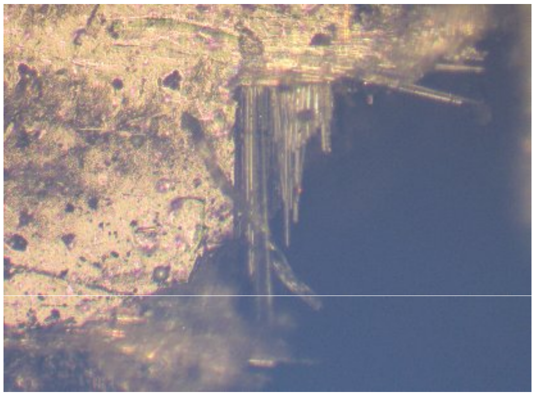
Twenty first hole



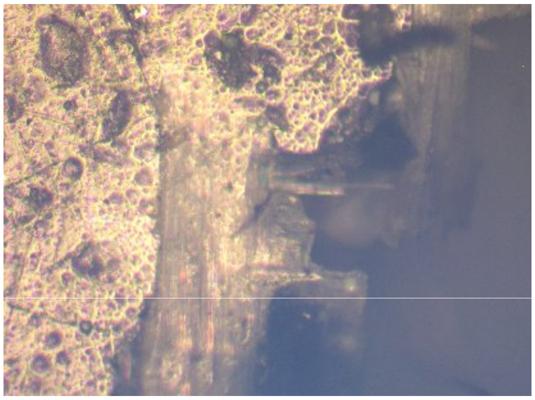
Twenty second hole



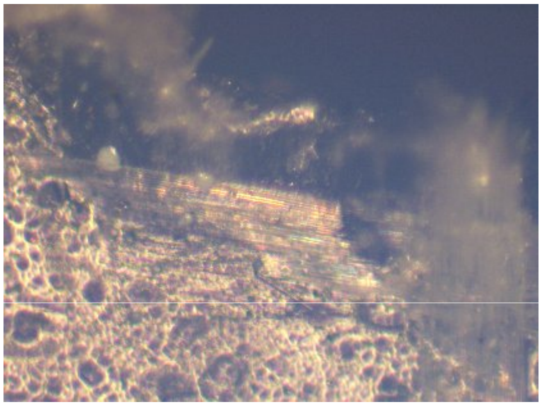
Twenty third hole



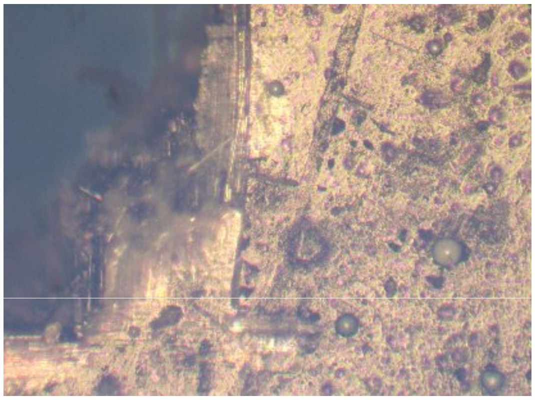
Twenty fourth hole



Twenty fifth hole



Twenty sixth hole



Twenty seventh hole