

**AN EXPERIMENTAL STUDY ON DRILLING OF GLASS FIBER  
REINFORCED PLASTIC**

**A  
Thesis Report**

**Submitted in partial fulfilment of the requirement for the award of degree of**

**MASTER OF ENGINEERING  
IN  
CAD/CAM & ROBOTICS**

**Submitted By  
Vikas Sharma  
Roll No. 800881022**

**Under Guidance of**

**Dr. V.K. Singla  
Assistant Professor  
Deptt. of Mechanical Engg.  
Thapar University, Patiala**



**DEPARTMENT OF MECHANICAL ENGINEERING  
THAPAR UNIVERSITY  
PATIALA-147004, INDIA**



## CERTIFICATE

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I hereby declare that the work which is being presented in the dissertation work entitled, "An **Experimental Study on Drilling of Glass Fiber Reinforced Plastic**" in partial fulfillment of the requirements for the award of degree of **Master of Engineering in Mechanical Engineering in CAD/CAM & ROBOTICS** submitted in Mechanical Engineering Department, Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of **Dr.V.K.Singla** refers other researchers work which are duly listed in the reference section.

The matter embodied in this thesis has not been submitted for the award of any other degree of this or any other university.


**Date: - July'2010**

**Place: - Patiala**

  
**(VIKAS SHARMA)**

.....

This is to certify that the above statement made by the candidate is correct and true to the best of our knowledge.

  
**Dr. V. K. Singla**

**Assistant Professor**

**Mechanical Engg. Department**

**Thapar University, Patiala**

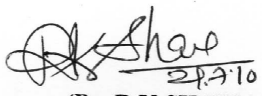
Countersigned by

  
**(Dr. S.K.MOHAPATRA)**

**Professor and Head**

**Mechanical Engineering Department**

**Thapar University, Patiala**

  
**(Dr. R.K.SHARMA)**

**Dean**

**Academic Affairs**

**Thapar University, Patiala**

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**Vikas Sharma**  
(800881022)

# ABSTRACT

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Delamination is recognized as one of the most critical defects that can result from the machining of composites. Delamination is a major problem associated with drilling fiber-reinforced composite materials that, in addition to reducing the structural integrity of the material, also results in poor assembly tolerance and has the potential for long-term performance deterioration. Delamination due to drilling has been a major research for many years and a considerable amount of work has been done to reduce it. This thesis work has involved the determination of different factors affecting the hole quality and cause of delamination in a glass fiber reinforced plastic. The various process parameters like different twist drill bits of different point angle and different materials have been taken. The thrust forces and torque were measured for different machining conditions. The piezoelectric dynamometer has been used for measuring thrust forces and torque on varying the feed rate, speed, point angle and drill materials. The different materials of drill bit has been used like Tungsten carbide, High speed steel and M50(high speed steel)

The optimum value has been determined with the help of main effect plot and ANOVA Tables to findout which parameter has affected most for increasing thrust force and torque. The mathematical modeling has been carried out sing Minitab 15 software and different models has been analysed with help of the taguchi design using orthogonal array. The Universal microscope has been used which determines delaminated diameter in GFRP specimens. The finite element method has been done by applied using Ansys11.0 software which helped to find out delaminated diameter with different control factors like point angle, drill material etc. The failure criteria has been applied in ansys software for finding delamination occurring glass fiber composite around the drilled holes.

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# CHAPTER-1

## INTRODUCTION

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Drilling machines were first invented and developed by Arthur James Arnot and William Blanch Brain. Development and improvements of the drilling machine and components continued, which resulted in the manufacturing of heavier arbors and high speed steel and carbide drills. These components allowed the operator to remove metal faster, and with more accuracy, than previous machines. Variations of drilling machines were also developed to perform special drilling operations. During this era, computerized machines have been developed to alleviate errors and provide better quality in the finished product. The drilling machine has revolutionized industrial work of every kind and made so such a lot of complex tasks seem easy. Drilling is the cutting process of using a drill bit in a drill to cut or enlarge holes in solid materials, such as wood or metal. Different tools and methods are used for drilling depending on the type of material, the size of the hole, the number of holes, and the time to complete the operation. Drilling is a cutting process in which a hole is originated or enlarged by means of a multipoint, fluted, end cutting tool. As the drill is rotated and advanced into the workpiece, material is removed in the form of chips that move along the fluted shank of the drill. A composite material is a heterogeneous material created by the synthetic assembly of two or more components, one a selected filler of reinforcing material and the other a compatible matrix binder, in order to obtain specific characteristics and performance. The binder and the filler have two very different properties but when combined together form a material with properties that are not found in either of the individual materials.

Machining of composites involves the removal of any extra or unwanted material. Some of the most common machining processes are drilling, turning, and milling. Earlier composites machined like metals. But poor surface finish and faster tool wear led to the further study of composite machining. Unlike metals, composites need separate tools and working conditions. Although tools used for machining of metals can still be used for composites, care must be taken to maintain optimum levels of, feed rate, thrust force, and other factors. Metal tools tend to wear out faster when used for machining of non-metals. One of the main advantages of composites has been the fact that an entire part can be manufactured. This minimizes the machining of composites. However with “part integration,” sometimes composites need to be joined to form a larger part, which means that a certain amount of machining needs to be done for composites too. “A typical aircraft wing might have as many as 5,000 holes” Hence, machining is a cost factor in the production of composites. A composite might have to go through all or some of the machining processes like milling, drilling and cutting.

## **1.1 RADIAL DRILLING MACHINE**

Radial Drilling machine is a machine fitted with a rotating cutting tool called drill bit. This radial drilling machine is used for drilling holes in various materials such as steel, cast iron and. The use of machine is in the metal working industry. A Radial Drilling machine is a large gear headed drill press in which the head moves along the arm that radiates from the column of the machine. The arm of the machine can swing in relation to the base of the machine. This swing operation helps the drill head to move out of the way so a large crane can place the heavy work piece on the base of the radial drilling machine. Also this helps in drilling holes at different locations of the work piece without actually moving the work piece. Power feed of the spindle is a common feature. Also coolant system is a common feature of the radial drilling machine. When it comes to mechanical machining, radial drilling machine is used for all functions such as drilling, counter boring, spot facing, lapping, screwing reaming, tapping and boring. Radial drilling machines work well with a variety of material such as cast iron, steel, plastic etc. Drilling machines hold a certain diameter of drill (called a chuck) rotates at a specified rpm (revolutions per minute) allowing the drill to start a hole.

A radial drilling machine or radial arm press is a geared drill head that is mounted on an arm assembly that can be moved around to the extent of its arm reach. The most important components are the arm, column, and the drill head. The drill head of the radial drilling machine can be moved, adjusted in height, and rotated. Aside from its compact design, the radial drill press is capable of positioning its drill head to the work piece through this radial arm mechanism. This is probably one of the reasons why more machinists prefer using this type of drilling machine. In fact, the radial drilling machine is considered the most versatile type of drill press. The tasks that a radial drilling machine can do include boring holes, countersinking, and grinding off small particles in masonry works. Although some drill presses are floor mounted, the most common set-up of radial arm drill presses are those that are mounted on work benches or Tables. With this kind of set-up, it is easier to mount the drill and the work pieces. There is no need to reposition work pieces because the arm can extend as far as its length could allow. Moreover, it is easier to maneuver large work pieces with the radial arm drilling machine. Large work pieces can be mounted on the Table by cranes as the arm can be swiveled out of the way.

### **1.1.1 Components of radial drilling machine**

Here are some of the major parts of the radial arm drilling machine explained below

Column - is the part of the radial arm drill press which holds the radial arm which can be moved around according to its length

Arm Raise - adjusts the vertical height of the radial arm along the column

On/Off Button - is the switch that activates and deactivates the drill press

Arm Clamp - secures the column and the arm in place

Table - is the area where the work pieces are fed and worked on

Base - is the radial arm drill press part that supports the column and the Table

Spindle - is the rotated part of the drill press which holds the drill chuck used in holding the cutting tool

Drill Head - is the part of the drill press that penetrates through the material or work piece and drill through the specific hole size

Radial Arm - holds and supports the drill head assembly and can be moved around on the extent of its length

There are a number of advantages of using the radial arm drill press. One of these advantages is the amount of area that it can cover which is only dependent on the length of the arm. Another advantage is the considerable size of work that it can handle since the arm can actually swivel out of the working area allowing cranes and derricks to place work pieces on the Table.

## **1.2 Classification of drilling machines**

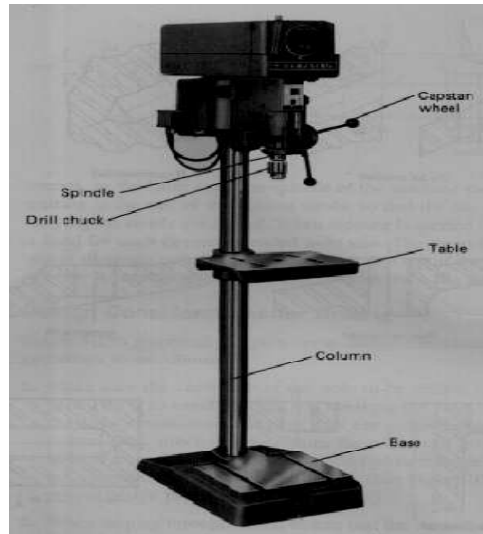
### **2.2.1 General purpose drilling machines of common use**

- **Table top small sensitive drilling machine**

These small capacity ( $\leq 0.5$  kW) upright (vertical) single spindle drilling machines are mounted (bolted) on rigid Table and manually operated using usually small size ( $\phi \leq 10$  mm) drills. Fig. 1.1 typically shows one such machine.

- **Pillar drilling machine**

These drilling machines, usually called pillar drills, are quite similar to the Table top drilling machines but of little larger size and higher capacity ( $0.55 \sim 1.1$  kW) and are grouted on the floor (foundation). Here also, the drill-feed and the work Table movement are done manually. Fig. 1.2 typically shows a pillar drill. These low cost drilling machines have tall tubular columns and are generally used for small jobs and light drilling.



**Fig. 1.1 Pillar Drilling machine**

- Radial drilling machine

This usually large drilling machine possesses a radial arm which along with the drilling head can swing and move vertically up and down. The radial, vertical and swing movement of the drilling head enables locating the drill spindle at any point within a very large space required by large and odd shaped jobs. There are some more versatile radial drilling machines where the drill spindle can be additionally swivelled or tilted.

- CNC column drilling machine

These versatile and flexibly automatic drilling machine having box-column type rigid structure the work Table movements and spindle rotation are programmed and accomplished by Computer Numerical Control (CNC). These modern sophisticated drilling machines are suitable for piece or batch production of precision jobs.

### **1.3. Kinematic System of general purpose drilling machine and their principle of working**

Kinematic system in any machine tool is comprised of chain(s) of several mechanisms to enable transform and transmit motion(s) from the power source(s) to the cutting tool and the workpiece for the desired machining action. The kinematic structure varies from machine tool to machine tool requiring different type and number of tool-work motions. Even for the same type of machine tool, say column drilling machine, the designer may take different kinematic structure depending upon productivity, process capability, durability, compactness, overall cost etc targeted.

Typical kinematic system of a very general purpose drilling machine, i.e., a column drilling machine having 12 spindle speeds and 6 feeds.

The kinematic system enables the drilling machine the following essential works as

- Cutting motion

The cutting motion in drilling machines is attained by rotating the drill at different speeds (r.p.m.). Like centre lathes, milling machines etc, drilling machines also need to have a reasonably large number of spindle speeds to cover the useful ranges of work material, tool material, drill diameter, machining and machine tool conditions. It is shown that the drill gets its rotary motion from the motor through the speed gear box (SGB) and a pair of bevel gears. For the same motor speed, the drill speed can be changed to any of the 12 speeds by shifting the cluster gears in the SGB. The direction of rotation of the drill can be changed, if needed, by operating the clutch in the speed reversal mechanism, RM-s shown in the Figure .

- Feed motion

In drilling machines, generally both the cutting motion and feed motion are imparted to the drill. Like cutting velocity or speed, the feed (rate) also needs varying (within a range) depending upon the tool-work materials and other conditions and requirements.

The drill receives its feed motion from the output shaft of the SGB through the feed gear box (FGA), and the clutch. The feed rate can be changed to any of the 6 rates by shifting the gears. And the automatic feed direction can be reversed, when required, by operating the speed reversal mechanism. The slow rotation of the pinion causes the axial motion of the drill by moving the rack provided on the quill.

The upper position of the spindle is reduced in diameter and splined to allow its passing through the gear without hampering transmission of its rotation.

- Tool work mounting

The taper shank drills are fitted into the taper hole of the spindle either directly or through taper socket(s). Small straight shank drills are fitted through a drill chuck having taper shank. The workpiece is kept rigidly fixed on the bed (of the Table). Small jobs are generally held in vice and large or odd shaped jobs are directly mounted on the bed by clamping tools using the T-slots made in the top and side surfaces of the bed.

## **1.4 General purpose drills**

They may be classified as

### **According to material**

- High speed steel – most common
- Cemented carbides
  - Without or with coating
  - In the form of brazed, clamped or solid

### **According to size**

Large twist drills of diameter around 40 mm

- Micro drills of diameter 25 to 500  $\mu\text{m}$
- Medium range (most widely used) diameter ranges between 3 mm to 25 mm.

### **According to number of flutes**

- Two fluted – most common
- Single flute – e.g., gun drill (robust)
- Three or four flutes – called slot drill

### **According to shank**

- Straight shank – small size drill being held in drill chuck
- Taper shank – medium to large size drills being fitted into the spindle nose directly or through taper sockets

### **According to specific applications**

- Centre drills- for small axial hole with 60° taper end to accommodate lathe centre for support

## **1.5 Basic Concepts of Composite Materials**

Composite materials are basically hybrid materials formed of multiple materials in order to utilize their individual structural advantages in a single structural material. Various scientific definitions for composite materials can be expressed. The word composite in the term composite material signifies that two or more materials are combined on a macroscopic scale to form a useful third material. The key is the macroscopic examination of a material wherein the components can be identified by the naked eye. Different materials can be combined on a microscopic scale, such as in alloying of metals, but the resulting material is, for all practical purposes, macroscopically homogeneous, i.e., the components cannot be distinguished by the naked eye and essentially act together.

Composite material is a material composed of two or more distinct phases (matrix phase and dispersed phase) and having bulk properties significantly different from those of any of the constituents.

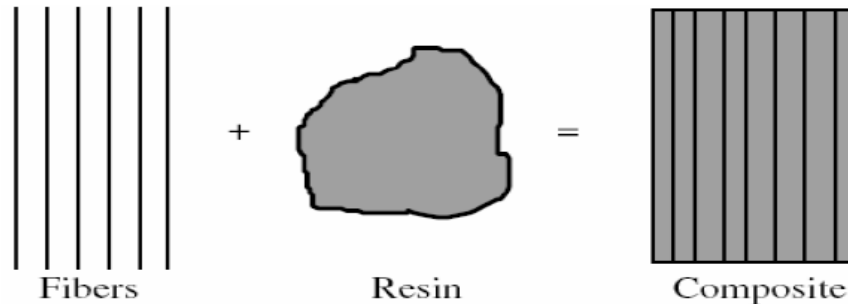
### **Matrix Phase**

The primary phase, having a continuous character, is called matrix. Matrix is usually more ductile and less hard phase. It holds the dispersed phase and shares a load with it.

## Dispersed (Reinforcing) Phase

The second phase (or phases) is imbedded in the matrix in a discontinuous form. This secondary phase is called dispersed phase. Dispersed phase is usually stronger than the matrix, therefore it is sometimes called reinforcing phase.

In other way we can also define composite materials like fiber and resin and if they get added make composites.



**Figure 1.2 Fibers and resin make composite material**

## 1.6 Classification of Composite

### Natural Composites

Several natural materials can be grouped under natural composites. Eg. bones, wood, shells, pearlite (steel which is a mixture of a phase and  $Fe_3C$ ) etc.

### Man-Made Composites

Man-made composites are produced by combining two or more materials in definite proportions under controlled conditions. Eg. Mud mixed straw to produce stronger mud mortar and bricks, Plywood, Chipboards, Decorative laminates, Fibre Reinforced Plastic (FRP), Carbon Composites, Concrete and RCC, Reinforced Glass etc.

## 1.7 Composites are used for many reasons

A single large part made of composites can replace many metal parts. Composite materials can be embedded with sensors, which can monitor fatigue and performance. They have a high stiffness to density ratio thereby providing greater strength at lighter weights. Composites have a low co-efficient of thermal expansion, which can help to provide dimensional stability when required. This property makes composites a good material to be used in plane and automobile interiors, galley ways, etc. The pressure and temperature for processing of composites is much less than that required for metals, thereby providing flexibility in the way composites are processed, in turn providing flexibility in production.

The matrix keeps the reinforcement material together, giving it shape and preserving it from external forces, including environmental effects. The matrix is responsible for the surface finish of composite materials and how long they last. The matrix material can be a metal, polymer, or ceramic. Depending on the matrix material, composites are classified into metal matrix composites, polymer matrix composites and ceramic matrix composites. The filler or reinforcement materials also differ. It is also responsible for the tensile strength, stiffness, and tensile modulus of composites.

## 1.8 Machining of Composites

Machining involves the removal of any extra or unwanted material. Some of the most common machining processes are drilling, turning, and milling. Earlier composites machined like metals. But poor surface finish and faster tool wear led to the further study of composite machining. Unlike metals, composites need separate tools and working conditions. Although tools used for machining of metals can still be used for composites, care must be taken to maintain optimum levels of, feed rate, thrust force, and other factors. The machining of composites seems to be as simple as machining of metals, but it has its own set of problems.

Some of these challenges faced during machining include the following

- Most composites are reinforced with fibers. Machining of composites makes the fibers discontinuous, which affects performance of the composite part.
- During machining, the matrix material and the reinforced material are removed, thereby exposing the reinforced material to nature and also to other chemicals, thus making them susceptible to chemical reactions and moisture.
- Most composites are very poor thermal conductors. During machining, heat can build up at the cutting edge of the tool.
- The sequence in a lay-up composite and the orientation are very important factors during machining. Knowing these might help reduce delamination at edge during machining. This is mostly observed in, but not limited to, continuous fiber composites.
- Some reinforcing materials are brittle, while others are ductile. During machining of aramid fibers, a common mode of failure is the axial splitting of the fiber in the direction transversal to the fiber due to weak molecular bonds.

## 1.9 Classification of FRP

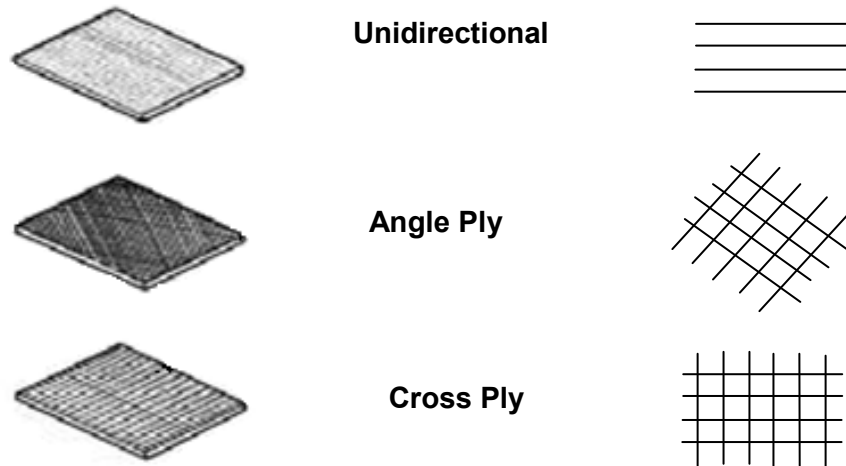
On the basis of

**a) Orientation** of fibre FRP can be categorized as

1. Unidirectional

## 2. Bidirectional

- Cross Ply
- Angle Ply



**Figure 1.3 Orientations of Fibers**

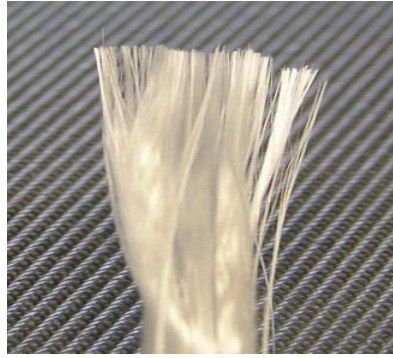
### **b) Types of Fiber**

1. **Carbon Fibre** is a material consisting of extremely thin fibers about 0.005–0.010 mm in diameter and composed mostly of carbon atoms. The carbon atoms are bonded together in microscopic crystals that are more or less aligned parallel to the long axis of the fiber. The crystal alignment makes the fiber very strong for its size.

2). **Glass Fiber** Glass fibres are made of silicon oxide with addition of small amounts of other oxides. Glass fibres are characteristic for their high strength, good temperature and corrosion resistance, and low price. The liquid is passed through micro-fine bushings and simultaneously cooled to produce glass fibre filaments from 5-24um in diameter.

#### **Glass fibre is available in the following forms**

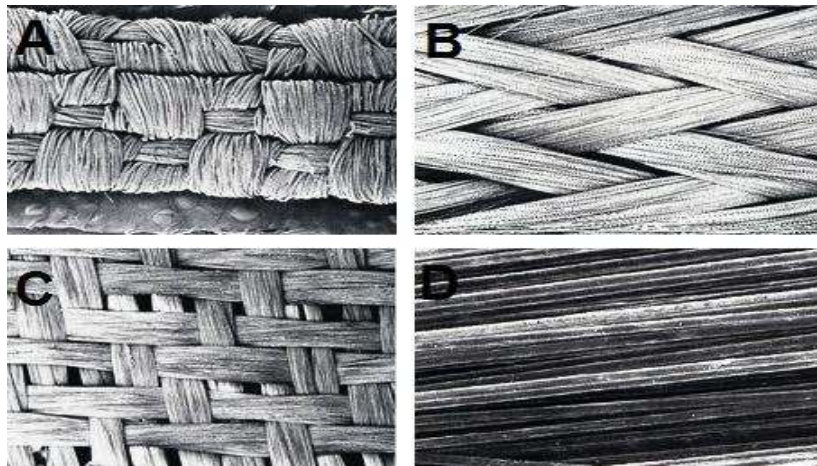
1. Continuous Fiber
2. Chopped strands
3. Woven



**Fig. 1.4 Continuous Fiber**



**Fig. 1.5 Chopped Strands**



**Fig.1.6 Woven Fabric**

**3). Aramid (Kevlar) Fibre** is a man-made organic polymer (an aromatic polyamide) produced by spinning a solid fibre from a liquid chemical blend. Aramid fibres are usually available in the form of rovings, with texes ranging from about 20 to 800.



**Fig.1.7 Aramid Fiber**

## 1.10 Applications of GFRP

### 1. Construction

Bathtubs, shower stalls and floors, hot tubs, spas, vanities and sinks, pipes, building panels, portable buildings, swimming pools, floor grating, doors, satellite dishes

### 2. Marine

Ski boats, fishing boats, sail boats, yachts, personal water craft, canoes, kayaks, docks

### 3. Corrosion

Tanks, processing vessels, pipes, fans, pollution control equipment, scrubbers

### 4. Transportation

Automobile body panels and structural components, truck hoods and caps, trailer sidewalls, RV sidewalls, train seating

### 5. Consumer

Sporting goods, hobby castings, decorative art

### 6. Electrical

Appliance housings, circuit boards, insulating boards.

## 1.11 Mechanical properties of different fibers

Selection of different fibers depends on type of mechanical properties required. Below shown are some of fibers and their properties.

**Table 1.1 Mechanical properties of different fibers**

Fiber	Fiber Diameter ( $\mu\text{m}$ )	Fiber Density		Tensile Strength		Tensile Modulus	
		(lb/in <sup>3</sup> )	(g/cc)	(ksi)	(GPa)	(Msi)	(GPa)
E-glass	8–14	0.092	2.54	500	3.45	10.5	72.4
S-glass	8–14	0.090	2.49	665	4.58	12.5	86.2
Polyethylene	10–12	0.035	0.97	392	2.70	12.6	87.0
Aramid (Kevlar 49)	12	0.052	1.44	525	3.62	19.0	130.0
HS Carbon, T300	7	0.063	1.76	514	3.53	33.6	230
AS4 Carbon	7	0.065	1.80	580	4.00	33.0	228
IM7 Carbon	5	0.065	1.80	785	5.41	40.0	276
XUHM Carbon	—	0.068	1.88	550	3.79	62.0	428
GY80 Carbon	8.4	0.071	1.96	270	1.86	83.0	572
Boron	50–203	0.094	2.60	500	3.44	59.0	407
Silicon Carbide		0.115	3.19	220	1.52	70.0	483

## 1.12 Properties of GFRP

**1. Mechanical Properties** characterize the strength, stiffness, toughness, and other load-carrying capabilities of materials. Typical tests used to characterize mechanical properties of GFRP composites include tensile, flexure (bending), compression, and impact properties.

**2. Hardness** of a GFRP laminate is an indication of the type of resin matrix and/or the extent of cure of the resin matrix. More rigid resins will give higher Barcol readings, while resilient and flexible resins will give lower readings. The most common are the Shore D, Barcol 935, and Barcol 934.

**3. Thermal Performance** of GFRP components are used in a number of elevated temperature applications, including under the hood applications in the transportation industry as well as numerous applications in the corrosion and electronic industries. The thermal performance of these components is largely determined by the polymer matrix, both the type of resin matrix and the component cure process.

**4. Chemical Properties** of GFRP components are used in many applications requiring chemical resistance. These include tanks, processing vessels, pipes, fans, pollution control equipment, and scrubbers. The chemical resistance of FRP components is influenced by both the resin matrix and the reinforcement. Polyester and vinyl ester resins resist chemical degradation to varying degrees.

**5. Electrical Properties** of GFRP components generally have excellent electrical properties and are used in a wide range of electrical applications. Electrical properties of FRP components are affected by the type of resin matrix, filler type and content, and glass content. Many electrical applications also require elevated temperature performance so the same types of resins used in thermal applications are used in electrical applications. These include isophthalics and vinyl esters.

**6. Fire Resistance** of GFRP components are used in many applications requiring fire resistance. The construction, transportation and consumer goods markets generally require some resistance to burning and have limitations on smoke generation and smoke toxicity. FRP components can meet many of these requirements.

**7. Optical Properties** of most general purpose polyester fiberglass laminates are translucent, although up to 90 percent light transmission can be achieved in a 1/16 inch to 1/8 inch GFRP laminate through the use of special resins and mat. Opaque laminates can be made by incorporating pigments and fillers in the resin. Color can be molded into the product so that painting is unnecessary.

**8. Polyester Shrinkage** All GFRP resin matrices shrink to varying degrees during cure. Reinforcements and fillers are inert and do not shrink. Shrinkage is an important consideration for mold building and must be accounted for to ensure that parts will have the correct dimensions. (For more information on shrinkage and Shrinkage of the resin matrix can also affect part cosmetics.

### 1.13 Delamination

Delamination is defined as “the separation of the layers of material in a laminate.” Delamination can occur at any time in the life of a laminate for various reasons and has various effects. It can affect the tensile strength performance depending on the region of delamination. Among the various defects that are caused by drilling, delamination is recognized as the most critical. Other defects are spalling and fiber pullout, but delamination can result in a reduction in the durability of the composite material and can cause a reduction in the bearing strength of the material and the structural integrity, resulting in performance issues.

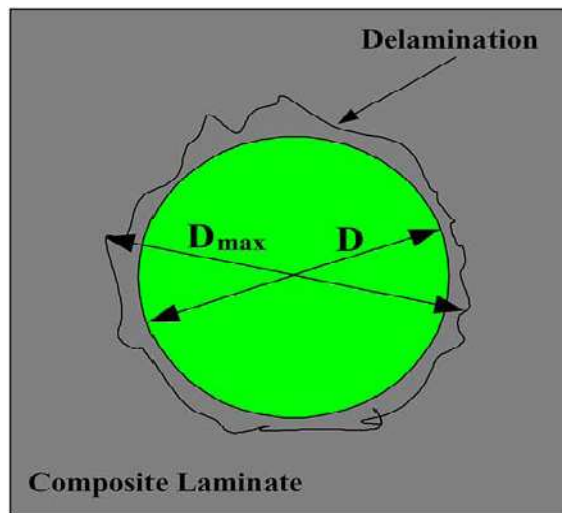
**Delamination factor** is defined by ratio of maximum diameter(of damaged zone around hole) to actual diameter.

$$\text{Delamination factor} = D_{\max}/D_{\text{actual}}$$

Where

$D_{\max}$  is damaged diameter around the hole

$D_{\text{actual}}$  real diameter to be drilled



**Fig. 1.8 Delamination in composite**

Some of the major reasons for the occurrence of delamination are the high thrust force and feed rate, other reasons include rapid tool wear and power. Some previous methods to avoid delamination have been to reduce the feed rate and thereby reduce the thrust force, using a backing plate. Recent methods have involved vibratory drilling.

Delamination is an important problem in the use of composite materials for structural purposes since it is a method of failure that is complex to understand and duplicate on computers. It tends to occur when the laminate is under tensile forces. Delamination caused by tensile forces has been attributed mainly to the stacking sequence of laminates. It is usually caused between plies due to out-of-plane tensile stresses and is also caused by cyclic

loads. This type of delamination is slow because the crack growth rate is very slow. Cyclic loads could be either tensile or compressive.

### 1.14 Twist Drills

Drill bits are cutting tools used to create cylindrical holes. Bits are held in a tool called a drill, which rotates them and provides torque and axial force to create the hole. Different point angle drills and different diameter drills and of different length of drills can be used according to the application of work.

Drills with no point angle are used in situations where a blind, flat-bottomed hole is required. These drills are very sensitive to changes in lip angle, and even a slight change can result in an inappropriately fast cutting drill bit that will suffer premature wear.

Drill bit geometry has several aspects

- The spiral, or rate of twist in the drill, controls the rate of chip removal in a drill. A fast spiral drill is used in high feed rate applications under low spindle speeds, where removal of a large volume of swarf is required.
- The point angle, or the angle formed at the tip of the drill, is determined by the material the drill will be operating in
- Harder materials require a larger point angle, and softer materials require a sharper angle
- The lip angle determines the amount of support provided to the cutting edge.
- Both conditions can cause binding, wear, and eventual catastrophic failure of the tool. The proper amount of lip clearance is determined by the point angle.

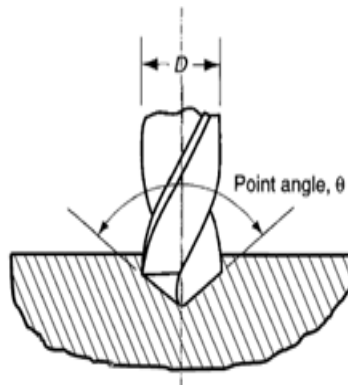
#### 1.14.1 Different geometry of drills on basis of material to be drilled

Point angle is considered as one of the main factor for quality of hole different materials have different point angle as shown. The main consideration has been given in this work towards diameter and point angle of twist drill.

**Table 1.2 Workpiece material and drill point angle**

Material	Point angle	Chisel angle
Aluminium	118°–130°	125°–130°
Brass	118°–125°	125°–135°
bronze (hard)	118°	115°–125°
Copper	100°–130°	125°–135°

Plastic	60°–118°	125°–135°
stainless steel	118°–140°	115°–125°
cast iron	90°–118°	115°–125°
cast steel	118°	125°–135°



**Fig.1.9 Point angle and diameter of drill**

### 1.15 Thrust Force

Thrust force during drilling can be defined as “the force acting along the axis of the drill during the cutting process.” Cutting forces help monitor tool wear, since forces increase with tool wear. Thrust force is also used to monitor tool wear and, in turn, monitor tool life. Tool failure can occur if tool wear is not monitored. Other than being an important factor in the monitoring of tool wear, thrust force is considered to be the major contributor of delamination during drilling. Considerable research has been done to prove that there is a “critical thrust force” that causes delamination, and thrust force below that will constrain or eliminate delamination during drilling. Vibratory drilling has been known as one of the methods to reduce thrust force during drilling of steel and during drilling of composites.

Machining of delamination free composites using conventional methods would lower the cutting quantities. If the “critical thrust force” is known, then the machining efficiency can be increased and higher quantities can be machined. This thesis deals with the prediction of thrust force at which delamination will occur during drilling of composites

## CHAPTER-2

### LITERATURE REVIEW

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Many scientists have used Taguchi methods for their design experiments. Taguchi method systematically reveals the complex cause and effect relationship between design parameter and performance. Taguchi methods are most recent additions to the tool kit of design, process, and manufacturing engineers and quality assurance experts. In contrast to statistical process control which attempt to control the factors that adversely affect the quality of production.

A considerable amount of research has been conducted on the effects of drilling on composite materials. Most has been targeted toward the study of delamination. There has been research on the quality of the holes drilled during research as well.

**Dipaolo g, Kapoor G and Devor R. E [1]** studied the crack growth phenomenon that occurs while drilling fiber-reinforced composite materials (FRCM), specifically unidirectional (UD) carbon fiber/epoxy resin. It used an experimental setup that exploits the technology of video to understand the complete crack growth phenomenon as the drill emerges from the exit side of the workpiece. Significant damage mechanisms are observed and defined, and correlations between the average exit drill forces and the crack tip position are shown. Instantaneous forces as they vary along the orientation of the cutting edges are identified in terms of their contribution to the crack propagation.

**Wen-Chou Chen [2]** studied the concept of delamination factor  $F_d$  (i.e. the ratio of the maximum diameter  $D_{max}$  in the damage zone to the hole diameter  $D$ ) is proposed to analyze and compare easily the delamination degree in the drilling of carbon fiber-reinforced plastic (CFRP) composite laminates. Experiments were performed to investigate the variations of cutting forces with or without onset of delamination during the drilling operations. The effects of tool geometry and drilling parameters on cutting force variations in CFRP composite materials drilling were also experimentally examined. The experimental results shown the delamination-free drilling processes may be obtained by the proper selections of tool geometry and drilling parameters. The effects of drilling parameters and tool wear on delamination factor are also presented and discussed.

**S. C. Lin, I. K. Chen [3]** studied the effects of increasing cutting speed on drilling characteristics of carbon fiber-reinforced composite materials. The effects of increasing cutting speed ranging from 9550 up to 38 650  $\text{rev min}^{-1}$  (from 210 to 850  $\text{m min}^{-1}$ ) on average thrust force, torque, tool wear and hole quality for both multifacet drill and twist drill are studied. It was found that increasing cutting speed will accelerate tool wear. And the thrust force increases as drill wear increases. Although tool geometries change quickly due to the fast development of tool wear and the thrust force increases drastically as cutting speed increases, an acceptable hole entry and exit quality is maintained. This is because relatively small feeds are used in this tests. It was concluded that tool wear was the major problem encountered when drilling carbon fiber-reinforced composite materials at high speed.

**R. Stone and K. Krishnamurthy[4]** studied the linear-elastic fracture mechanics theory which proposed critical cutting and thrust forces in the various drilling regions that can be used as a guide in preventing crack growth or delamination. Using these critical force curves as a guide, a thrust force controller was developed to minimize the delamination while drilling a graphite-epoxy laminate. A neural network control scheme was implemented which required a neural network identifier to model the drilling dynamics and a neural network controller to learn the relationship between feed rate and the desired thrust force. Experimental results verifying the validity of this control approach as well as the robustness of the design are presented. Visual measurements of the delamination zones were used to quantify the benefits of the thrust force controlled drilling process versus the conventional constant feed rate drilling process.

**J. Mathew, N. Ramakrishnan and N. K. Naik[5]** studied that thrust is a major factor responsible for delamination and it mainly depends on tool geometry and feed rate. Trepanning tools, which were used in this study, were found to give reduced thrust while making holes on thin laminated composites. In this work the peculiarities of trepanning over drilling of unidirectional composites has been emphasised. The models for prediction of critical thrust and critical feed rate at the onset of delamination during trepanning of uni-directional composites based on fracture mechanics and plate theory also have been presented. Mathematical models correlating thrust and torque with tool diameter and feed rate have been developed through statistically designed experiments and effect of various parameters on them have been discussed. It is observed that sub-laminate thickness is the most decisive parameter from the viewpoint of critical feed rates.

**Capello E, Tagliaferri V [6]** studied the effect of the drilling on the residual mechanical behavior of glass fiber reinforced plastic (GFRP) laminates when the hole is subjected to bearing load. In the first part, the influence of drilling parameters on the type and extension of the damage is analyzed. The damage was described at the macro level (delaminated area) and at the micro level (cracks, fiber-matrix debonding, etc.). The Design of Experiments and Analysis of Variance techniques are used in order to determine the statistical influence of the drilling parameters on the delamination area. Moreover, the effects of drilling with or without a support beneath the specimens are analyzed and discussed. Push-down delamination was mainly affected by the feed rate, by the presence of support beneath the specimen, and by the twist drill temperature.

**G. Caprino and V. Tagliaferri [7]** studied to clarify the interaction mechanisms between the drilling tool and material. Drilling tests were carried out on glass-polyester composites using standard HSS tools; drilling was interrupted at preset depths to study damage development during drilling. The specimens, polished by a metallographic technique, were examined by optical microscopy to identify any damage. The results obtained were useful in describing the damage history and to help design drill geometries specifically conceived for composite machining. The qualitative agreement of the observed behaviour with the predictions of the model presented in the literature and some of their intrinsic limitations are assessed.

**R. Piquet et. al [8]** studied the drilling with a twist drill and a specific cutting tool of structural thin backing plates in carbon/epoxy. The possibility to manufacture carbon/epoxy with a conventional cutting tool was analysed and the limits of the twist drill were shown. Consequently we defined a specific cutting tool. Series of comparative experiments were carried out using a conventional twist drill and this specific cutting tool. The results shown the capabilities of the

specific cutting tool because several defects and damages usually encountered in twist drilled holes were minimised or avoided (entrance damage, roundness and diameter defects and plate exit damage).

**E.-S. Lee [9]** studied the machinability of GFRP by means of tools made of various materials and geometries was investigated experimentally. By proper selection of cutting tool material and geometry, excellent machining of the workpiece is achieved. The surface quality relates closely to the feedrate and cutting tool. When using glass fibre reinforced plastics (GFRP) it is often necessary to cut the material, but the cutting of GFRP is often made difficult by the delamination of the composite and the short tool life.

**L-B Zhang, L-J Wang and X-Y Liu[10]** studied the analysis for multidirectional composite laminates is based on linear elastic fracture mechanics (LEFM), classical bending plate theory and the mechanics of composites. This paper presents a general closed-form mechanical model for predicting the critical thrust force at which delamination is initiated at different ply locations. Good correlation is observed between the model and the experimental results.

**E. Ugo. Enemuoh et. al [11]** studied new comprehensive approach to select cutting parameters for damage-free drilling in carbon fiber reinforced epoxy composite material is presented. The approach is based on a combination of Taguchi's experimental analysis technique and a multi-objective optimization criterion. The optimization objective includes the contributing effects of the drilling performance measures: delamination, damage width, surface roughness, and drilling thrust force. A hybrid process model based on a database of experimental results together with numerical methods for data interpolation are used to relate drilling parameters to the drilling performance measures. Case studies are presented to demonstrate the application of this method in the determination of optimum drilling conditions for damage-free drilling in BMS 8-256 composite laminate.

**J. Paulo Davim and Pedro Reis[12]** studied the cutting parameters (cutting velocity and feed rate) on power ( $P_c$ ), specific cutting pressure ( $K_s$ ), and delamination in carbon fiber reinforced plastics (CFRPs). A plan of experiments, based on the techniques of Taguchi, was established considering drilling with prefixed cutting parameters in an autoclave CFRP composite laminate. The analysis of variance was performed to investigate the cutting characteristics of CFRPs using cemented carbide (K10) drills with appropriate geometries. The objective was to establish a correlation between cutting velocity and feed rate with the power ( $P_c$ ) specific cutting pressure ( $K_s$ ) and delamination factor ( $F_d$ ) in a CFRP material. Finally, this correlation was obtained by multiple linear regressions.

**C. C. Tsao, H. Hocheng[13]** studied prediction and evaluation of delamination factor in use of twist drill, candle stick drill and saw drill. The approach is based on Taguchi's method and the analysis of variance (ANOVA). An ultrasonic C-Scan to examine the delamination of carbon fiber-reinforced plastic (CFRP) laminate is used in this paper. The experiments were conducted to study the delamination factor under various cutting conditions. The experimental results indicate that the feed rate and the drill diameter are recognized to make the most significant contribution to the overall performance. The objective was to establish a correlation between feed rate, spindle speed and drill diameter with the induced delamination in a CFRP laminate.

The correlation was obtained by multi-variable linear regression and compared with the experimental results.

**U. A. Khashaba [14]** studied the Delamination-free in drilling different fiber reinforced thermoset composites was the main objective of research. Therefore the influence of drilling and material variables on thrust force, torque and delamination of GFRP composites was investigated experimentally. Drilling variables were cutting speed and feed. Material variable include matrix type, filler and fiber shape. Drilling process was carried out on cross-winding/polyester, continuous-winding with filler/polyester, chopped/polyester, woven/polyester and woven/epoxy composites. A simple inexpensive accurate technique was developed to measure delamination size. The thrust forces in drilling continuous-winding composite are more than three orders of magnitude higher than those in the cross-winding composites. Delamination, chipping and spalling damage mechanisms were observed in drilling chopped and continuous-winding composites. Delamination-free in drilling cross-winding composites was achieved using variable feed technique.

**J. Paulo Davim, Pedro Reis and C. Conceicao Antonio [15]** studied the cutting parameters (cutting velocity and feed) and the influence of the matrix under specific cutting force ( $kc$ ), delamination factor ( $F_d$ ) and surface roughness ( $R_a$ ) in two types of matrix (Viapal VUP 9731 and ATLAC 382-05). A plan of experiments, based on the orthogonal array, was established considering drilling with prefixed cutting parameters in two hand lay-up FRPs materials. Finally the analysis of variance (ANOVA) was preformed to investigate the cutting characteristics of FRPs composite material using a cemented carbide (K10) drill with appropriate geometry.

**I. El-Sonbaty, U. A. Khashaba and T. Machaly [16]** studied the influence of some parameters on the thrust force, torque and surface roughness in drilling processes of fiber-reinforced composite materials. These parameters include cutting speed, feed, drill size and fiber volume fraction. The quasi-isotropic composite materials were manufactured from randomly oriented glass fiber-reinforced epoxy, with various values of fiber volume fractions ( $V_f$ ), using hand-lay-up technique. Two components drill dynamometer has been designed and manufactured to measure the thrust and torque during the drilling process. The dynamometer was connected with a data acquisition, which installed in a PC computer. This set-up enables to monitor and record the thrust force and torque with the aid of a computer program that designed using Lab View utilities.

**Jin Pyo Jung, Geun Woo Kim and Kang Yong Lee [17]** studied new formulation for the critical thrust force necessary to propagate the delamination generated during the drilling operation of an antisymmetric angle-ply laminate is proposed by modeling the delamination zone as an elliptical shape. The critical thrust force is analytically derived with the consideration of bending, twisting and mid-plane extension of the delamination zone. And then to maximize the critical thrust force, the optimal design of an angle-ply laminate is performed to find the optimal number of fiber per millimeter, optimum diameter of fiber and optimum lamination angle using ADS (Automated Design Synthesis).

**Velayudham A, Krishnamurthy R and Soundarapandian T [18]** studied the dynamics of drilling of high volume fraction glass fibre reinforced composite. At high fibre volume, fibres do not show much relaxation and normal hole shrinkage associated with polymeric composites was

not observed during drilling. Peak drilling thrust, dimension of holes drilled and vibration induced during drilling are observed to correlate with each other. Vibrations study has been attempted through wavelet packet transform and the results demonstrated its capability in signal characterisation.

**N.S. Mohan, S.M. Kulkarni and A. Ramachandra [19]** studied the drilling parameters and specimen parameters evaluated were speed, feed rate, drill size and specimen thickness on FRP. A signal-to-noise ratio is employed to analyze the influence of various parameters on peel up and push down delamination factor in drilling of glass fibre reinforced plastic (GFRP) composite laminates. The main objective of this study was to determine factors and combination of factors that influence the delamination using Taguchi and response surface methodology and to achieve the optimization machining conditions that would result in minimum delamination. From the analysis it is evident that among the all significant parameters, specimen thickness and cutting speed have significant influence on peel up delamination and the specimen thickness and feed have more significant influence on push down delamination.

**C.C. Tsao and H. Hocheng [20]** studied the effects of backup plate on delamination in drilling composite materials using saw drill and core drill. The critical drilling thrust force at the onset of delamination is calculated and compared with that without backup. Saw drills and core drills produce less delamination than twist drills by distributing the drilling thrust toward the hole periphery. Delamination can be effectively reduced or eliminated by slowing down the feed rate when approaching the exit and by using back-up plates to support and counteract the deflection of the composite laminate leading to exit side delaminations. The use of the back-up does reduce the delamination in practice, which its effects have not been well explained in analytical fashion.

**I. Singh and N. Bhatnagar [21]** studied to correlate drilling-induced damage with drilling parameters. Tool point geometry is considered a major factor that influences drilling-induced damage. Experiments were conducted and drilling-induced damage was quantified using the digital image processing technique. The results also reestablished the cutting speed to feed ratio as an important variable that influences drilling-induced damage. Mathematical models for thrust, torque, and damage are proposed that agree well with the experiments.

**S. Arul et. al [22]** studied the drilling of polymeric composites which aimed to establish a technology that would ensure minimum defects and longer tool life. Specifically, the authors conceived a new drilling method that imparts a low-frequency, high amplitude vibration to the workpiece in the feed direction during drilling. Using high-speed steel (HSS) drill, a series of vibratory drilling and conventional drilling experiments were conducted on glass fiber-reinforced plastics composites to assess thrust force, flank wear and delamination factor. In addition, the process-status during vibratory drilling was also assessed by monitoring acoustic emission from the workpiece. From the drilling experiments, it was found that vibratory drilling method is a promising machining technique that uses the regeneration effect to produce axial chatter, facilitating chip breaking and reduction in thrust force.

**H. Hocheng and C.C. Tsao[23]** studied the critical thrust force at the onset of delamination, and compares the effects of these different drill bits. The results confirm the analytical findings and are consistent with the industrial experience. Ultrasonic scanning is used to evaluate the extent of drilling-induced delamination in fiber-reinforced materials. The advantage of these

special drills is illustrated mathematically as well as experimentally, that their thrust force is distributed toward the drill periphery instead of being concentrated at the center. The allowable feed rate without causing delamination is also increased. The analysis can be extended to examine the effects of other future innovative drill bits.

**J. Rubio et. al [24]** studied HSM to realize high performance drilling of glass fibre reinforced plastics (GFRP) with reduced damage. In order to establish the damage level, digital analysis is used to assess delamination. A comparison between the conventional (Fd) and adjusted (Fda) delamination factor is presented. The experimental results indicate that the use of HSM is suitable for drilling GFRP ensuring low damage levels. Drilling is probably the machining process most widely applied to composite materials; nevertheless, the damage induced by this operation may reduce drastically the component performance.

**V. Krishnaraj, S. Vijayarangan and A. Ramesh Kumar [25]** studied the damage generated during the drilling of Glass Fibre Reinforced Plastics (GFRP) which was detrimental for the mechanical behaviour of the composite structure. This work was focused on analysing the influence of drilling parameters (spindle speed and feed) on the strength of the GFR woven fabric laminates and further to study the residual stress distribution around the hole after drilling. Holes were drilled at the centre of the specimens in a CNC machining centre using 6 mm diameter micrograin carbide drill for various spindle speeds (1000 4000 rpm) and feed rates (0.02, 0.06, 0.10 and 0.20 rev/min). Degree of damage depends on the feed rate and spindle speed. Experimental results indicate that failure strength and stress concentration are related to the drilling parameters and a drilling parameter (3000 rpm and 0.02 mm/rev), which gives better mechanical strength.

**U.A. Khashaba M.A. Seif and M.A. Elhamid [26]** studied the effects of the drilling parameters, speed, and feed, on the required cutting forces and torques in drilling chopped composites with different fiber volume fractions. Three speeds, five feeds, and five fiber volume fractions are used in this study. The results show that feeds and fiber volumes have direct effects on thrust forces and torques. On the other hand, increasing the cutting speed reduces the associated thrust force and torque, especially at high feed values. Using multivariable linear regression analysis, empirical formulas that correlate favorably with the obtained results have been developed. These formulas would be useful in drilling chopped composites. The influence of cutting parameters on peel-up and push-out delaminations that occurs at drill entrance and drill exit respectively the specimen surfaces have been investigated. No clear effect of the cutting speed on the delamination size is observed, while the delamination size decreases with decreasing the feed. Delamination-free in drilling chopped composites with high fiber volume fraction remains as a problem to be further investigated.

**Redouane Zitoune, Vijayan Krishnaraj and Francis Collombet [27]** studied the parametric influences on thrust force, torque as well as surface finish, the experimental results shown that the quality of holes can be improved by proper selection of cutting parameters. This is substantiated by monitoring thrust force, torque, surface finish, circularity and hole diameter. For the CFRP, the circularity is found to be around 6  $\mu$ m at low feed rates, when the feed is increased the circularity increases to 25  $\mu$ m. The wear tests carried out show that, during first 30 holes, thrust force in CFRP undergoes a more important increase (90%) than thrust force of aluminium (6%).

**I.S. Shyha et. al [28]** studied the effect of drill geometry and drilling conditions on tool life and hole quality. Main effects plots and percentage contribution ratios (PCR) are detailed in respect of response variables and process control factors. More conventionally, tool wear and cutting force data are plotted tabulated, together with micrographs of hole entry/exit condition and internal hole damage. Drill geometry and feed rate in general had the most effect on measured outputs. Thrust force was typically below 100 N at test cessation; however, drill wear progression effectively doubled the magnitude of force from test outset. Entry and exit delamination factors (Fd) of 1.3 were achieved while the maximum number of drilled holes for a tool life criterion VBB max of r 100 mm was 2900 holes using a stepped, uncoated drill with a feed rate of 0.2 mm/rev.

**S.R. Karnik et.al [29]** studied the delamination behaviour as a function of drilling process parameters at the entrance of the CFRP plates. The delamination analysis in high speed drilling is performed by developing an artificial neural network (ANN) model with spindle speed, feed rate and point angle as the affecting parameters. A multilayer feed forward ANN architecture, trained using error-back propagation training algorithm (EBPTA) is employed for this purpose. Drilling experiments were conducted as per full factorial design using cemented carbide (grade K20) twist drills that serve as input-output patterns for ANN training. The validated ANN model is then used to generate the direct and interaction effect plots to analyze the delamination behavior. The simulation results illustrate the effectiveness of the ANN models to analyze the effects of drilling process parameters on delamination factor. The analysis also demonstrates the advantage of employing higher speed in controlling the delamination during drilling.

**L.M.P. Duraõ et.al [30]** studied to minimization of axial thrust force during drilling reduces the probability of delamination onset, as it has been demonstrated by analytical models based on linear elastic fracture mechanics (LEFM). A finite element model considering solid elements of the ABAQUS<sup>®</sup> software library and interface elements including a cohesive damage model was developed in order to simulate thrust forces and delamination onset during drilling. Thrust force results for delamination onset are compared with existing analytical models.

**Redouane Zitoun and Francis Collombe [31]** studied a numerical FE analysis is proposed to calculate the thrust forces responsible for the defect at the exit of the hole during the drilling phase of long-fibre composite structures, within a quasi-static framework. This numerical model compared with the analytical models studied in the literature – takes into account the tool point geometry as well as the shear force effects in the laminate. The validation of this numerical model is carried out thanks to punching tests conducted at low speed on two types of semi products in carbon/epoxy long fibre manufactured by Hexcel composites. The numerical results provide the right correlation with the experimental values. Moreover, the comparison between the numerical thrust forces and those provided by the analytical models of the literature is called into question.

## CHAPTER-3

### DESIGN OF EXPERIMENT

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#### 3.1 Outline of Thesis Work

The recent study consists of experimentations, parametric analysis using ANSYS 11.0 software and finally mathematical modeling using MINITAB 15 software. Experimentation generally specifies the machining of Glass Fiber specimen on Radial drilling machine. A piezoelectric dynamometer has been installed on drilling machine for calculating thrust forces and torque on work piece while machining. Taguchi method using design of experiments approach has been used to optimize a process. Here we have applied D.O.E approach for modeling of thrust forces and torque in drilling process, the various input parameters have been taken under experimental investigation and then model has prepared for doing experimentation. The results obtain has been analyzed and the models produced by using MINITAB software. These models produced shown the results that which parameter is more effective in producing more thrust forces and torque. Different tool materials of drill bits have been used made of HSS, Carbide, M50.

#### 3.2 Various Input Parameters

1. Point angle
2. Feed rate
3. Speed
4. Drill bit material
5. Geometry of drill bit

After research it has been found that above are important input parameters for studying Thrust forces and Torque. After literature review three main input parameters are Speed, Feed Rate, Point Angle are used for experimentation and other is drill bit material. Three type of drill material has been used for three set of experimentation by taking same input parameters. The specimen is made of Glass fiber reinforced plastic. Composite laminates are made from cross-ply woven glass fiber . The reinforcement was in the form of E-glass fiber tape and the matrix was polyester resin, with hardener HY 951. The specimen plates are cut into same pieces of dimension 14cm×12 cm. 12 layered lamina make the plate thickness of 5mm. Fiber volume fraction is 0.56–0.60. The standard high-speed steel, tungsten carbide and M50 (high speed steel) twist drill of 6 mm diameter with different point angles was used in the present investigation. Each fresh drill point was used to make only 9 holes, in order to nullify the effect of tool wear on cutting forces.

### 3.3 Design of Experiment

The objective of this research work is to study the effect of different parameters such as point angle, feed rate and speed for this design models have been prepared by choosing three levels:

- a) Three levels of the point angle have been used.
- b) Three levels of feed rate have been used.
- c) Three levels of speed have been used.
- d) Three different materials.

For conducting the experiments, it has been decided to follow the Taguchi method of experimental design and an appropriate orthogonal array is to be selected after taking into consideration the above design variables. Out of the above listed design variables, the orthogonal array was to be selected for four design variables (namely point angle, feed rate and speed) which would constitute the orthogonal array.

The two most important outputs are thrust force and torque for this research work has been analyzed. The effect of the variation in input process parameter will be studied on these two response parameters and the experimental data will be analyzed as per Taguchi method to find out the optimum machining condition and percentage contribution of each factor.

### 3.4 Tool Used in Machining

Twist drill has been used of 3 different materials made of HSS, Tungsten Carbide and M50 (namely high speed steel).

**HSS composition** 1.20 -1.40% carbon; 0.50% Manganese; 1.00% maximum Silicon; 3.5 to 4.5% Chromium; 2.25-2.75% Vanadium; 5.60- 6.40% Tungsten; 5.60- 6.40% Molybdenum; 5.0 to 7.0% Cobalt

**Tungsten Carbide composition** 8.0% cobalt (Co), 78.0% Tungsten carbide (WC), Tantalum carbide 8.0 % (TaC) ,6.0% Titanium carbide (TiC)

**M50 composition** 10% Molybdenum, 4.25% Chromium, 0.85% Tungsten, 4% Vanadium

### 3.5 Experimental Procedure

The key factor in developing a mathematical model is to obtain sufficient experimental data simulating the working environment in the laboratory. Three dependently controllable factors affecting the thrust forces and torque were identified as the Point angle, Feed rate, Cutting speed. The Experiment has been conducted by Drilling of glass fiber reinforced plastic, using Tungsten carbide, HSS and M50 Twist Drill of 6mm diameter. The cutting force components and torque (ch4) has been measured with a Piezo-electric three- component dynamometer (Kistler, Type 5070A), a multi channel charge amplifier (Kistler, Type 5070A) and a data acquisition system. Experiments were carried out under various cutting conditions like different speeds, feed rates and different point angle of different twist drill. To reduce the total number of experiments and to obtain data uniformly from all the regions of the selected working area, a factorial design procedure has been adopted. A Universal Microscope has been used for observing the damaged area around the hole and for checking the diameter of delaminated area.

### 3.6 Experiment Set Up

Radial drilling has been used for experimental work for drilling 81 holes by doing 27 holes for one set. Three different types of drills has been used of different point angles as 85°, 100° and 118°. Total nine drills has been used for experiment by taking three point angle of one material. In every experiment drill bit of 6 mm has been used for drilling 6 mm diameter hole.

Below fig. showing different drill bits of different material



**Fig.3.1 Tungsten Carbide**



**Fig. 3.2 HSS**



**Fig. 3.3 M50**

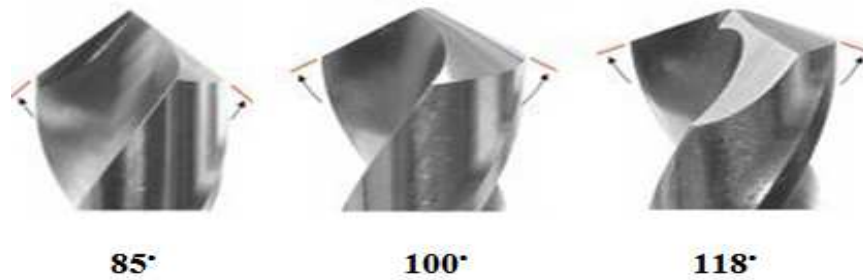


**Fig.3.4 All drills**

### 3.7 Drill point angle

Different drills can be identified by considering their geometry like rake angle, drill point angle etc. In this thesis work we are considering point angle as main parameter of twist drill. Different

drill point angle has been taken as 85°, 100° and 118°. Below shown fig. signifies for different point angle.



**Fig.3.5 Different point angle**

### 3.8 Radial drilling machine

A radial drilling machine has been used for the experiment having different range of speed and feed. Different range of speed can be chosen in machine by shifting the gears acc. to needed speed.

**Table 3.1 Speed ranges of radial drilling machine**

Speed (rpm)			
160	244	580	890
80	122	290	445

Different range of feed like coarse, fine and manual can be chosen from this machine like coarse have feed of the range 0.2 mm/rev. and fine have range of 0.1 mm/rev. And manual feed we can give by own acc. to time a drill takes to travel into workpiece.

**Table 3.2 Feed ranges of radial drilling machine**

Coarse (mm/rev.)	Fine	Manual
0.2	0.1	Acc. to thickness



**Fig. 3.6 A radial drilling machine**

### **3.9 Dynamometer**

Piezo-electric three-component dynamometer (Kistler, Type 5070A) has been used for measuring the thrust forces and torque. Reading from the dynamometer were fed to the computer for analytical and saving purposes. Each of these values were measured by voltage fluctuation recorded by dynamometer during drilling operation.



**Fig. 3.7 Dynamometer (Kistler, Type 5070A)**

### 3.10 Universal Microscope

A universal microscope has been used for checking the damage area around the hole. A universal microscope has a resolution of  $1\ \mu\text{m}$  and  $30\times$  magnifications was used in experiment for measuring the diameter of damaged hole.

#### Specifications

Longitudinal travel 0 - 150mm

Transversal travel 0 - 50mm

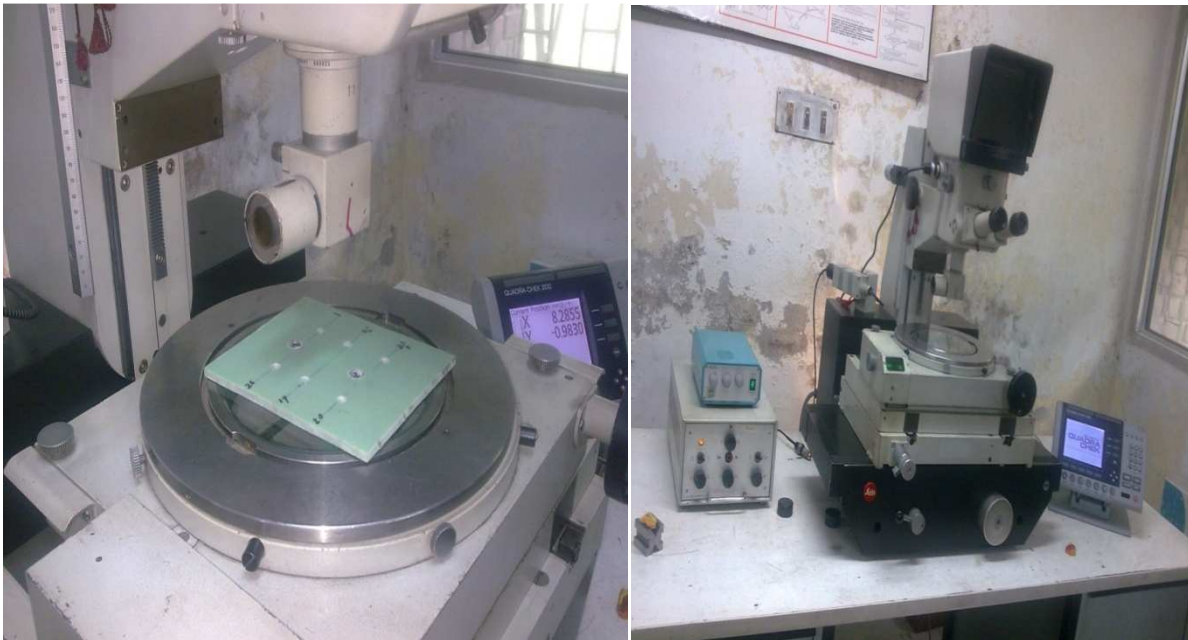
Travel of the micrometer drum 0 - 25mm

Lateral inclination range of the microscope column  $\pm 12^\circ$

Angular scale range of the goniometer eyepiece 0 -  $360^\circ$

Angular graduation of the goniometer eyepiece 1'

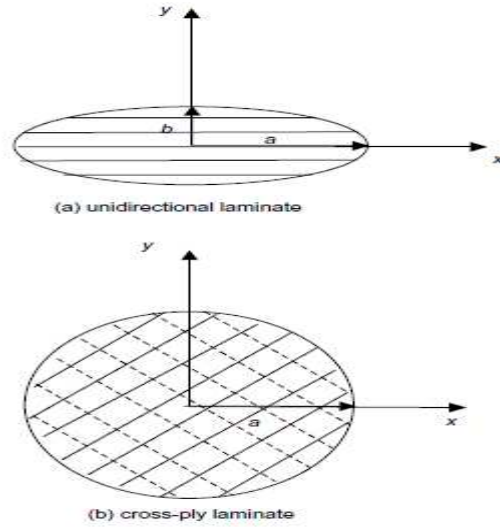
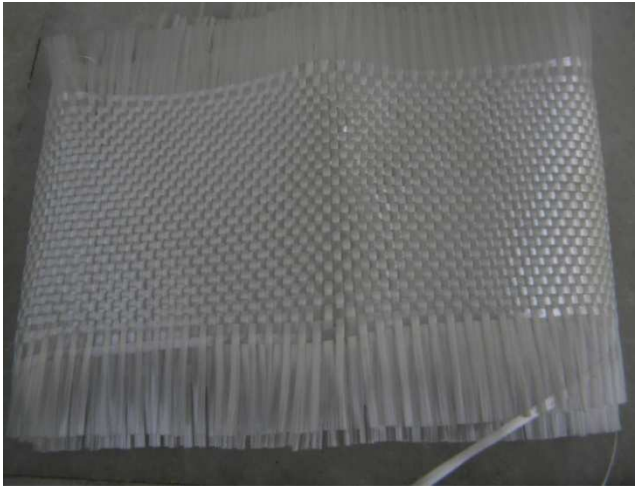
Angular scale range of the thread template eyepiece  $\pm 7^\circ$



**Fig. 3.8 Universal Microscope**

### 3.11 Specimen

Composite laminates are made from cross-ply glass fiber. The reinforcement was in the form of E-glass fiber tape and the matrix was polyester resin, with hardener HY 951. The specimen plates are cut into same pieces of dimension  $14\text{cm}\times 12\text{cm}$ . 10 layered lamina make the plate thickness of 5mm. Fiber volume fraction is 0.56–0.60 and specimen having density valued  $3.6\text{--}3.8\ \text{gm}/\text{m}^3$ . The standard high-speed steel, Tungsten Carbide, M50 were used in twist drill of 6 mm diameter with different point angles was used in the present investigation. Each fresh drill point was used to make only 9 holes, in order to nullify the effect of tool wear on cutting forces.



**Fig. 3.9 Glass Fibers Composite**

Different specimens were drilled with different twist drills made of different composition namely Tungsten carbide, High speed steel and M50. Each specimen has six hole, drilled with different cutting parameters.

### 3.12 Selection of Orthogonal Array & Parameter Assignment

In this experiment, there are three parameters at three levels each. There are three different materials for three same experiment and same orthogonal array and Taguchi design has been implemented for this work. L27 (3\*3) has been used for this experiment.

Taguchi design for experimentation by applying L27 orthogonal array by taking three levels for each factor

**Table 3.3 Taguchi Design**

Exp. No.	Point Angle(deg.)	Feed (mm/rev.)	Speed(rpm)
1	1	1	1
2	1	1	2
3	1	1	3
4	1	2	1
5	1	2	2
6	1	2	3
7	1	3	1
8	1	3	2
9	1	3	3

10	2	1	1
11	2	1	2
12	2	1	3
13	2	2	1
14	2	2	2
15	2	2	3
16	2	3	1
17	2	3	2
18	2	3	3
19	3	1	1
20	3	1	2
21	3	1	3
22	3	2	1
23	3	2	2
24	3	2	3
25	3	3	1
26	3	3	2
27	3	3	3

Input Parameters, Factors and Levels are given below for experimentation

**Table 3.4 Input Parameters**

SAMPLE	CONTROL FACTOR	UNIT	LEVEL 1	LEVEL 2	LEVEL 3
A	POINT ANGLE	Degree	85	100	118
B	FEED	mm/rev	0.08	0.1	0.2
C	SPEED	rpm	244	580	890

### 3.13 Experimental Data and Analysis of Drilled Hole In GFRP Material

The above mentioned specimen are machined on radial drilling machine for Experimentation a Kistler Dyno Ware is installed on the machine bed according to the design of experiment input variables are varied, while drilling the forces and torque on the work pieces are calculated by dynamometer which was coupled with CPU for each set of different readings and readings given by dynamometer for specified duration of time. Now we will discuss each specimen's hole reading one by one by taking its forces values and torque values by varying different factors like feed, speed and point angle of the twist drill. Different materials of twist drill has been taken like HSS, Tungsten carbide and M50(HSS), below shown graphs show thrust forces and torque of different drilled holes.

All experiments were performed according to variation of parameters and by given design of taguchi design.

#### 3.13.1 Calculations of thrust forces and torque values with Tungsten Carbide drill

According to designed experiment by Taguchi design the experiment was performed for finding the values of thrust forces and torque values. Tungsten carbide drill bit is used for experiment, below is the composition shown for carbide drill bit.

**Table 3.5 Composition of Tungsten Carbide Twist Drill**

<b>CO</b>	<b>WC</b>	<b>Tac</b>	<b>Tic</b>
7-8 %	77-78 %	7-8 %	5-6 %

Five specimen were taken for drilling of 27 holes, all drilled holes were according to Taguchi design of experiment. These holes were drilled with different variation of parameters. Calculations of thrust forces and torque values with Tungsten Carbide drill with diameter of 6 mm. All holes are drilled by 6 mm diameter drill bit for getting 6 mm hole of diameter.

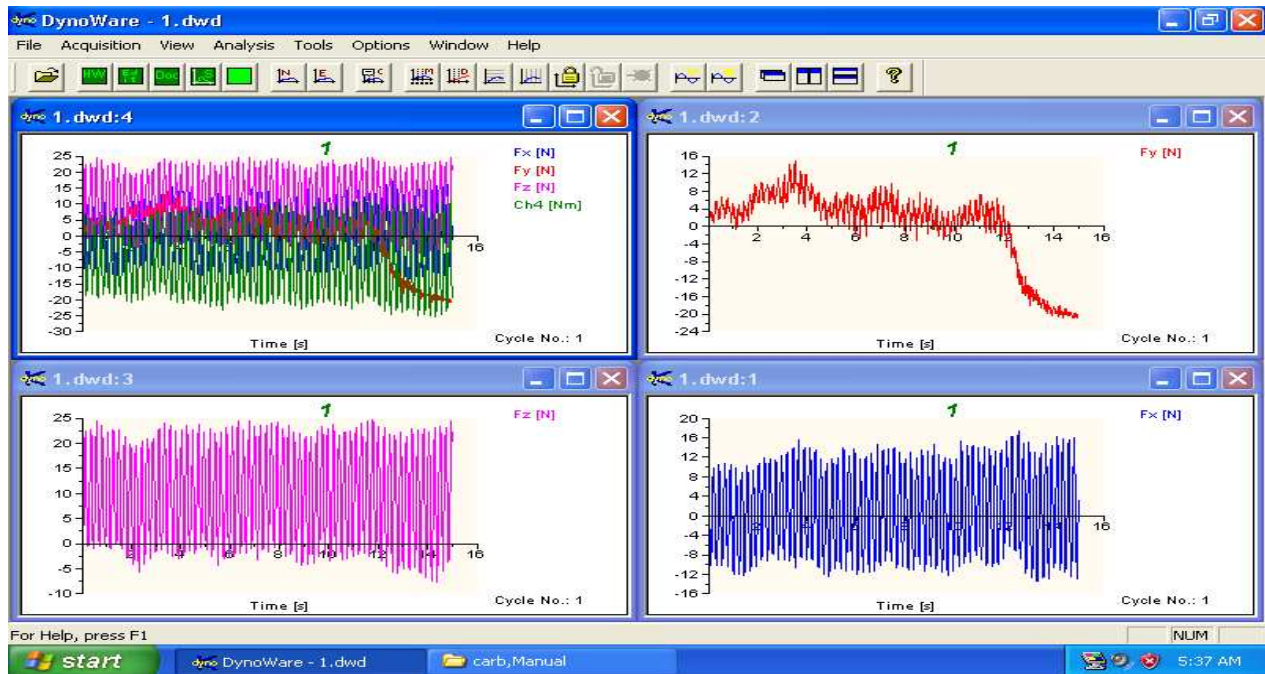


**Fig.3.10 GFRP drilled by tungsten carbide drill bit**

Parameters like point angle, feed rate and speed were varied according to taguchi design. Below shown are the different experiments according to the variation in parameters.

**Table 3.6 Different Parameters For Tungsten Carbide Drill**

Exp. No.	POINT ANGLE(deg.)	FEED (mm/rev.)	SPEED(rpm)
1	85	0.08	244



**Fig. 3.11 Graphical representation for feed .08mm/rev., speed 244 rpm and point angle 85°**

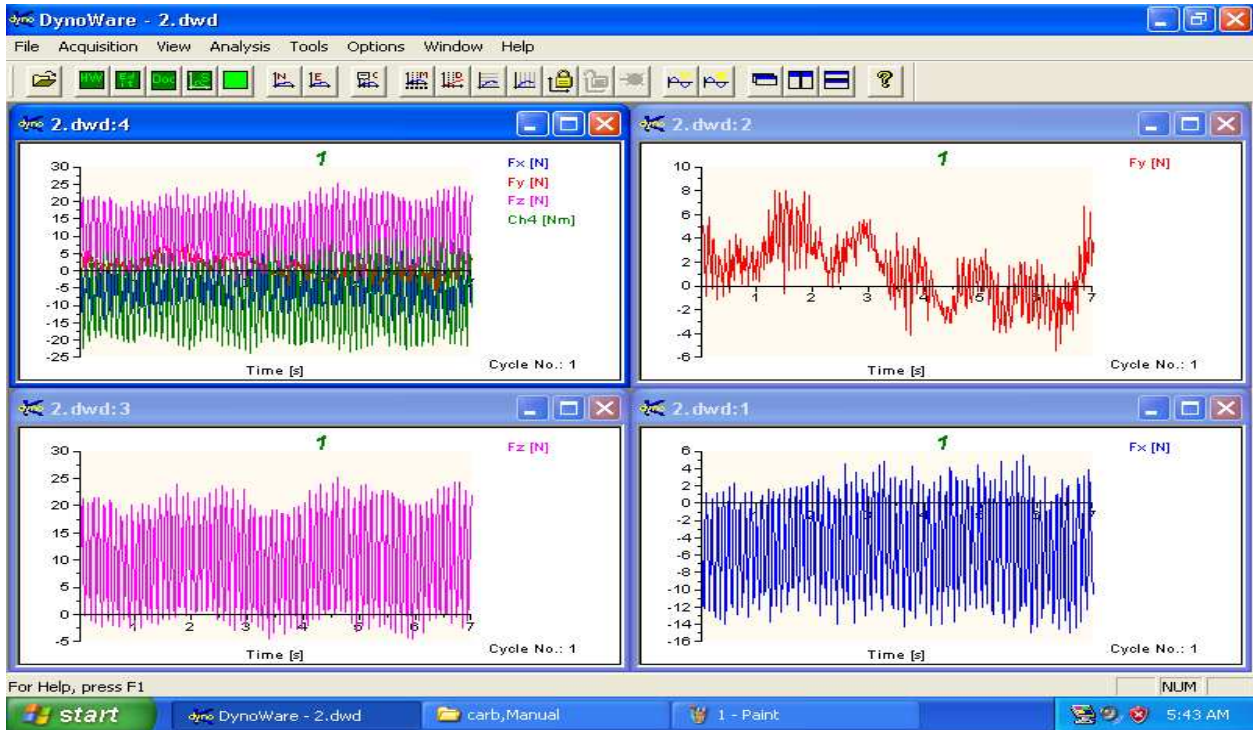
**Table 3.7 Different value of thrust forces and torque value for tungsten carbide drill**

File Type:				
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File name	1.dwd			
Config ID	1.cfg			
Sampling rate [Hz]:	50			
Measuring time [s]:	15			
Delay time [s]:	0			
Cycle time [s]:	0			
Cycles:	1			
Samples/ channel:	751			
Cycle interval:	0			
Channel enabled:	1	1	1	1
Cycle No:	1			
Time [s]	Fx	Fy	Fz	Ch4
0.1	-10.2295	3.27148	17.749	2.90527
0.6	-2.97852	4.1748	20.6299	-11.1816
0.98	-7.22656	4.80957	7.4707	6.03027

1	-10.5957	5.2002	13.916	4.22363
1.02	-11.9385	4.02832	20.2148	-1.0498
1.96	-5.46875	7.42188	19.751	-6.93359
1.98	-2.31934	6.34766	18.6279	-15.4297
2	5.44434	6.22559	12.6221	-18.5547
2.02	9.8877	5.51758	7.03125	-20.752
2.06	10.5713	7.42188	-3.02734	-10.2051
3.04	-4.32129	9.57031	4.63867	7.86133
3.08	-8.81348	11.7676	19.4824	1.53809
3.1	-3.24707	7.22656	22.583	-7.54395
4.86	-4.98047	4.39453	3.93066	5.85938
4.9	-12.3535	3.32031	15.2588	7.12891
6.5	-11.499	4.46777	18.5547	7.00684
6.52	-10.8643	7.20215	21.4355	2.05078
6.54	-4.24805	6.20117	22.6807	-8.49609
6.5	-11.499	4.46777	18.5547	7.00684
7.1	9.83887	5.2002	-3.19824	-5.41992
7.08	13.501	2.29492	1.36719	-16.5039
8.4	4.41895	1.02539	16.748	-19.3359
9.3	1.70898	-0.90332	19.2627	-17.9688
9.32	7.44629	-0.14648	13.3301	-21.8018
10.98	8.20313	1.70898	-2.63672	-4.93164
11	3.36914	3.2959	-0.85449	2.41699
10.98	8.20313	1.70898	-2.63672	-4.93164
11	3.36914	3.2959	-0.85449	2.41699
12	-4.90723	1.61133	22.5342	-3.51563
13	15.1123	-16.4551	-1.95313	-19.9951
13.02	11.1084	-15.5029	-5.05371	-10.083
13.04	5.17578	-17.9932	-5.00488	-1.46484
13	15.1123	-16.4551	-1.95313	-19.9951
14	-10.6689	-18.7988	10.5957	8.49609
14.02	-10.2539	-18.1885	13.6963	5.00488
14	-10.6689	-18.7988	10.5957	8.49609
15	3.4668	-20.7275	20.166	-19.5801

**Table 3.8 Different Parameters For Tungsten Carbide Drill**

Exp. No.	POINT ANGLE(deg.)	FEED (mm/rev.)	SPEED(rpm)
2	85	0.08	580



**Fig. 3.12 Graphical representation for feed .08mm/rev.,speed 580 rpm and point angle 85°**

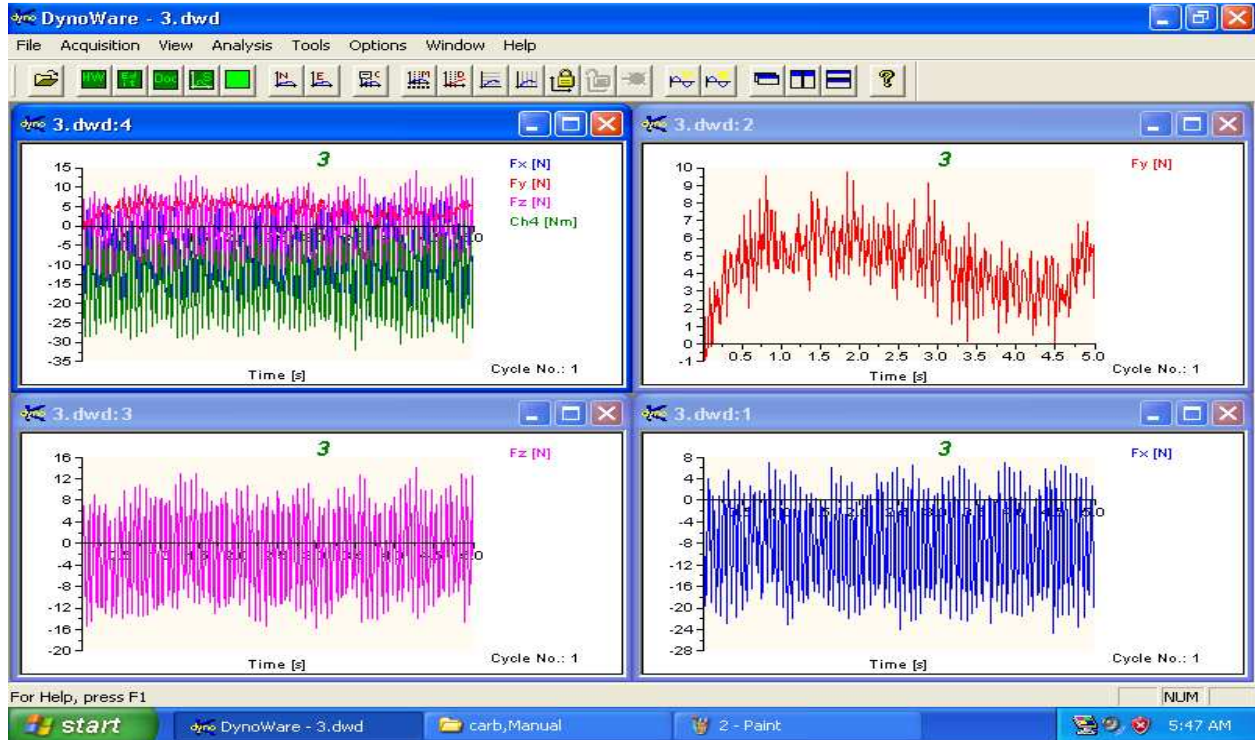
**Table 3.9 Different value of thrust forces and torque value for tungsten carbide drill**

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Delay time [s]:	0			
Cycle time [s]:	0			
Cycles:	1			
Samples per channel:	751			

Cycle interval:	0			
Channel enabled:	1	1	1	1
Cycle No:	1			
Time [s]	Fx	Fy	Fz	Ch4
0	0.317383	0.756836	0.366211	-11.6943
0.1	1.17188	-0.87891	-0.29297	-11.4014
0.2	0.512695	-0.19531	-1.19629	-8.78906
0.3	1.19629	-1.19629	-1.46484	-8.81348
0.4	1.31836	-0.87891	-2.31934	-7.91016
0.5	1.92871	-0.56152	-1.19629	-8.20313
0.6	2.22168	0.463867	-2.09961	-8.10547
0.7	-0.14648	1.0498	-2.22168	-8.49609
0.8	1.17188	1.29395	-0.90332	-6.73828
0.98	-2.22168	0.537109	2.27051	-20.5322
1	-9.77E-02	1.44043	-2.27051	-4.39453
1.5	1.53809	4.80957	-1.00098	-2.29492
1.76	-5.9082	5.88379	13.1104	-21.4355
1.98	1.26953	2.56348	2.09961	-17.4316
2	2.44141	3.17383	0.854492	0.12207
2.5	-0.41504	1.2207	3.17383	3.07617
2.76	-2.73438	1.70898	9.69238	-21.6309
2.98	2.34375	5.27344	-2.02637	-11.9873
3	-0.46387	2.92969	3.41797	3.58887
3.5	-5.29785	4.44336	7.61719	7.03125
3.76	-1.02539	-4.07715	2.31934	-21.0693
3.98	2.14844	0.78125	-2.70996	-2.58789
4	-2.97852	2.44141	7.20215	5.12695
4.5	-6.20117	-0.83008	13.9893	8.93555
4.76	2.75879	-1.87988	0.463867	-13.6963
4.98	1.48926	1.07422	4.07715	5.83496
5	-8.27637	2.44141	17.7979	4.41895
5.5	-12.2803	1.68457	22.8027	-0.24414
5.76	5.51758	-2.39258	-3.2959	-2.73438
5.98	-5.61523	-0.21973	8.44727	6.81152
6	-14.209	2.19727	20.4102	-4.56543
6.5	-13.5498	-1.9043	23.4619	-4.83398
6.76	1.68457	3.32031	3.32031	4.3457
6.98	-7.69043	1.66016	17.5537	3.80859
7	-10.5469	3.75977	22.0215	-10.6689

**Table 3.10 Different Parameters For Tungsten Carbide Drill**

Exp. No.	POINT ANGLE(deg.)	FEED (mm/rev.)	SPEED(rpm)
3	85	0.08	890



**Fig. 3.13 Graphical representation for feed .08mm/rev., speed 890 rpm and point angle 85°**

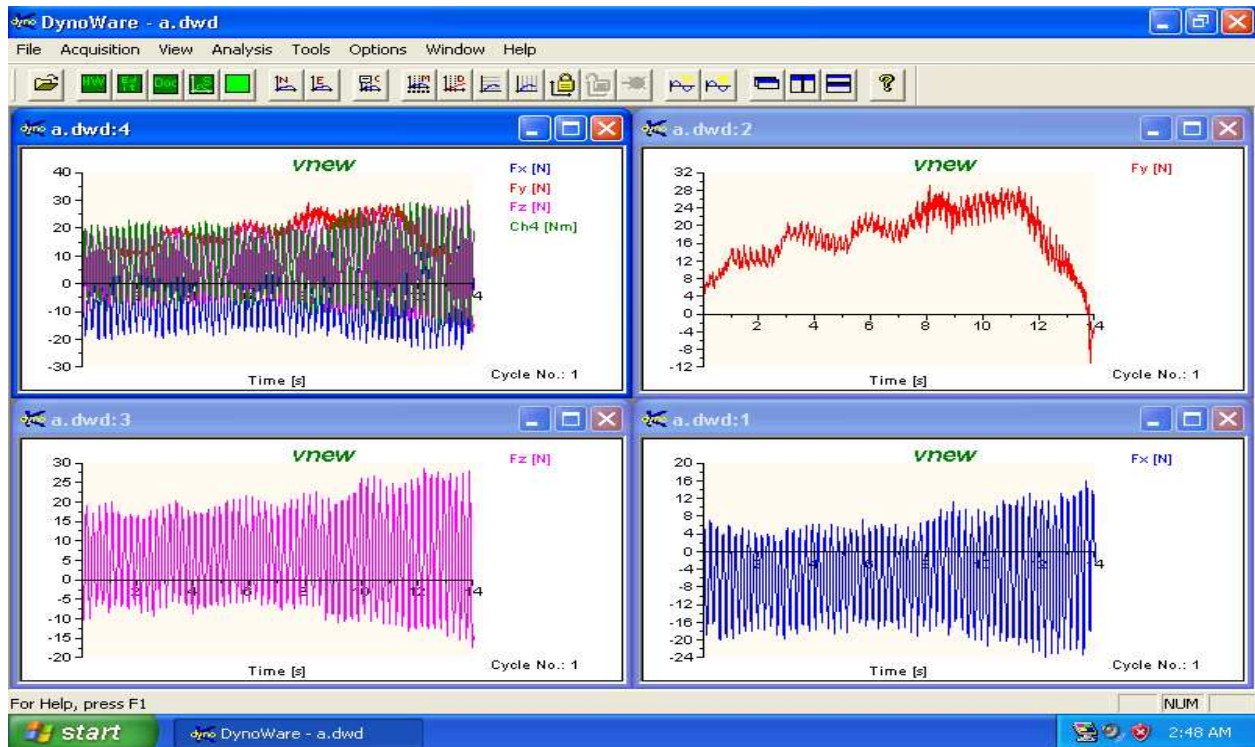
**Table 3.11 Different value of thrust forces and torque value for tungsten carbide drill**

File Type:				
Path	C:\Documents and Settings\STUDENT\Desktop\carb,Manual\1\			
File name	1.dwd			
Config ID	1.cfg			
Sampling rate [Hz]:	50			
Measuring time [s]:	5			
Cycle time [s]:	0			
Samples per channel:	751			
Cycle interval:	0			
Channel enabled:	1	1	1	1

Cycle No:	1			
Time [s]	Fx	Fy	Fz	Ch4
0	3.02734	-0.24414	-16.4307	-13.0371
0.1	-19.0186	1.51367	7.27539	-18.8721
0.2	0.878906	1.17188	-11.8896	-9.79004
0.3	-22.9736	1.5625	7.25098	-25.0244
0.4	1.95313	3.27148	-10.1074	-3.41797
0.5	-20.2393	4.46777	1.3916	-27.6611
0.6	2.56348	7.59277	-3.125	-1.14746
0.7	-13.501	5.81055	-4.07715	-28.54
0.8	-1.2207	9.52148	-0.41504	-5.78613
0.9	-12.6221	5.10254	-7.95898	-25.9766
1	-6.27441	6.4209	7.93457	-3.49121
1.2	-10.9863	5.85938	10.9375	-8.66699
1.5	-0.21973	5.0293	-11.1816	-12.3535
1.7	3.02734	3.66211	-13.0127	-7.00684
2	-21.167	4.39453	0.537109	-28.4424
2.2	-17.6025	4.71191	-1.68457	-26.9043
2.5	-10.0586	6.83594	9.69238	-5.56641
2.7	-10.6934	8.25195	8.78906	-9.7168
3	1.31836	1.5625	-15.8447	-13.501
3.2	4.56543	3.58887	-12.9639	-7.61719
3.5	-19.8242	4.32129	-1.66016	-32.1289
3.7	-13.3545	2.58789	-3.93066	-24.5117
3.9	-14.5996	1.83105	-6.00586	-22.9492
4	-4.1748	4.3457	8.64258	-3.2959
4.2	-14.9902	5.27344	11.9385	-13.1348
4.5	5.32227	0.756836	-11.6455	-5.81055
4.7	4.93164	2.46582	-8.66699	-5.39551
5	-20.1172	2.51465	-2.51465	-26.5381

**Table 3.12 Different Parameters For Tungsten Carbide Drill**

Exp. No.	POINT ANGLE(deg.)	FEED (mm/rev.)	SPEED(rpm)
4	85	0.1	244



**Fig. 3.14 Graphical representation for feed .1mm/rev., speed 244 rpm and point angle 85°**

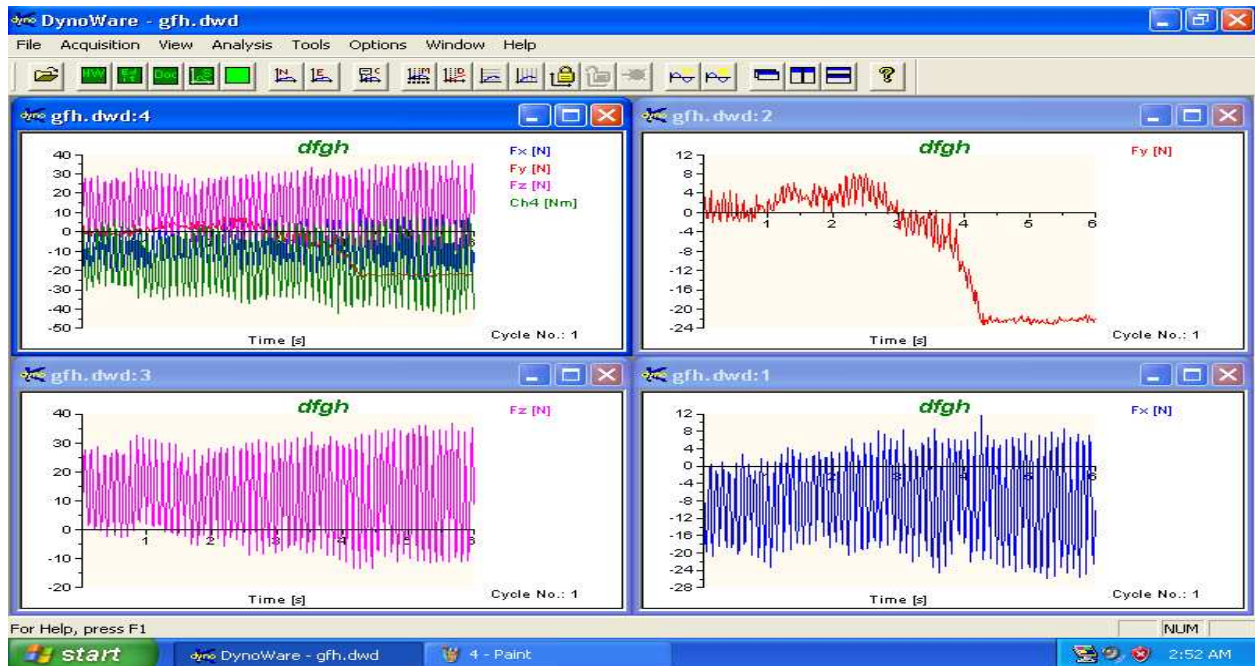
**Table 3.13 Different value of thrust forces and torque value for tungsten carbide drill**

File Type:				
Path	C:\Documents and Settings\STUDENT\Desk\carb,Manual\1\			
File name	1.dwd			
Config ID	1.cfg			
Sampling rate [Hz]:	50			
Measuring time [s]:	14			
Samples per channel:	751			
Cycle interval:	0			
Channel enabled:	1	1	1	1
Time [s]	Fx	Fy	Fz	Ch4
0	0.244141	3.41797	5.24902	-3.68652
0.1	-9.93652	6.15234	-4.32129	18.4082
0.2	-8.34961	6.20117	15.625	-3.07617
0.3	1.09863	8.27637	-9.8877	7.71484
0.4	-15.6738	5.85938	13.7695	9.96094
0.5	5.66406	8.00781	-3.80859	-3.95508

0.6	-19.6045	10.1074	8.3252	20.8984
0.7	2.0752	9.44824	5.9082	-6.37207
0.8	-13.916	11.4014	1.26953	20.5811
0.9	-2.75879	11.4014	15.3809	-8.22754
1	-3.66211	13.6475	-6.27441	12.915
1.9	3.14941	12.2559	-5.68848	4.02832
2	-14.1846	12.1826	15.5029	7.27539
2.98	-2.44E-02	17.7002	8.47168	-5.93262
3	4.22363	18.5547	1.85547	-6.20117
3.98	-10.5469	19.7998	-2.27051	19.5313
4	-12.1826	18.8232	-0.61035	21.0449
4.98	-7.42188	14.6973	15.6738	-0.43945
5	-4.27246	15.1611	12.8418	-3.36914
5.98	3.83301	20.3857	-3.51563	1.14746
6	-0.90332	21.8506	-5.59082	11.8408
6.98	-17.5293	17.2119	13.3789	18.4814
7	-14.4775	16.8213	17.9443	10.1563
7.98	2.14844	25.1221	11.084	-8.76465
8	4.80957	23.0469	6.78711	-8.64258
8.98	-1.07422	23.4619	-8.78906	14.3799
9	-8.56934	25.1221	-2.02637	21.3867
9.98	-16.7969	27.124	23.6328	8.34961
10	-14.209	24.3408	26.1475	1.24512
10.98	10.5713	23.6084	-0.85449	-10.0586
11	10.2295	27.2461	-10.1807	-2.14844
11.98	-17.3828	21.1426	2.31934	28.4424
12	-22.4121	19.1162	10.6689	29.1748
12.98	-2.70996	14.3311	20.8008	-12.5732
13	6.27441	11.1328	13.4277	-14.3066
13.98	6.81152	-3.41797	-17.4072	10.8154
14	-2.6123	-2.75879	-14.1602	19.0674

**Table 3.14 Different Parameters For Tungsten Carbide Drill**

Exp. No.	POINT ANGLE(deg.)	FEED (mm/rev.)	SPEED(rpm)
5	85	0.1	580



**Fig. 3.15 Graphical representation for feed .1mm/rev., speed 580 rpm and point angle 85°**

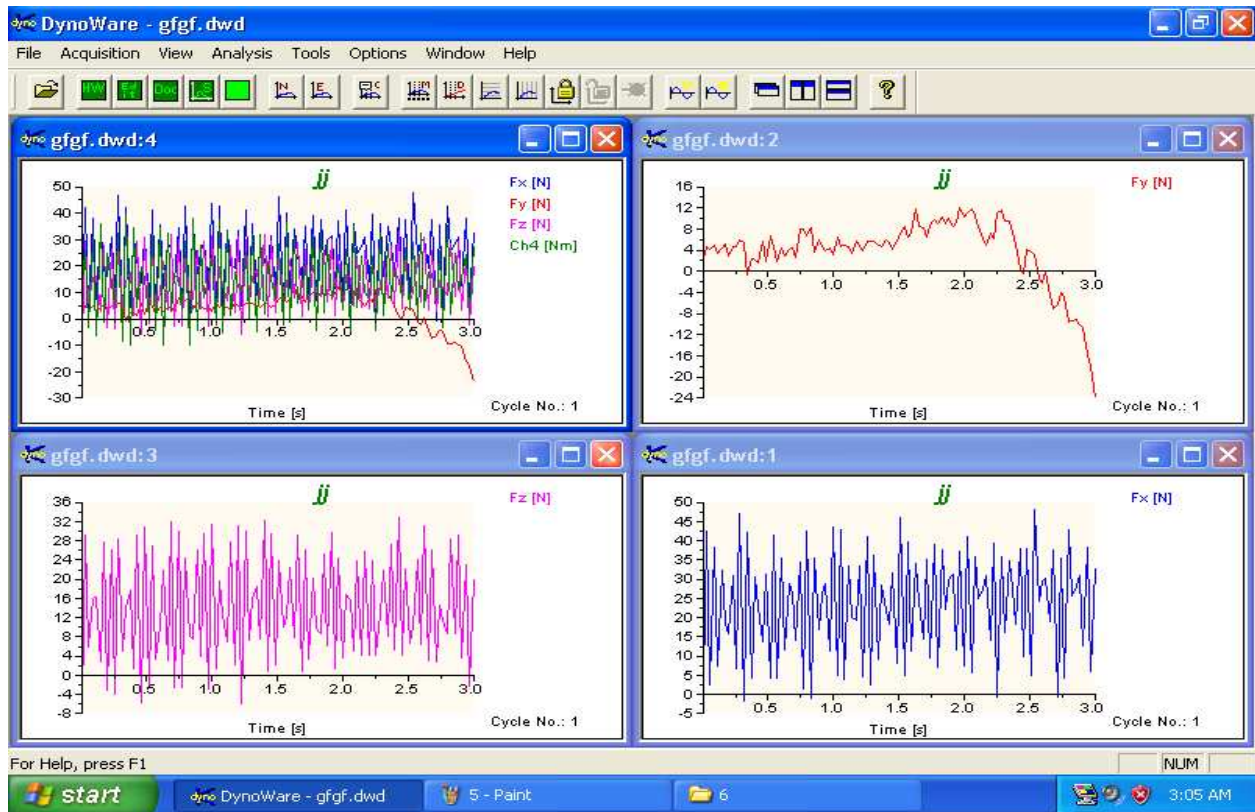
**Table 3.15 Different value of thrust forces and torque value for tungsten carbide drill**

File Type:				
Path	C:\Documents and Settings\STUDENT\Desk\carb,Manual\1\			
File name	1.dwd			
Config ID	1.cfg			
Sampling rate [Hz]:	50			
Measuring time [s]:	6			
Delay time [s]:	0			
Cycle time [s]:	0			
Cycles:	1			
Samples per channel:	751			
Cycle interval:	0			
Channel enabled:	1	1	1	1
Cycle No:	1			
Time [s]	Fx	Fy	Fz	Ch4
0	-2.68555	-0.19531	1.61133	-21.46
0.1	-1.12305	1.26953	1.41602	-18.5791
0.2	-1.09863	0.268555	0	-17.1631
0.3	1.00098	1.36719	-0.48828	-15.4297

0.4	-1.36719	-0.43945	-2.14844	-13.208
0.5	0.634766	-0.5127	-1.80664	-11.1328
0.6	2.6123	1.00098	-2.73438	-12.9883
0.7	0.439453	-1.97754	-2.0752	-12.4512
0.8	-1.02539	-1.12305	-0.1709	-12.2803
0.9	1.58691	1.26953	2.83203	-10.9863
1	0.854492	2.0752	2.85645	-10.1563
1.5	2.92969	4.76074	-0.65918	-1.75781
1.98	3.2959	3.80859	-4.22363	-17.4805
2	0.561523	2.51465	-0.39063	2.44141
2.5	0.317383	7.91016	3.19824	7.32E-02
2.98	5.76172	2.41699	-7.95898	-1.68457
3	-4.12598	-3.22266	10.4248	4.73633
3.5	-18.1885	-2.88086	24.6582	-0.78125
3.98	-2.39258	-10.1074	5.34668	-0.36621
4	-17.5781	-11.8652	29.126	-5.41992
4.5	-22.6318	-21.8018	34.5947	-13.6963
4.98	-21.8994	-21.582	31.9824	-3.83301
5	-23.4131	-22.9736	33.374	-29.126
5.5	-18.7256	-22.3145	24.4629	-42.4072
5.98	-22.4609	-22.8271	35.1563	-21.9971
6	-10.0098	-21.875	8.54492	-40.5029

**Table 3.16 Different Parameters For Tungsten Carbide Drill**

Exp. No.	POINT ANGLE(deg.)	FEED (mm/rev.)	SPEED(rpm)
6	85	0.1	890



**Fig. 3.16 Graphical representation for feed .1mm/rev., speed 890 rpm and point angle 85°**

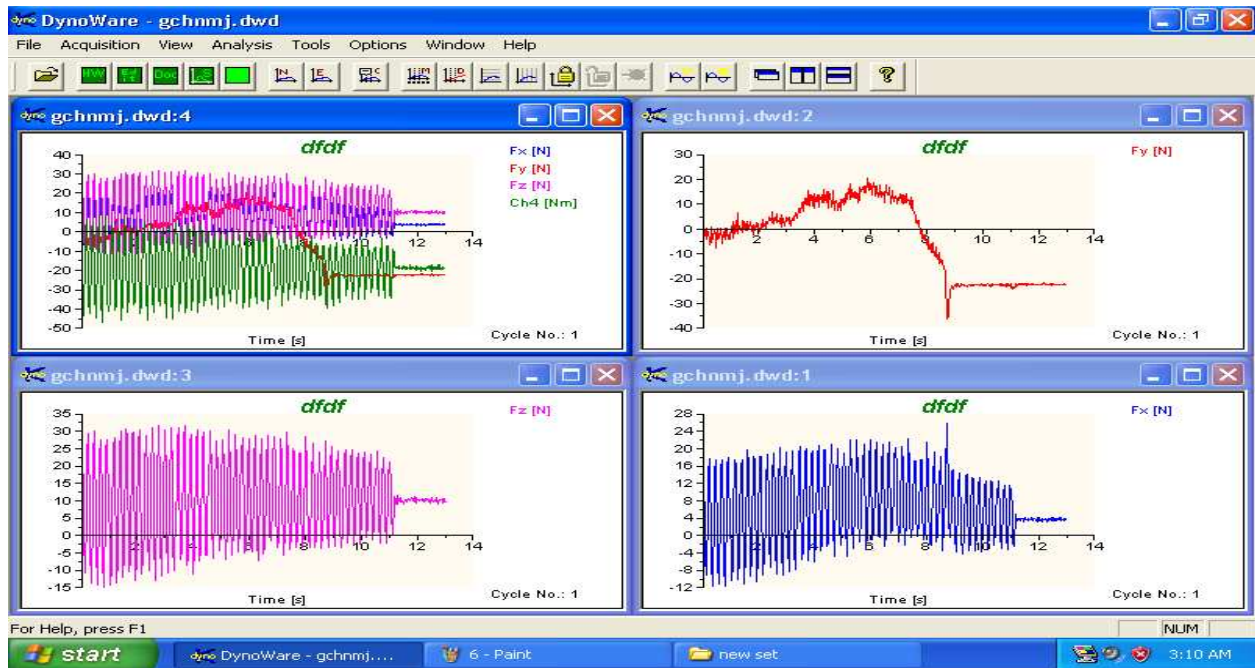
**Table 3.17 Different value of thrust forces and torque value for tungsten carbide drill**

File Type:				
Path	C:\Documents and Settings\STUDENT\Desk\carb,Manual\1\			
File name	1.dwd			
Config ID	1.cfg			
Sampling rate [Hz]:	50			
Measuring time [s]:	3			
Delay time [s]:	0			
Cycle time [s]:	0			
Cycles:	1			
Samples per channel:	751			
Cycle interval:	0			
Channel enabled:	1	1	1	1
Cycle No:	1			
Time [s]	Fx	Fy	Fz	Ch4
0	2.7832	2.44141	-6.93359	13.2324

0.114286	7.56836	3.34473	16.2354	-6.12793
0.2	15.9424	2.90527	-3.125	24.6338
0.314286	-1.87988	5.51758	4.93164	-8.34961
0.4	30.5664	2.0752	1.26953	34.668
0.514286	4.1748	6.64063	-1.97754	0.219727
0.6	35.3027	4.29688	10.1318	34.2773
0.714286	14.0625	2.73438	-2.66113	16.7969
0.8	42.5537	6.7627	24.5117	29.1748
0.914286	26.0254	4.56543	3.93066	27.9785
1	43.6523	3.02734	31.4209	24.2676
1.11429	33.3496	4.58984	7.03125	33.1299
1.2	33.3984	4.90723	31.1523	11.9141
1.31429	36.2549	5.71289	16.0156	31.8115
1.4	21.7773	5.93262	32.1045	1.78223
1.51429	46.0693	7.2998	23.6816	28.3203
1.6	11.377	7.17773	22.29	-1.3916
1.71429	35.1807	6.56738	26.0986	20.8496
1.8	7.03125	8.91113	9.76563	-4.19922
1.91429	31.3721	8.42285	29.7607	7.6416
2	7.37305	10.1807	3.56445	3.34473
2.11429	24.8535	8.61816	23.9014	4.54102
2.2	13.9893	7.27539	4.07715	8.03223
2.31429	16.333	9.57031	21.9727	1.19629
2.4	18.1885	4.80957	5.2002	18.8232
2.51429	4.90723	3.75977	6.83594	3.27148
2.6	29.3457	-2.12402	6.51855	32.3242
2.71429	-0.73242	-6.27441	2.80762	6.83594
2.8	42.8467	-9.52148	8.74023	35.2783
2.97143	5.98145	-17.7002	-2.27051	2.92969
3	33.0078	-23.9258	20.2637	27.9297

**Table 3.18 Different Parameters For Tungsten Carbide Drill**

Exp. No.	POINT ANGLE(deg.)	FEED (mm/rev.)	SPEED(rpm)
7	85	0.2	244



**Fig. 3.17** Graphical representation for feed .2mm/rev., speed 244 rpm and point angle 85°

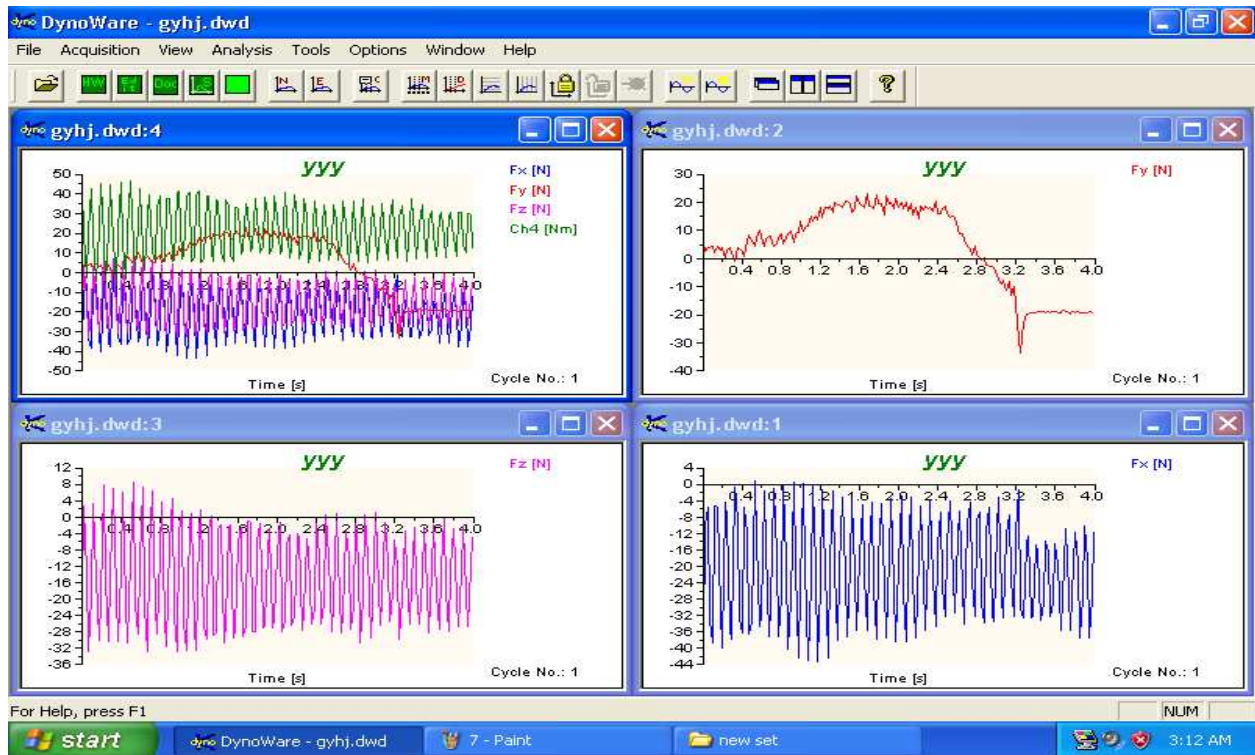
**Table 3.19** Different value of thrust forces and torque value for tungsten carbide drill

File Type:				
Path	C:\Documents and Settings\STUDENT\Desktop\carb,Manual\1\			
File name	1.dwd			
Config ID	1.cfg			
Sampling rate [Hz]:	50			
Measuring time [s]:	13			
Delay time [s]:	0			
Cycle time [s]:	0			
Cycles:	1			
Samples per channel:	751			
Cycle interval:	0			
Channel enabled:	1	1	1	1
Cycle No:	1			
Time [s]	Fx	Fy	Fz	Ch4
0	18.4326	-4.58984	28.6133	-15.4785
0.2	14.502	-2.27051	23.0225	-1.80664

0.4	3.61328	-0.92773	3.83301	5.39551
0.6	-7.25098	-2.05078	-9.7168	-3.71094
0.8	-11.6699	0.439453	-14.8438	-22.1191
1	-4.8584	1.17188	-3.10059	-35.3271
1.6	19.7266	-0.56152	30.5908	-16.748
2	4.5166	1.92871	5.29785	2.31934
2.6	-2.70996	4.05273	-0.85449	-34.0332
3	19.2627	3.00293	30.2979	-30.5176
3.6	5.27344	10.1074	3.4668	3.27148
4	-5.93262	8.52051	-11.0107	-20.874
4.6	20.9717	8.76465	30.0537	-30.7129
5	12.915	12.0605	15.2344	-3.02734
5.6	-0.75684	11.6943	-2.90527	-22.6074
6	15.6738	18.335	21.6309	-38.9648
6.6	9.13086	13.5742	9.76563	-0.26856
7	-1.5625	12.0117	-3.36914	-10.4248
7.6	17.2607	5.22461	23.877	-32.0557
8	12.5732	-6.46973	17.5293	-9.47266
8.6	2.09961	-15.2588	0.219727	-18.9697
9	4.78516	-22.7783	11.6699	-38.4277
9.6	13.2324	-22.2656	19.0918	-6.98242
10	2.39258	-22.7051	5.27344	-9.79004
10.6	5.0293	-22.0215	13.4521	-33.3496
11	9.00879	-22.1436	18.2861	-17.3584
11.6	3.68652	-22.7295	10.3516	-18.2861
12	3.39355	-22.2656	10.4736	-19.0918
12.6	4.00391	-22.3633	10.0586	-18.2861
13	3.51563	-22.3633	9.35059	-19.2871

**Table 3.20 Different Parameters For Tungsten Carbide Drill**

Exp. No.	POINT ANGLE(deg.)	FEED (mm/rev.)	SPEED(rpm)
8	85	0.2	580



**Fig. 3.18 Graphical representation for feed .2mm/rev., speed 580 rpm and point angle 85°**

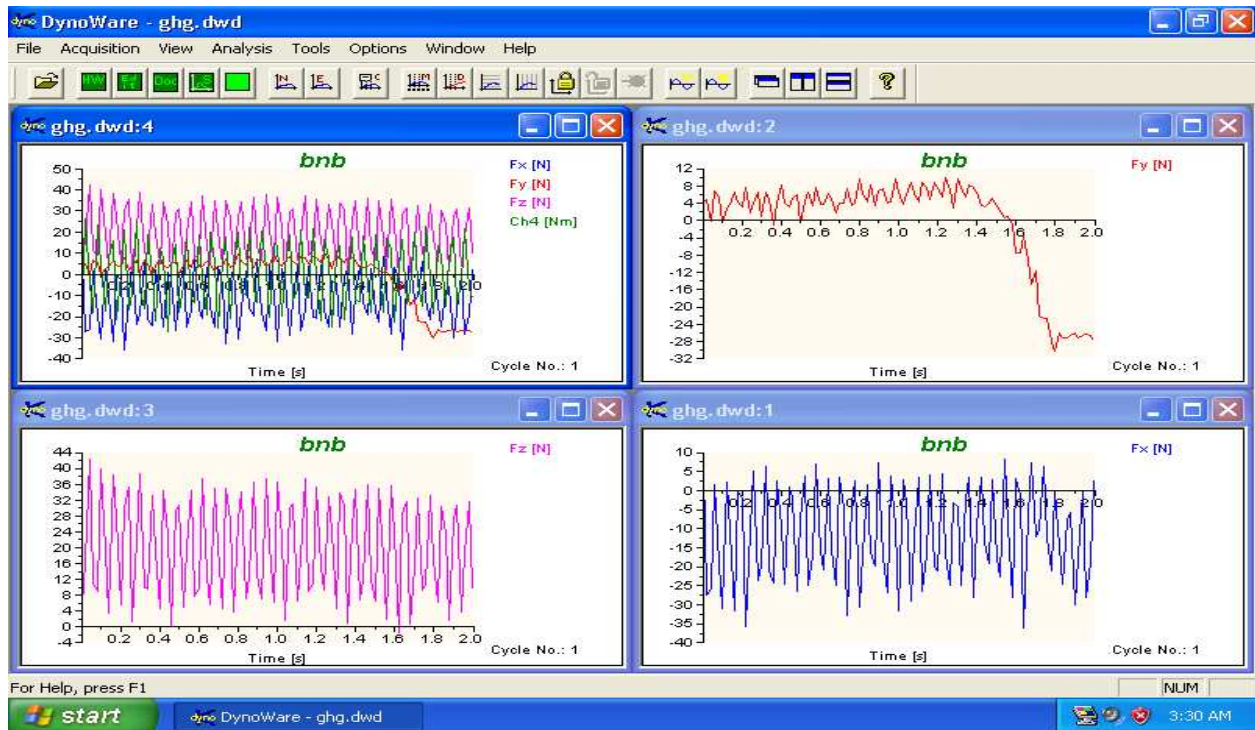
**Table 3.21 Different value of thrust forces and torque value for tungsten carbide drill**

File Type:				
Path	C:\Documents and Settings\STUDENT\Desk\carb,Manual\1\			
File name	1.dwd			
Config ID	1.cfg			
Sampling rate [Hz]:	50			
Measuring time [s]:	4			
Delay time [s]:	0			
Cycle time [s]:	0			
Cycles:	1			
Samples per channel:	751			
Cycle interval:	0			
Channel enabled:	1	1	1	1
Cycle No:	1			
Time [s]	Fx	Fy	Fz	Ch4
0	-39.1357	5.49316	-19.0674	43.3594
0.1	-38.5498	4.46777	-19.458	42.7734

0.2	-39.8926	3.73535	-19.6045	45.2148
0.3	-37.7686	2.0752	-13.7207	44.3848
0.4	-36.1816	2.36816	-12.9883	46.0938
0.5	-33.5693	6.66504	-10.6201	46.7773
0.6	-32.2998	7.9834	-10.376	42.627
0.7	-29.8096	7.73926	-8.81348	39.7949
0.8	-27.4902	8.91113	-8.71582	38.6963
0.9	-28.125	9.8877	-6.20117	37.5977
1	-24.1699	13.208	-3.80859	41.333
1.2	-24.6582	18.0908	-3.88184	41.1377
1.4	-20.4834	19.0674	-2.88086	36.1816
1.6	-17.9932	19.6777	-6.00586	32.373
1.8	-18.4082	19.3359	-5.88379	28.9307
2	-19.6533	18.1152	-8.76465	28.8574
2.2	-17.1143	14.209	-4.00391	27.7832
2.4	-14.6973	15.9668	-0.97656	29.4678
2.6	-12.5488	10.5713	0.732422	26.0986
2.8	-8.74023	1.07422	-1.24512	19.7021
3	-10.7422	-5.81055	1.14746	19.9951
3.2	-11.792	-16.1377	-5.66406	20.5322
3.4	-14.7705	-19.4824	-2.63672	19.0918
3.6	-14.502	-19.0674	-1.85547	19.2871
3.8	-11.6699	-19.0918	-2.83203	17.9932
4	-11.3525	-19.043	-4.71191	12.4023

**Table 3.22 Different Parameters For Tungsten Carbide Drill**

Exp. No.	POINT ANGLE(deg.)	FEED (mm/rev.)	SPEED(rpm)
9	85	0.2	890



**Fig. 3.19 Graphical representation for feed .2mm/rev., speed 890 rpm and point angle 85°**

**Table 3.23 Different value of thrust forces and torque value for tungsten carbide drill**

File Type:				
Path	C:\Documents and Settings\STUDENT\Desk\carb,Manual\1\			
File name	1.dwd			
Config ID	1.cfg			
Sampling rate [Hz]:	50			
Measuring time [s]:	2			
Delay time [s]:	0			
Cycle time [s]:	0			
Cycles:	1			
Samples per channel:	751			
Cycle interval:	0			
Channel enabled:	1	1	1	1
Cycle No:	1			
Time [s]	Fx	Fy	Fz	Ch4
0	5.93262	4.37012	5.17578	-8.56934
0.1	-30.835	-0.41504	39.9902	4.73633
0.2	-2.39258	3.07617	5.56641	0.65918

0.3	-19.3359	0.90332	38.5986	-7.71484
0.4	-9.7168	8.12988	4.76074	12.3047
0.5	-7.61719	-0.36621	30.6152	-18.1152
0.6	-16.1133	3.68652	9.79004	19.0186
0.7	3.56445	3.95508	20.3369	-25.2441
0.8	-30.7861	9.57031	26.6602	20.0439
0.9	7.32422	6.95801	13.1104	-13.5986
1	-31.5674	6.4209	36.6699	13.7939
1.1	3.61328	4.29688	6.44531	-6.88477
1.2	-20.9961	7.6416	35.2051	-1.51367
1.3	-4.29688	9.57031	4.61426	9.17969
1.4	-9.17969	6.5918	34.79	-12.0117
1.5	-17.4072	3.44238	6.64063	18.5059
1.6	3.07617	-7.34863	23.584	-22.5342
1.7	-12.1582	-11.5479	15.1367	20.166
1.8	-2.44E-02	-30.1514	16.8945	-18.5059
1.9	-29.9316	-25.9766	27.1729	17.4561
2	2.70996	-27.6367	9.69238	-11.0596

**Table 3.24 Different Parameters For Tungsten Carbide Drill**

Exp. No.	POINT ANGLE(deg.)	FEED (mm/rev.)	SPEED(rpm)
10	100	0.08	244

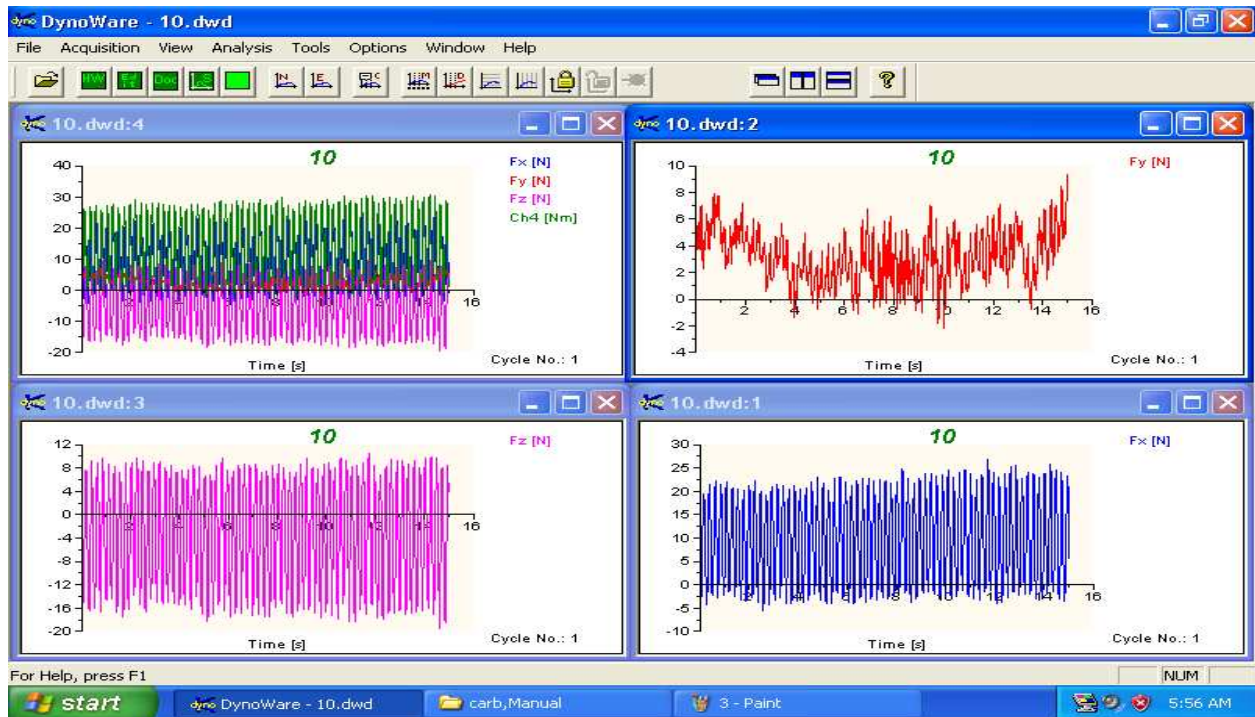


Fig. 3.20 Graphical representation for feed .08mm/rev., speed 244 rpm and point angle 100°

Table 3.25 showing thrust forces and torque value for tungsten carbide drill

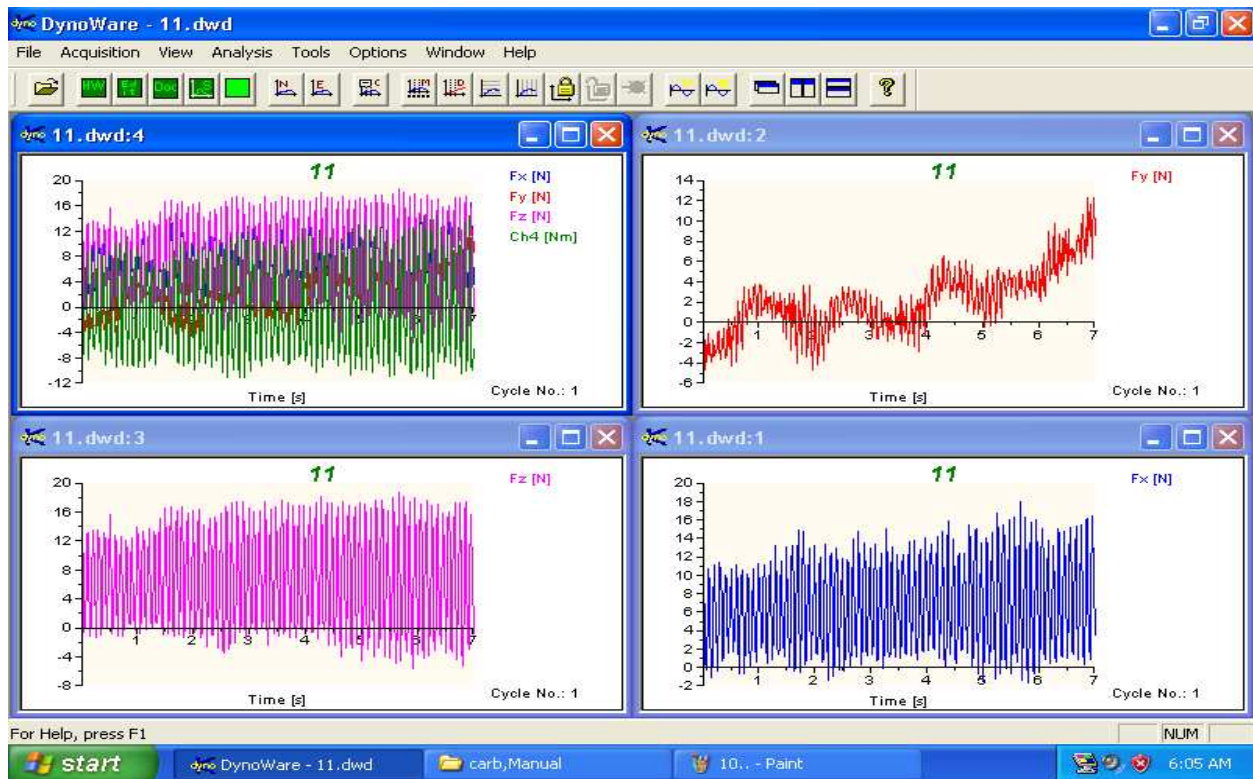
File Type:				
Path	C:\Documents and Settings\STUDENT\Desk\carb,Manual\1\			
File name	1.dwd			
Config ID	1.cfg			
Sampling rate [Hz]:	50			
Measuring time [s]:	15			
Delay time [s]:	0			
Cycle time [s]:	0			
Cycles:	1			
Samples per channel:	751			
Cycle interval:	0			
Channel enabled:	1	1	1	1
Cycle No:	1			
Time [s]	Fx	Fy	Fz	Ch4
0	1.41602	2.46582	2.09961	-5.05371
0.1	1.14746	2.44E-02	-15.625	-7.71484
0.5	0.585938	-2.27051	-0.3418	-14.3799

0.98	-4.88E-02	0.952148	-6.4209	-17.8955
1	-4.88E-02	-1.00098	-13.9404	-14.4287
1.52	2.44141	-4.46777	-13.5254	1.9043
1.98	1.51367	-0.14648	-15.4053	0.292969
2	2.19727	1.07422	-11.8164	2.68555
2.52	0.927734	-4.37012	3.75977	-1.97754
2.98	1.48926	-1.70898	3.88184	-4.90723
3	1.07422	1.51367	4.66309	-9.98535
3.52	1.12305	-4.76074	-8.95996	-15.0879
3.98	-0.3418	-2.0752	-11.9873	-19.5068
4	-0.58594	-4.5166	-16.2109	-14.5264
4.52	1.61133	-7.51953	-12.793	2.66113
4.98	1.83105	-4.39453	-12.6709	1.2207
5	1.85547	-2.85645	-7.66602	3.80859
5.52	0.463867	-7.39746	4.66309	-8.00781
5.98	1.36719	-3.83301	4.05273	-8.30078
6	1.36719	-3.41797	4.3457	-16.8945
6.52	1.14746	-6.78711	-10.9863	-16.0889
6.98	0.390625	-6.0791	-15.6738	-18.457
7	-0.43945	-7.93457	-17.6025	-11.5723
7.52	1.17188	-6.12793	-10.498	3.17383
7.98	1.87988	-4.41895	-10.5713	3.6377
8	2.75879	-4.24805	-5.27344	5.0293
8.52	1.07422	-4.05273	3.97949	-12.4023
8.98	0.756836	-7.05566	4.63867	-10.5469
9	0.756836	-6.39648	1.80664	-19.1406
9.52	1.75781	-5.2002	-18.6768	-13.8428
9.98	1.2207	-7.25098	-18.6035	-14.624
10	1.66016	-5.54199	-19.9951	-5.7373
10.52	2.29492	0.170898	-9.61914	3.07617
10.98	2.22168	-2.00195	-6.4209	4.54102
11	2.63672	-3.05176	-2.66113	4.10156
11.52	1.58691	-1.0498	3.49121	-16.333
11.98	1.2207	-7.4707	3.41797	-16.8213
12	4.88E-02	-1.17188	1.48926	-21.7041
12.52	1.61133	-0.92773	-22.9492	-13.1104
12.98	1.24512	-3.73535	-20.6787	-11.2549
13	1.53809	-6.10352	-20.4346	-2.66113

13.52	2.05078	3.22266	-7.00684	2.22168
13.98	2.88086	0.952148	-8.78906	5.71289
14	3.4668	4.41895	-2.46582	2.36816
14.52	2.92969	10.7666	2.36816	-19.7021
14.98	2.39258	9.375	1.09863	-18.6768
15	1.5625	9.39941	-4.22363	-23.999

**Table 3.26 Different Parameters For Tungsten Carbide Drill**

Exp. No.	POINT ANGLE(deg.)	FEED (mm/rev.)	SPEED(rpm)
11	100	0.08	580



**Fig. 3.21 Graphical representation for feed .08mm/rev., speed 580 rpm and point angle 100°**

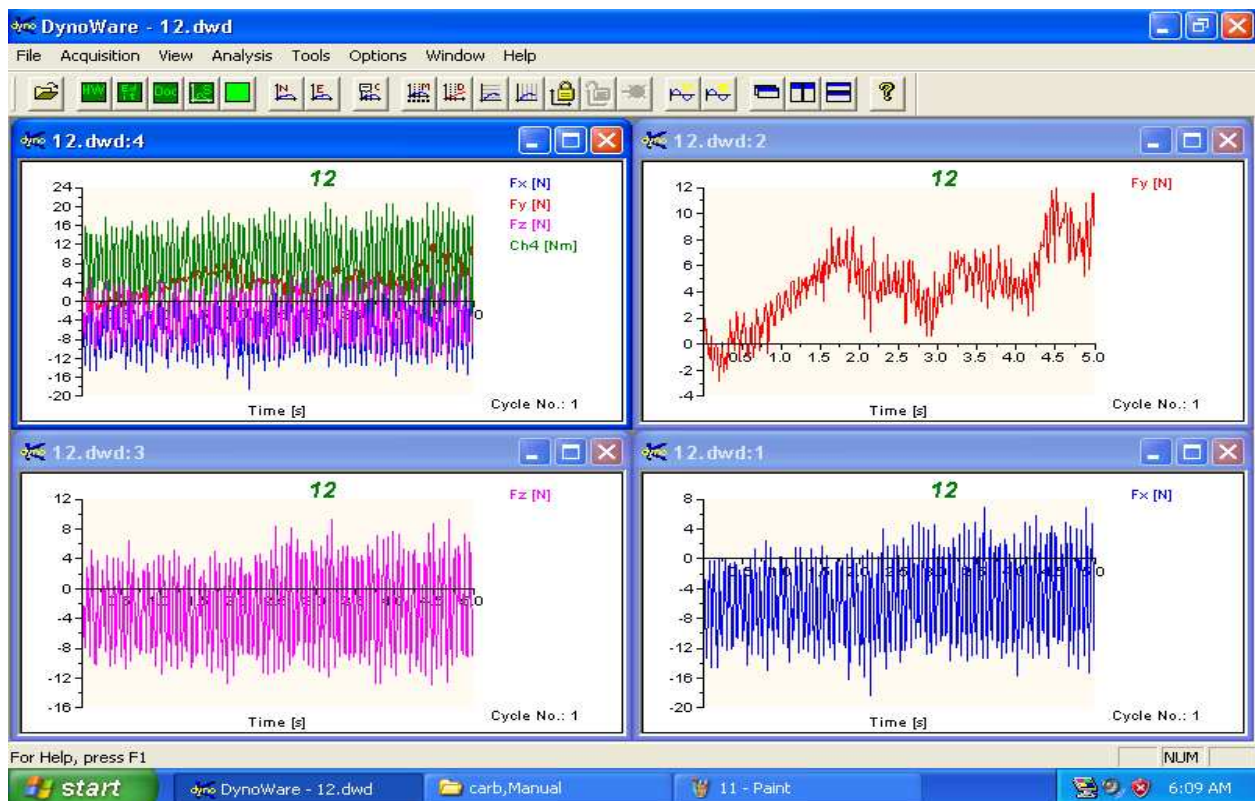
**Table 3.27 Different value of thrust forces and torque value for tungsten carbide drill**

File Type:				
Path	C:\Documents and Settings\STUDENT\Desk\carb,Manual\1\			
File name	1.dwd			
Config ID	1.cfg			
Sampling rate [Hz]:	50			
Measuring time [s]:	7			
Delay time [s]:	0			
Cycle time [s]:	0			
Cycles:	1			
Samples per channel:	751			
Cycle interval:	0			
Channel enabled:	1	1	1	1
Cycle No:	1			
Time [s]	Fx	Fy	Fz	Ch4
0	10.791	-1.68457	13.0615	4.71191
0.1	10.7422	-3.00293	12.9395	3.61328
0.2	11.084	-2.63672	13.1348	2.19727
0.3	11.4014	-2.34375	13.4521	3.39355
0.4	10.0342	-3.54004	13.0615	3.125
0.5	10.6201	-4.29688	15.6982	2.97852
0.6	11.1328	-3.88184	12.8418	1.61133
0.7	10.498	-2.6123	11.1084	1.75781
0.8	10.1807	0.317383	12.1094	1.34277
0.9	10.6201	2.92969	12.3535	1.14746
1	11.2061	2.12402	13.8672	-2.44E-02
1.4	11.5479	1.83105	15.0879	-0.14648
1.8	14.6973	3.56445	16.7236	1.58691
2	13.2324	1.70898	16.2598	7.32E-02
2.4	10.6201	2.51465	14.209	-3.41797
2.8	10.3027	3.125	13.7451	-8.78906
3	9.0332	2.68555	11.7432	-6.73828
3.4	10.4736	-0.1709	10.2051	-7.37305
3.8	7.17773	1.51367	11.4258	-8.00781
4	9.13086	3.75977	8.1543	-8.39844

4.4	8.64258	6.0791	11.1328	-8.30078
4.8	5.15137	5.61523	6.83594	-10.6201
5	4.46777	3.41797	5.34668	-9.8877
5.4	1.80664	3.75977	4.10156	-9.27734
5.8	0.976563	5.0293	-0.31738	-9.15527
6	-0.12207	4.58984	-2.14844	-9.17969
6.4	1.46484	5.2002	0.219727	-6.22559
6.8	2.00195	9.59473	-2.31934	-6.46973
7	3.36914	8.49609	-0.97656	-6.44531

**Table 3.28 Different Parameters For Tungsten Carbide Drill**

Exp. No.	POINT ANGLE(deg.)	FEED (mm/rev.)	SPEED(rpm)
12	100	0.08	890



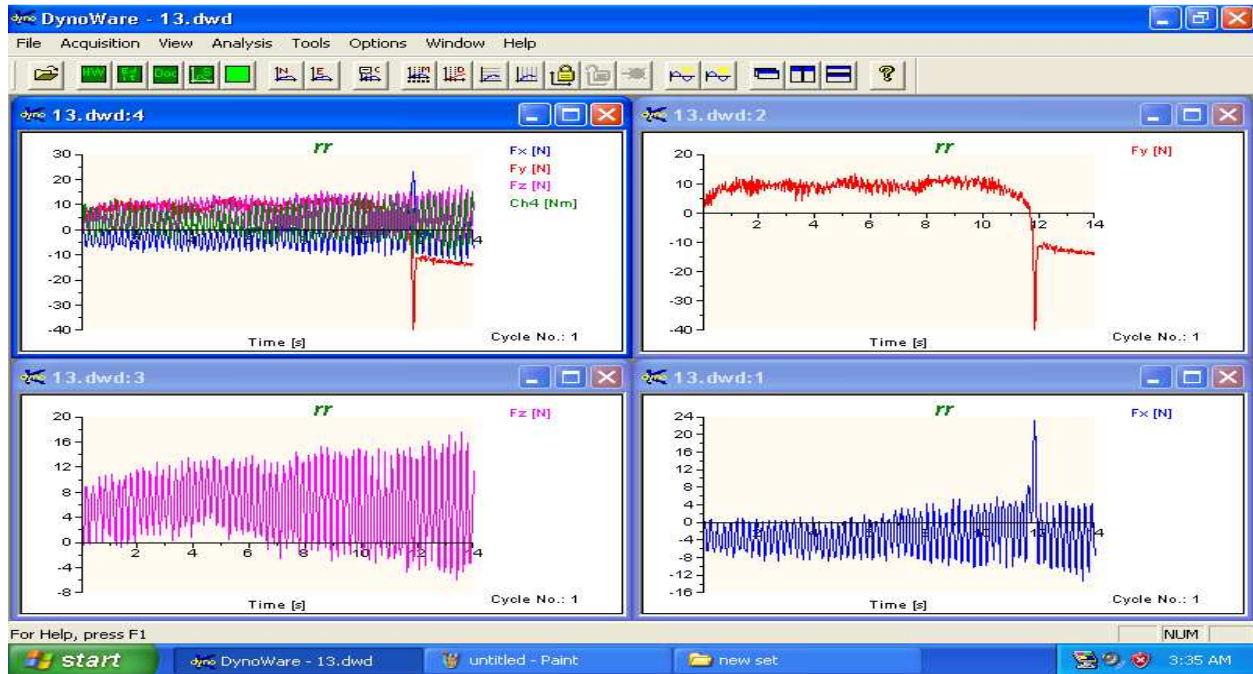
**Fig. 3.22 Graphical representation for feed .08mm/rev., speed 890 rpm and point angle 100°**

**Table 3.29 Different value of thrust forces and torque value for tungsten carbide drill**

File Type:				
Path	C:\Documents and Settings\STUDENT\Desk\carb,Manual\1\			
File name	1.dwd			
Config ID	1.cfg			
Sampling rate [Hz]:	50			
Measuring time [s]:	5			
Delay time [s]:	0			
Cycle time [s]:	0			
Cycles:	1			
Samples per channel:	751			
Cycle interval:	0			
Channel enabled:	1	1	1	1
Cycle No:	1			
Time [s]	Fx	Fy	Fz	Ch4
0	-6.10352	-0.24414	-1.29395	13.4277
0.1	-7.42188	0.634766	-9.15527	0.537109
0.2	-4.32129	-2.88086	3.68652	10.8643
0.3	-11.499	-1.92871	-8.42285	5.71289
0.4	-0.43945	-0.48828	3.97949	9.00879
0.5	-10.9863	0.878906	-9.15527	10.7422
0.6	-0.19531	0.830078	6.32324	6.44531
0.7	-12.7441	1.61133	-7.88574	14.1602
0.8	2.36816	3.07617	2.22168	1.9043
0.9	-12.7441	1.46484	-7.42188	16.7969
1	0.268555	1.87988	-0.41504	1.00098
1.4	-5.9082	4.46777	-10.5469	2.44E-02
1.8	-11.2549	6.05469	-10.9131	8.64258
2	-14.1602	3.95508	-9.0332	16.5283
2.4	-12.4756	3.88184	-2.58789	19.6289
2.8	-4.56543	3.22266	2.9541	12.4756
3	-1.14746	2.6123	4.95605	11.499
3.4	3.78418	6.22559	5.7373	3.80859
3.8	2.02637	5.07813	-1.51367	7.32E-02
4	-3.125	5.0293	-5.71289	-1.48926
4.8	-14.8193	8.10547	-9.22852	12.6465
5	-12.4023	8.95996	-6.5918	18.1885

**Table 3.30 Different Parameters For Tungsten Carbide Drill**

Exp. No.	POINT ANGLE(deg.)	FEED (mm/rev.)	SPEED(rpm)
13	100	0.1	244



**Fig. 3.23 Graphical representation for feed .1mm/rev., speed 244 rpm and point angle 100°**

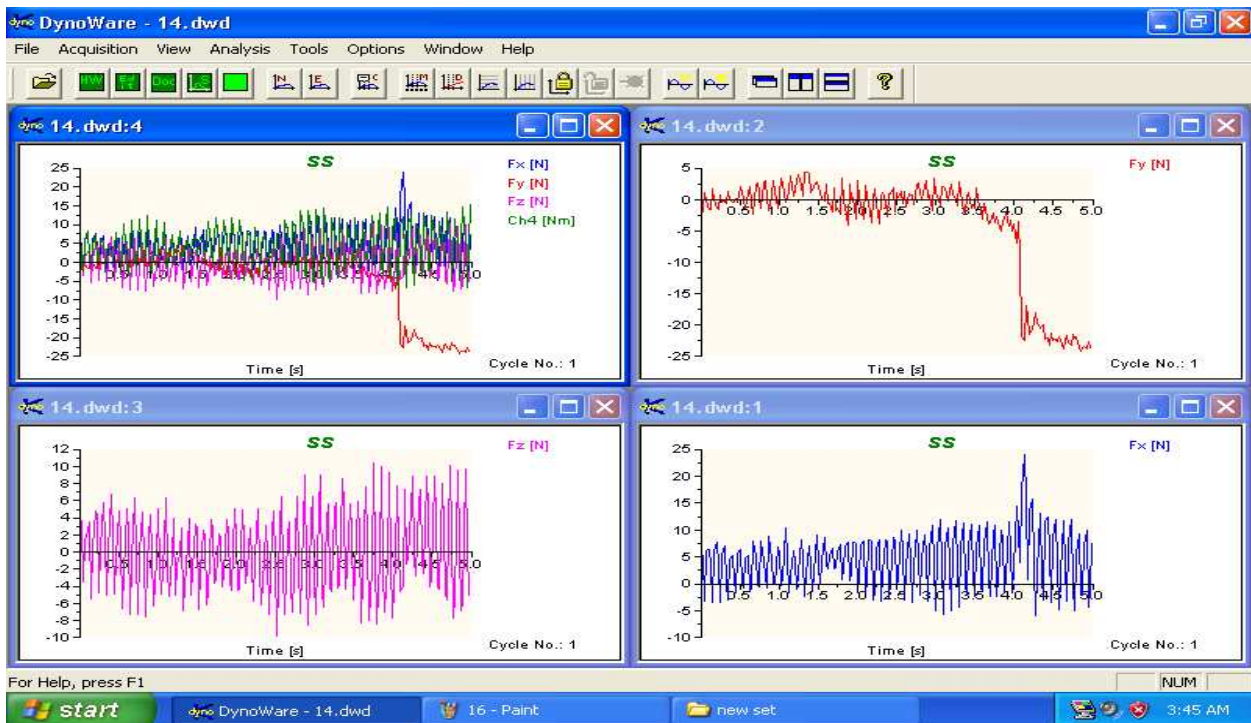
**Table 3.31 Different value of thrust forces and torque value for tungsten carbide drill**

File Type:				
Path	C:\Documents and Settings\STUDENT\Desk\carb,Manual\1\			
File name	1.dwd			
Config ID	1.cfg			
Sampling rate [Hz]:	50			
Measuring time [s]:	14			
Delay time [s]:	0			
Cycle time [s]:	0			
Cycles:	1			
Samples per channel:	751			

Cycle interval:	0			
Channel enabled:	1	1	1	1
Cycle No:	1			
Time [s]	Fx	Fy	Fz	Ch4
0	-4.10156	2.00195	5.44434	-1.53809
0.1	0.12207	2.17285	1.41602	9.64355
0.5	2.44E-02	8.76465	-2.44E-02	2.34375
0.975	0	8.61816	1.58691	3.83301
1	-0.92773	9.91211	1.07422	5.34668
1.975	-5.76172	7.8125	10.0342	7.76367
2	-6.93359	6.56738	11.4502	4.58984
2.975	-4.00391	11.5479	5.66406	-2.97852
3	0.537109	10.7666	4.54102	0.512695
3.975	-1.68457	9.32617	4.76074	10.376
4	-4.41895	8.91113	8.03223	1.5625
4.975	-6.20117	8.98438	10.2539	3.4668
5	-3.54004	10.7422	7.93457	-0.12207
5.975	-0.70801	9.76563	1.83105	4.73633
6	0.439453	8.03223	1.95313	8.27637
6.975	-8.05664	7.9834	12.7197	5.05371
7	-6.78711	6.83594	12.2314	1.14746
7.975	0.317383	11.8896	2.85645	-4.73633
8	3.39355	11.2061	-1.31836	2.34375
8.975	0.732422	12.3535	4.02832	13.1836
9	-6.22559	11.2793	11.5723	5.41992
9.975	-4.88281	7.66602	8.10547	-1.9043
10	0.268555	8.71582	3.90625	-2.83203
10.975	4.1748	8.52051	-1.97754	6.66504
11	4.02832	5.85938	-2.19727	12.5244
11.975	-9.13086	-11.4258	13.3545	-0.43945
12	-9.57031	-11.4746	13.208	-6.25
12.975	4.71191	-13.1592	-4.71191	5.05371
13	2.92969	-12.6465	-3.71094	7.00684
13.975	-3.90625	-14.1357	3.73535	9.96094
14	-7.66602	-13.9404	11.5723	7.34863

**Table 3.32 Different Parameters For Tungsten Carbide Drill**

Exp. No.	POINT ANGLE(deg.)	FEED (mm/rev.)	SPEED(rpm)
14	100	0.1	580



**Fig. 3.24 Graphical representation for feed .1mm/rev., speed 580 rpm and point angle 100°**

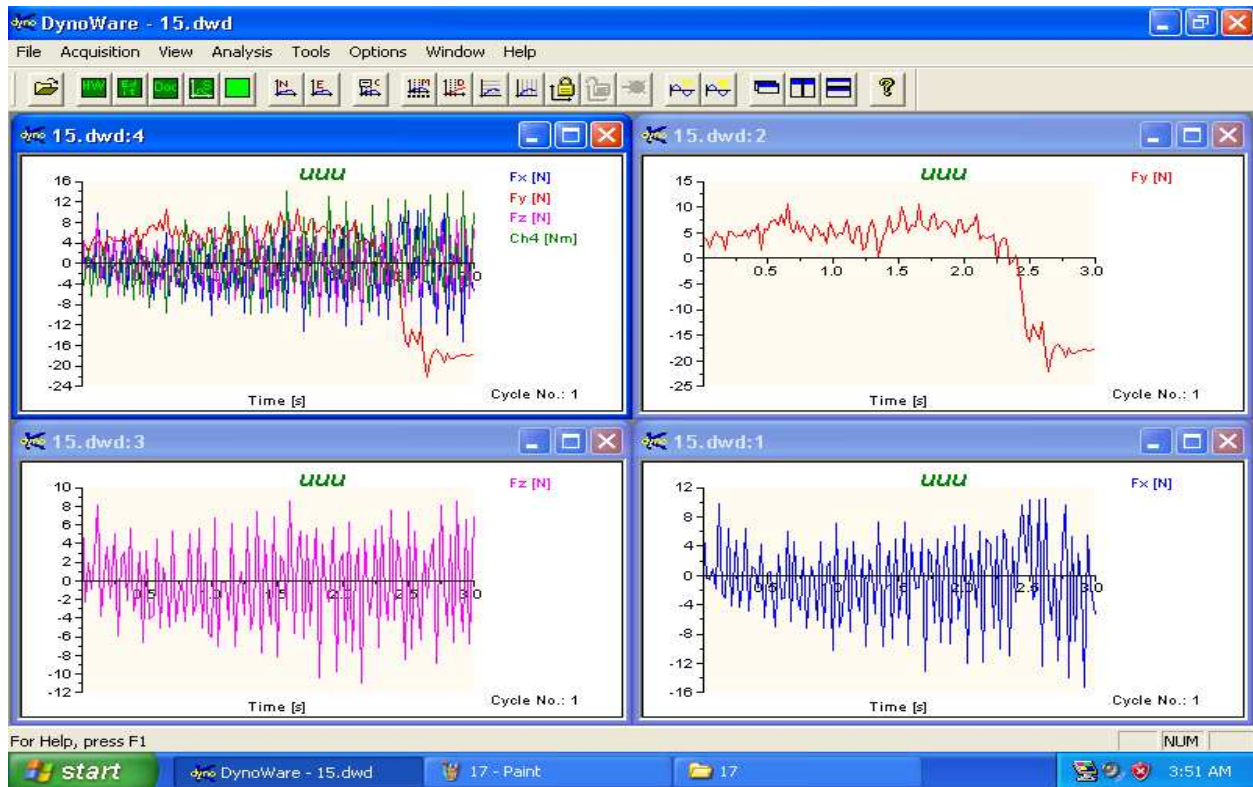
**Table 3.33 Different value of thrust forces and torque value for tungsten carbide drill**

File Type:				
Path	C:\Documents and Settings\STUDENT\Desk\carb,Manual\1\			
File name	1.dwd			
Config ID	1.cfg			
Sampling rate [Hz]:	50			
Measuring time [s]:	5			

Delay time [s]:	0			
Cycle time [s]:	0			
Cycles:	1			
Samples per channel:	751			
Cycle interval:	0			
Channel enabled:	1	1	1	1
Cycle No:	1			
Time [s]	Fx	Fy	Fz	Ch4
0	6.39648	-3.07617	0.976563	8.8623
0.1	6.44531	-1.63574	2.51465	8.39844
0.2	7.76367	-1.46484	4.76074	6.93359
0.4	5.32227	-0.36621	6.73828	3.125
0.6	5.34668	1.14746	5.12695	-0.58594
0.8	4.37012	2.6123	4.6875	0.390625
1	5.83496	0.854492	5.10254	2.14844
1.2	4.41895	1.5625	3.97949	9.77E-02
1.4	3.27148	1.09863	3.93066	-0.5127
1.6	3.41797	2.46582	1.97754	2.44E-02
1.8	0.878906	3.4668	1.68457	-1.78223
2	-1.66016	3.10059	1.63574	-3.75977
2.2	-2.97852	0.341797	-1.29395	-4.39453
2.4	-2.49023	0.927734	-0.43945	-4.54102
2.6	-2.92969	1.34277	-2.39258	-1.2207
2.8	-2.14844	1.00098	-1.41602	-2.44141
3	-4.93164	1.02539	-3.39355	-5.34668
3.2	-4.95605	2.41699	-4.12598	-4.5166
3.4	-2.05078	0.463867	-4.3457	-0.36621
3.6	-1.53809	-3.05176	-8.3252	1.2207
3.8	0.830078	-3.58887	-8.42285	5.39551
4	2.73438	-3.93066	-7.6416	8.76465
4.2	13.4766	-21.4355	-0.73242	10.2539
4.4	11.7432	-22.3389	-2.56348	13.0615
4.6	1.87988	-22.4365	-4.29688	10.9863
4.8	5.46875	-21.9238	-5.32227	11.499
5	7.73926	-23.5107	-4.90723	15.7715

**Table 3.34 Different Parameters For Tungsten Carbide Drill**

Exp. No.	POINT ANGLE(deg.)	FEED (mm/rev.)	SPEED(rpm)
15	100	0.1	890



**Fig. 3.25 Graphical representation for feed .1mm/rev., speed 890 rpm and point angle 100°**

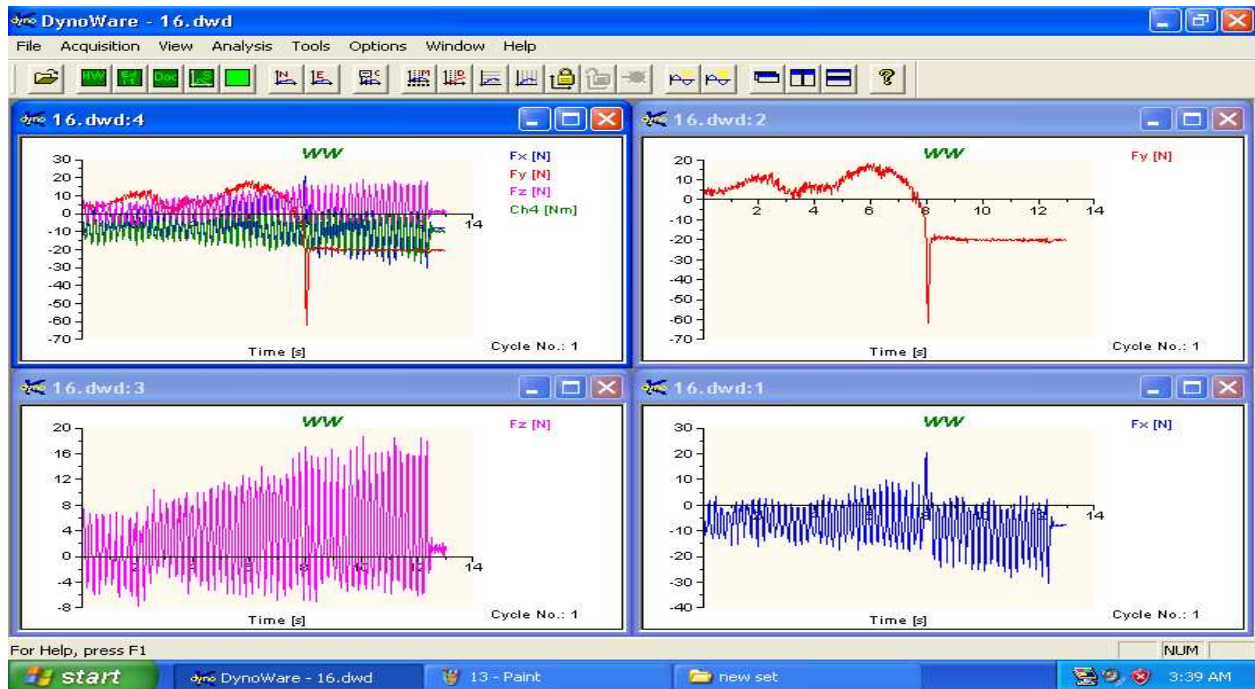
**Table 3.35 Different value of thrust forces and torque value for tungsten carbide drill**

File Type:				
Path	C:\Documents and Settings\STUDENT\Desk\carb,Manual\1\			
File name	1.dwd			
Config ID	1.cfg			
Sampling rate [Hz]:	50			
Measuring time [s]:	3			
Delay time [s]:	0			

Cycle time [s]:	0			
Cycles:	1			
Samples per channel:	751			
Cycle interval:	0			
Channel enabled:	1	1	1	1
Cycle No:	1			
Time [s]	Fx	Fy	Fz	Ch4
0	6.29883	4.05273	7.00684	-4.90723
0.1	-1.83105	5.07813	2.6123	1.92871
0.2	6.4209	5.07813	3.56445	-6.46973
0.4	0.854492	5.27344	-3.22266	-7.12891
0.6	-3.27148	8.47168	-5.0293	-0.19531
0.8	-7.20215	4.71191	-4.3457	8.39844
1	-10.2051	5.39551	-6.10352	6.71387
1.2	-4.78516	6.15234	-0.83008	2.7832
1.4	0.708008	5.32227	4.39453	2.51465
1.6	4.29688	6.51855	8.47168	-1.31836
1.8	5.00488	5.83496	5.54199	-4.54102
2	6.83594	4.95605	2.92969	-6.81152
2.2	4.27246	4.19922	-3.66211	-9.42383
2.4	-3.54004	0.537109	-4.29688	1.36719
2.6	-12.3291	-12.3291	-6.29883	9.74121
2.8	-13.8916	-17.5049	-4.8584	13.5986
3	-5.41992	-17.4072	6.93359	9.98535

**Table 3.36 Different Parameters For Tungsten Carbide Drill**

Exp. No.	POINT ANGLE(deg.)	FEED (mm/rev.)	SPEED(rpm)
16	100	0.2	244



**Fig. 3.26 Graphical representation for feed .2mm/rev., speed 244 rpm and point angle 100°**

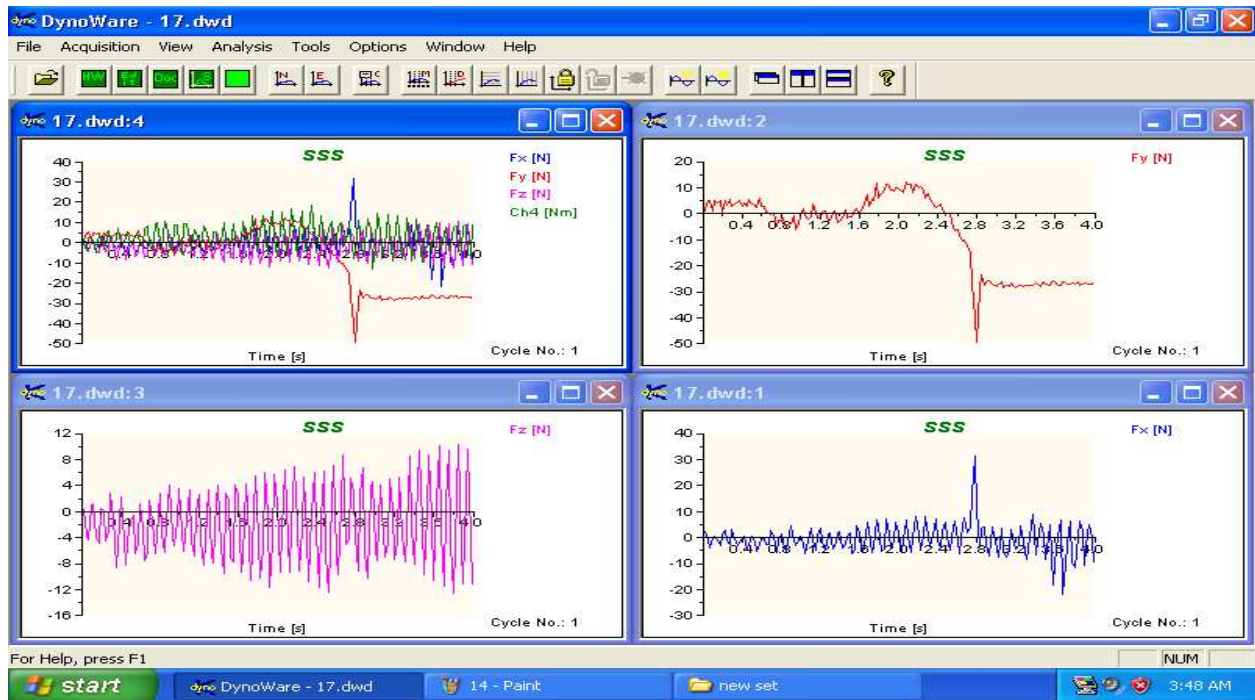
**Table 3.37 Different value of thrust forces and torque value for tungsten carbide drill**

File Type:				
Path	C:\Documents and Settings\STUDENT\Desk\carb,Manual\1\			
File name	1.dwd			
Config ID	1.cfg			
Sampling rate [Hz]:	50			
Measuring time [s]:	13			
Delay time [s]:	0			
Cycle time [s]:	0			
Cycles:	1			
Samples per channel:	751			
Cycle interval:	0			
Channel enabled:	1	1	1	1
Cycle No:	1			
Time [s]	Fx	Fy	Fz	Ch4
0	0.585938	2.0752	-4.5166	-4.98047
0.5	-5.71289	3.78418	3.85742	-6.05469

0.975	-4.56543	4.95605	2.49023	-5.76172
1	-8.98438	6.39648	4.6875	-10.2051
1.975	-5.93262	11.6699	1.12305	-10.6445
2	0.683594	11.3525	-4.73633	-7.83691
2.975	-1.92871	2.9541	1.3916	-4.71191
3	-6.78711	3.125	4.07715	-5.98145
3.975	-11.4014	4.63867	7.91016	-11.0352
4	-12.1094	6.29883	4.12598	-13.7695
4.975	1.68457	11.499	-4.00391	-6.46973
5	1.78223	9.49707	-1.5625	-1.92871
5.975	-10.7178	16.3818	11.8652	-6.98242
6	-13.3789	17.4561	12.2314	-12.2559
6.975	-8.56934	12.3535	-1.97754	-18.0908
7	1.2207	11.9629	-4.71191	-9.17969
7.975	20.6543	-27.6611	3.2959	-5.00488
8	7.32422	-28.8086	13.501	-4.56543
8.975	-15.8447	-18.6523	6.64063	-18.8232
9	-9.27734	-19.0918	-0.39063	-17.2852
9.975	-1.66016	-20.6055	-4.10156	-6.7627
10	0.585938	-19.8975	1.07422	2.24609
10.975	-21.167	-19.5557	16.3574	-13.4277
11	-28.0029	-20.0439	14.9414	-24.3408
11.975	-3.68652	-20.0684	-4.39453	-11.0596
12	0.976563	-19.6045	-6.0791	-5.85938
12.975	-7.86133	-20.6299	-0.14648	-10.3516
13	-8.03223	-20.1904	1.66016	-9.05762

**Table 3.38 Different Parameters For Tungsten Carbide Drill**

Exp. No.	POINT ANGLE(deg.)	FEED (mm/rev.)	SPEED(rpm)
17	100	0.2	580



**Fig. 3.27 Graphical representation for feed .2mm/rev., speed 580 rpm and point angle 100°**

**Table 3.39 Different value of thrust forces and torque value for tungsten carbide drill**

File Type:				
Path	C:\Documents and Settings\STUDENT\Desk\carb,Manual\1\			
File name	1.dwd			
Config ID	1.cfg			
Sampling rate [Hz]:	50			
Measuring time [s]:	4			
Delay time [s]:	0			
Cycle time [s]:	0			
Cycles:	1			
Samples per channel:	751			
Cycle interval:	0			
Channel enabled:	1	1	1	1
Cycle No:	1			
Time [s]	Fx	Fy	Fz	Ch4
0	1.3916	4.88E-02	0.65918	3.39355
0.1	0.12207	1.07422	0.927734	2.19727
0.2	1.07422	0.439453	0.439453	3.27148

0.4	0.12207	2.90527	2.22168	0.415039
0.6	-0.58594	3.00293	1.26953	0.12207
0.8	1.61133	-3.10059	2.88086	0
1	0.708008	-0.87891	3.58887	-0.73242
1.2	3.68652	-2.0752	2.70996	2.44E-02
1.4	2.51465	-2.73438	4.15039	0.610352
1.6	2.02637	0.317383	2.6123	0.390625
1.8	4.61426	5.76172	1.12305	-4.61426
2	2.46582	9.49707	1.14746	-6.71387
2.2	1.58691	10.1807	-1.83105	-6.49414
2.4	-1.14746	2.90527	-3.05176	-4.44336
2.6	-1.09863	-6.15234	-6.81152	1.0498
2.8	10.9863	-49.3408	-3.80859	-5.32227
3	-4.22363	-27.7588	-5.66406	-0.80566
3.2	-4.29688	-28.3691	-7.2998	-0.39063
3.4	-6.7627	-26.709	-8.12988	0.146484
3.6	-9.93652	-26.2695	-10.6445	3.44238
3.8	-11.499	-26.8311	-12.5977	7.66602
4	-9.76563	-26.3916	-11.3281	9.08203

**Table 3.40 Different Parameters For Tungsten Carbide Drill**

Exp. No.	POINT ANGLE(deg.)	FEED (mm/rev.)	SPEED(rpm)
18	100	0.2	890

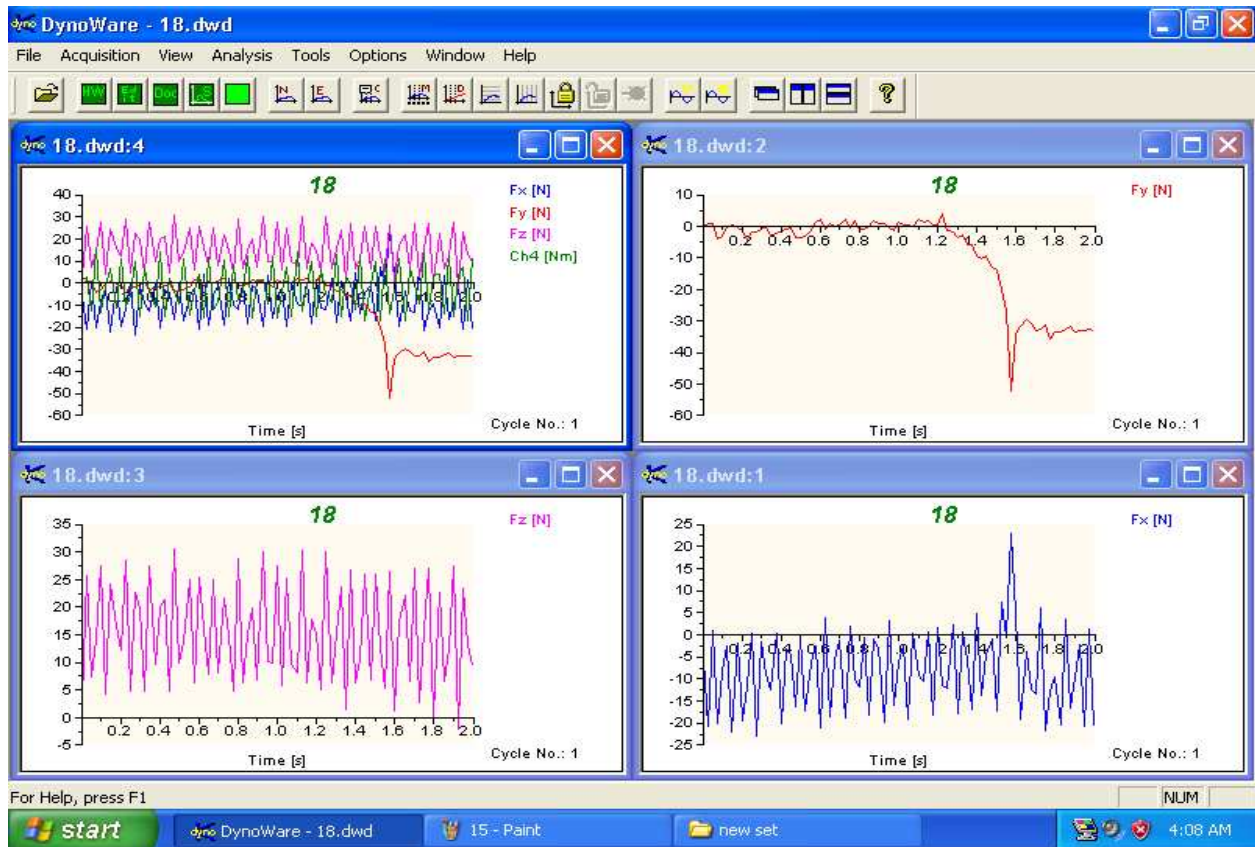


Fig. 3.28 Graphical representation for feed .2 mm/rev., speed 890 rpm and point angle 100°

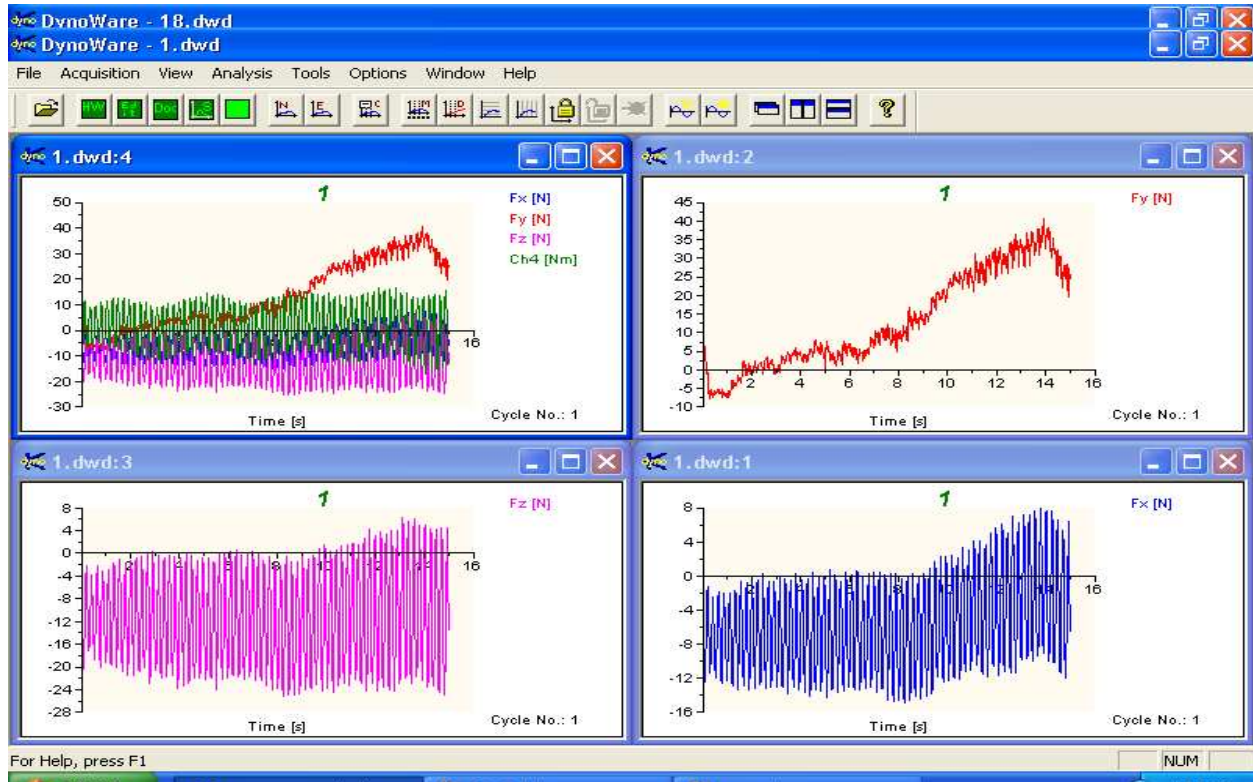
Table 3.41 Different value of thrust forces and torque value for tungsten carbide drill

File Type:				
Path	C:\Documents and Settings\STUDENT\Desk\carb,Manual\1\			
File name	1.dwd			
Config ID	1.cfg			
Sampling rate [Hz]:	50			
Measuring time [s]:	2			
Delay time [s]:	0			
Cycle time [s]:	0			
Cycles:	1			
Samples per channel:	751			
Cycle interval:	0			
Channel enabled:	1	1	1	1
Cycle No:	1			
Time [s]	Fx	Fy	Fz	Ch4

0	-5.46875	0.146484	2.97852	1.66016
0.1	-8.30078	-3.00293	27.5879	-13.501
0.2	-19.5313	-1.14746	12.2559	11.1572
0.4	-20.1172	-1.46484	19.8975	14.4775
0.6	-21.1182	2.36816	25.5371	4.10156
0.8	-11.7432	-0.97656	28.7109	-7.32422
1	-6.4209	1.26953	27.4658	-15.8447
1.2	1.68457	0.415039	15.1367	-15.3564
1.4	4.71191	-9.375	6.39648	-12.207
1.6	4.93164	-34.3018	1.09863	-2.88086
1.8	-9.57031	-33.5693	9.77E-02	3.66211
2	-20.7764	-32.9102	9.47266	11.6211

**Table 3.42 Different Parameters For Tungsten Carbide Drill**

Exp. No.	POINT ANGLE(deg.)	FEED (mm/rev.)	SPEED(rpm)
19	118	0.08	244



**Fig. 3.29 Graphical representation for feed .08mm/rev., speed 244 rpm and point angle 118**

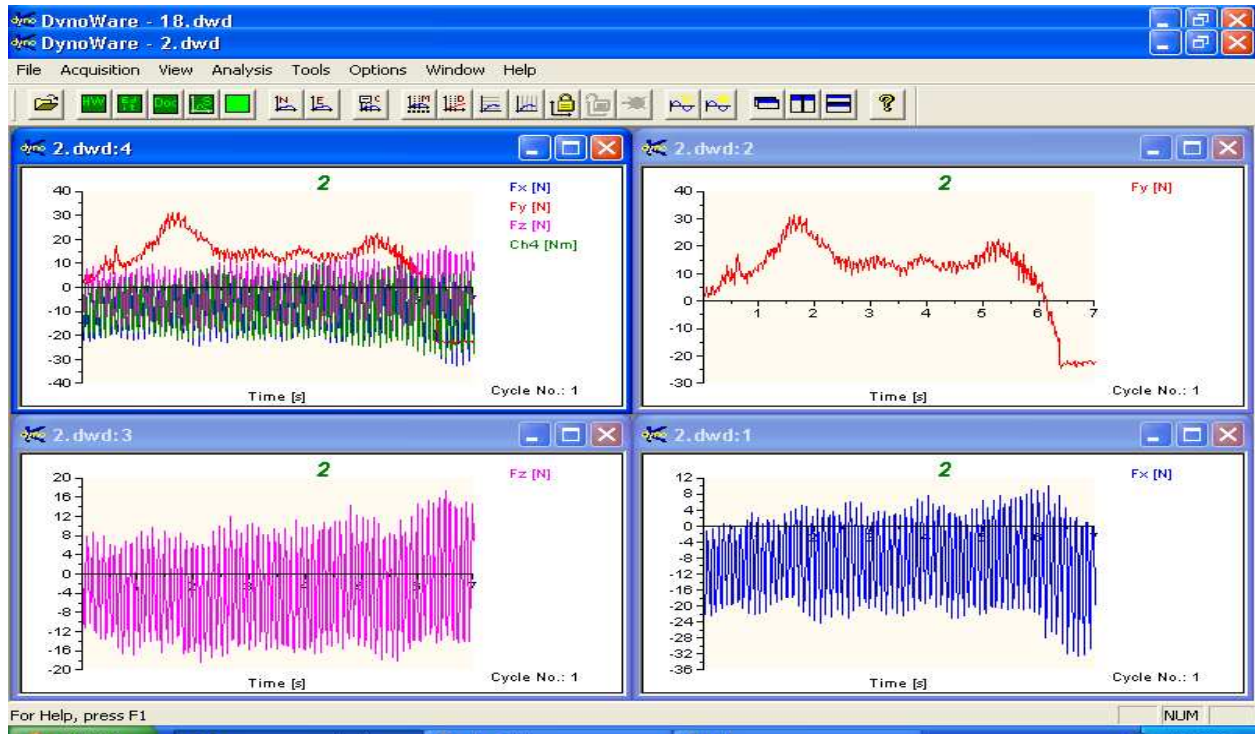
**Table 3.43 Different value of thrust forces and torque value for tungsten carbide drill**

File Type:				
Path	C:\Documents and Settings\STUDENT\Desk\carb,Manual\1\			
File name	1.dwd			
Config ID	1.cfg			
Sampling rate [Hz]:	50			
Measuring time [s]:	15			
Delay time [s]:	0			
Cycle time [s]:	0			
Cycles:	1			
Samples per channel:	751			
Cycle interval:	0			
Channel enabled:	1	1	1	1
Cycle No:	1			
Time [s]	Fx	Fy	Fz	Ch4
0	-3.44238	3.78418	-5.2002	-5.93262
0.1	-11.3037	4.95605	-19.7266	8.03223
0.5	-10.1318	-6.27441	-14.0625	-5.78613
1	-11.2549	-6.64063	-19.2139	7.42188
1.98	-2.36816	-1.31836	-5.24902	7.61719
2	-0.78125	-0.78125	-1.3916	1.9043
2.98	-9.27734	0.439453	-12.6953	-11.4502
3	-11.5723	-0.31738	-17.6758	-8.05664
3.98	-9.22852	3.78418	-17.9199	10.7666
4	-5.76172	4.1748	-11.9385	10.7666
4.98	-1.83105	3.19824	-2.46582	-6.46973
5	-6.0791	9.77E-02	-9.27734	-8.17871
5.98	-12.3535	6.93359	-21.875	4.88281
6	-10.0586	5.83496	-18.6768	10.376
6.98	-0.56152	5.83496	-2.9541	2.31934
7	0.488281	7.42188	0.219727	-5.54199
7.98	-13.0371	9.57031	-18.9453	-8.61816
8	-14.5752	10.0342	-23.6816	-2.31934
8.98	-6.00586	14.2822	-14.4775	14.2822
9	-2.73438	13.2813	-8.81348	11.6211
9.98	-1.66016	20.4346	-4.71191	-10.0098

10	-5.76172	20.874	-11.4502	-9.91211
10.98	-9.2041	24.9756	-19.458	8.1543
11	-9.10645	25.3418	-18.7256	11.4014
11.98	5.71289	24.6582	1.70898	-0.19531
12	4.24805	25.708	3.10059	-5.10254
12.98	-8.44727	35.0098	-19.6045	-4.6875
13	-9.375	34.0332	-22.9492	-1.17188
13.98	-0.5127	32.666	-10.7422	12.915
14	4.12598	33.9844	-1.9043	9.10645
14.52	1.7334	32.1289	-2.27051	-14.3555
14.98	-9.77E-02	27.3926	-3.85742	-13.3789
15	-6.54297	24.0234	-13.7207	-10.9863

**Table 3.44 Different Parameters For Tungsten Carbide Drill**

Exp. No.	POINT ANGLE(deg.)	FEED (mm/rev.)	SPEED(rpm)
20	118	0.08	580



**Fig. 3.30 Graphical representation for feed .08mm/rev., speed 580 rpm and point angle 118°**

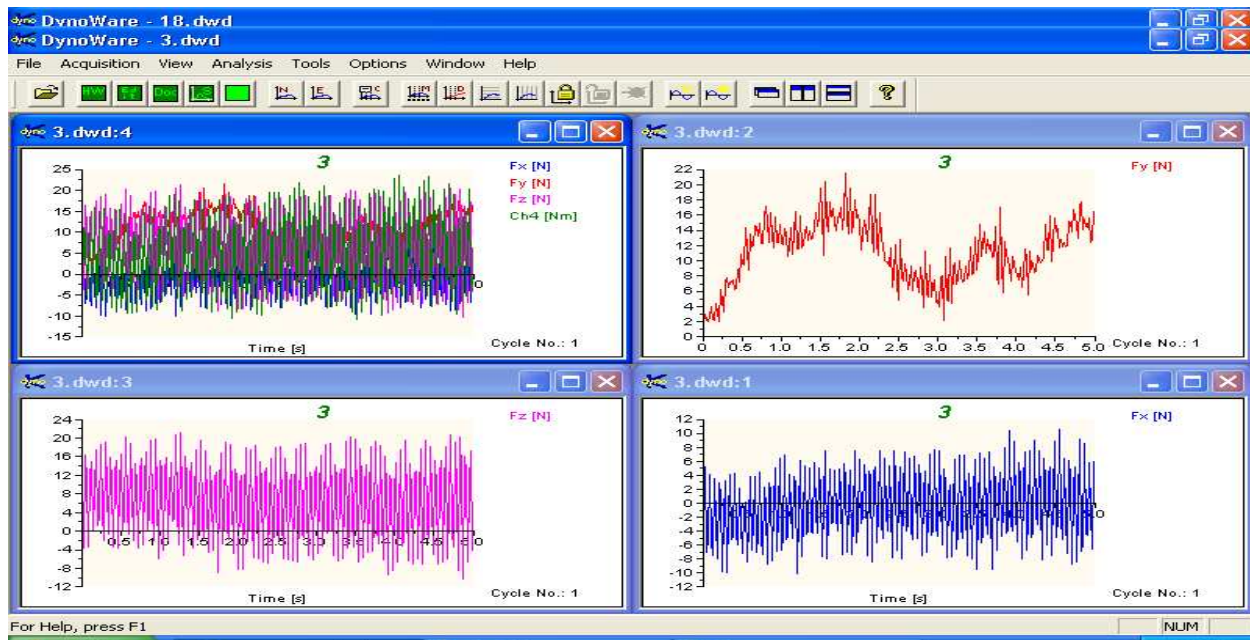
**Table 3.45 Different value of thrust forces and torque value for tungsten carbide drill**

File Type:				
Path	C:\Documents and Settings\STUDENT\Desk\carb,Manual\1\			
File name	1.dwd			
Config ID	1.cfg			
Sampling rate [Hz]:	50			
Measuring time [s]:	7			
Delay time [s]:	0			
Cycle time [s]:	0			
Cycles:	1			
Samples per channel:	751			
Cycle interval:	0			
Channel enabled:	1	1	1	1
Cycle No:	1			
Time [s]	Fx	Fy	Fz	Ch4
0	-3.51563	2.22168	7.22656	-9.42383
0.1	-5.51758	1.44043	7.8125	-10.083
0.2	-5.59082	2.31934	8.71582	-11.499
0.4	-8.1543	6.27441	8.03223	-13.5986
0.6	-7.00684	14.9658	5.95703	-15.5762
0.8	-7.9834	9.0332	6.88477	-15.8447
1	-10.3271	12.6709	3.56445	-15.0635
1.2	-12.9883	19.043	2.51465	-16.1865
1.4	-15.8447	23.5352	-0.61035	-20.3125
1.6	-17.8955	29.3945	-4.98047	-20.1172
1.98	-6.49414	22.3389	6.49414	-13.2568
2	-23.7793	22.2656	-9.96094	-20.7031
2.2	-22.1436	19.165	-11.2793	-19.2871
2.4	-20.9229	16.1865	-13.5986	-16.1621
2.6	-22.9004	15.9668	-14.5264	-16.5039
2.98	-20.459	11.792	-4.41895	-21.7285
3	-16.2354	15.5518	-15.7471	-9.7168
3.2	-13.1836	14.502	-14.1357	-5.00488
3.4	-12.4023	14.7461	-15.4053	-2.27051
3.6	-8.00781	12.3047	-14.7949	-2.44E-02
3.98	-19.2627	15.8691	-15.625	-11.8408

4	-2.56348	14.5264	-15.8691	8.12988
4.2	3.00293	12.6465	-10.5225	9.74121
4.4	2.83203	14.502	-8.05664	8.78906
4.6	2.29492	13.7695	-3.51563	4.07715
4.98	-5.44434	16.3574	-12.3291	1.75781
5	6.22559	17.4805	1.48926	3.51563
5.4	5.49316	17.0654	6.83594	0.732422
5.98	8.81348	3.22266	3.05176	4.5166
6	3.27148	5.49316	14.4287	-11.4502
6.4	-3.27148	-24.5605	15.918	-23.6328
6.98	-0.63477	-22.998	14.5996	-10.6445
7	-20.0195	-21.9482	6.68945	-27.8076

**Table 3.46 Different Parameters For Tungsten Carbide Drill**

Exp. No.	POINT ANGLE(deg.)	FEED (mm/rev.)	SPEED(rpm)
21	118	0.08	890



**Fig. 3.31 Graphical representation for feed .08mm/rev., speed 890 rpm and point angle 118°**

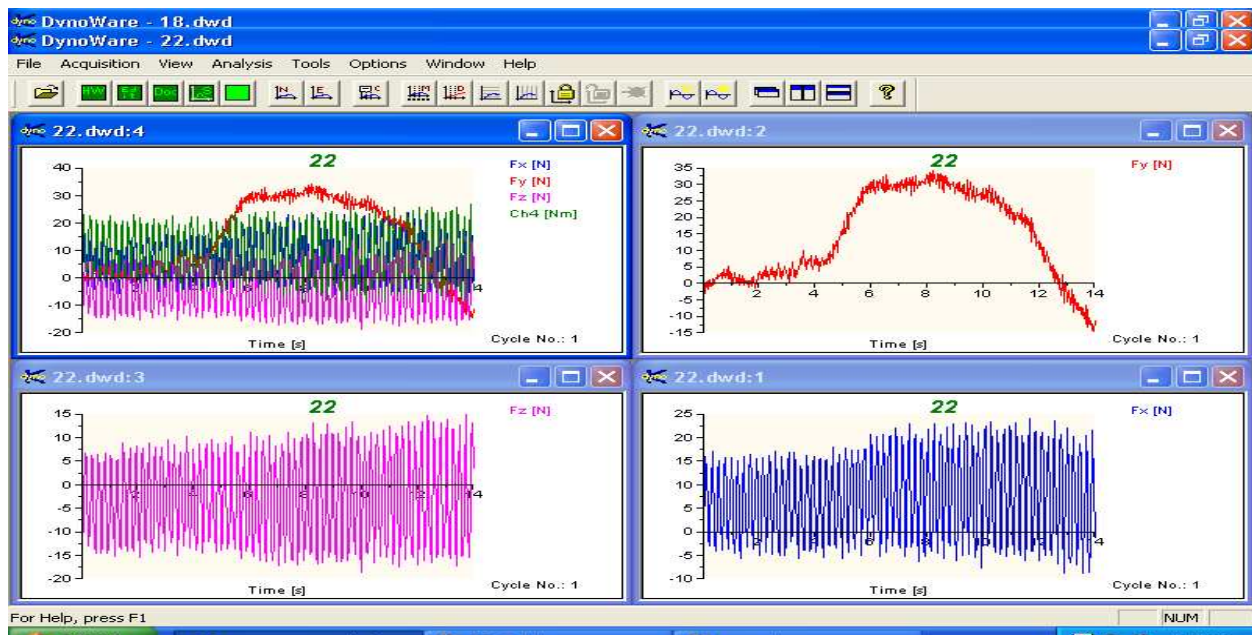
**Table 3.47 Different value of thrust forces and torque value for tungsten carbide drill**

File Type:				
Path	C:\Documents and Settings\STUDENT\Desktop\carb,Manual\1\			
File name	1.dwd			
Config ID	1.cfg			
Sampling rate [Hz]:	50			
Measuring time [s]:	5			
Delay time [s]:	0			
Cycle time [s]:	0			
Cycles:	1			
Samples per channel:	751			
Cycle interval:	0			
Channel enabled:	1	1	1	1
Cycle No:	1			
Time [s]	Fx	Fy	Fz	Ch4
0	7.34863	4.44336	0.90332	7.76367
0.1	9.74121	2.83203	-13.5742	2.12402
0.2	-0.31738	-0.39063	2.66113	2.00195
0.4	-2.12402	2.70996	-1.70898	-4.71191
0.6	1.2207	-1.66016	-7.39746	-1.95313
0.98	-2.9541	3.88184	-3.125	-9.27734
1	12.1826	5.2002	-15.3076	4.46777
1.2	19.751	7.54395	-13.3789	12.1094
1.6	10.9863	5.44434	-2.12402	12.3535
1.98	16.5283	9.98535	-4.1748	15.9668
2	-2.85645	3.61328	2.53906	-2.80762
2.2	-2.44E-02	6.39648	-7.2998	-5.81055
2.6	11.7188	9.0332	-17.0166	0.756836
2.98	8.03223	8.91113	-14.7461	-1.66016
3	24.0234	15.3809	-11.6943	19.4092
3.2	16.8701	14.6729	-1.9043	17.2363
3.6	-5.10254	13.6719	5.61523	-4.00391
3.98	1.51367	16.6748	6.27441	5.24902
4	3.95508	10.2783	-7.44629	-6.61621
4.2	8.08105	14.1357	-14.1846	-2.12402
4.6	28.1982	22.5586	-16.1377	19.5557

4.98	23.1934	23.0225	-17.1875	11.8896
5	11.6943	22.7051	2.88086	13.5986

**Table 3.48 Different Parameters For Tungsten Carbide Drill**

Exp. No.	POINT ANGLE(deg.)	FEED (mm/rev.)	SPEED(rpm)
22	118	0.1	244



**Fig. 3.32 Graphical representation for feed .1mm/rev., speed 244 rpm and point angle 118°**

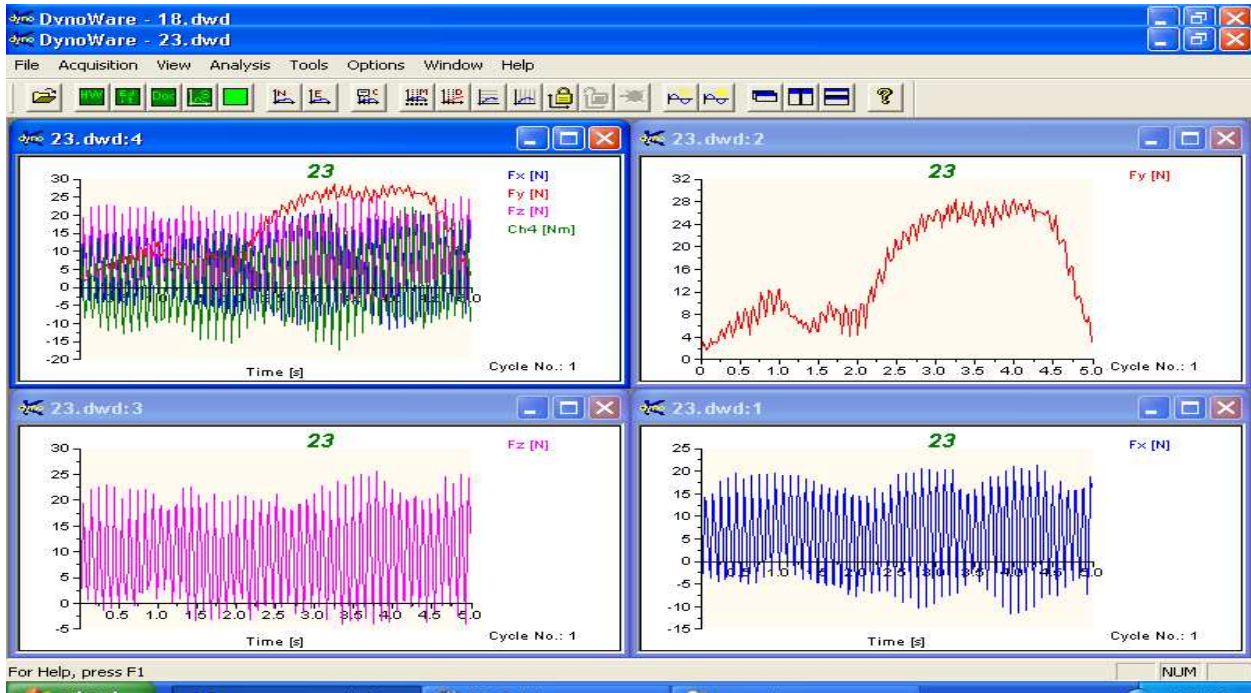
**Table 3.49 Different value of thrust forces and torque value for tungsten carbide drill**

File Type:				
Path	C:\Documents and Settings\STUDENT\Desktop\carb,Manual\1\			
File name	1.dwd			
Config ID	1.cfg			
Sampling rate [Hz]:	50			
Measuring time [s]:	14			
Delay time [s]:	0			

Cycle time [s]:	0			
Cycles:	1			
Samples per channel:	751			
Cycle interval:	0			
Channel enabled:	1	1	1	1
Cycle No:	1			
Time [s]	Fx	Fy	Fz	Ch4
0	-2.66113	-2.46582	-7.76367	3.71094
0.5	3.93066	1.46484	-14.5996	17.4072
0.966667	6.29883	2.66113	-13.3545	19.2383
1	15.6494	-0.19531	-2.97852	22.6807
1.96667	10.4248	1.19629	8.22754	6.98242
2	0.366211	2.19727	1.09863	-0.14648
2.96667	-2.27051	3.90625	-14.0381	8.91113
3	7.22656	3.97949	-10.5957	17.4072
3.96667	16.0156	6.17676	6.61621	14.1602
4	8.52051	7.03125	7.51953	3.54004
4.96667	-5.61523	16.2598	-7.34863	-5.15137
5	-2.66113	14.7461	-13.8916	6.7627
5.56667	17.2607	26.2939	6.90918	10.8398
6	20.6543	27.3926	0.634766	21.6309
6.56667	-4.29688	27.8564	-12.6953	1.36719
7	-2.22168	29.6631	-2.66113	-4.24805
7.53333	9.32617	29.5654	-16.0156	20.4102
8	12.1826	32.8857	-11.6943	19.6045
8.56667	1.75781	32.6172	3.66211	-6.64063
9	9.96094	28.2959	10.5957	-0.73242
9.56667	7.78809	30.6396	-13.4766	15.8203
10	1.36719	25.708	-18.5547	12.0605
10.5333	21.582	26.1719	6.51855	17.2363
11	20.9473	22.0703	10.6201	13.4277
11.5333	-6.10352	16.9922	-5.71289	-6.17676
12	-6.20117	12.9395	-8.61816	-4.8584
12.5333	16.04	5.44434	-8.37402	25.6836
13	18.5303	-5.66406	-4.24805	23.8037
13.5333	5.54199	-9.10645	10.5469	-2.51465
14	-1.3916	-11.0107	3.27148	-4.83398

**Table 3.50 Different Parameters For Tungsten Carbide Drill**

Exp. No.	POINT ANGLE(deg.)	FEED (mm/rev.)	SPEED(rpm)
23	118	0.1	580



**Fig. 3.33 Graphical representation for feed .1mm/rev., speed 580 rpm and point angle 118°**

**Table 3.51 Different value of thrust forces and torque value for tungsten carbide drill**

File Type:				
Path	C:\Documents and Settings\STUDENT\Desk\carb,Manual\1\			
File name	1.dwd			
Config ID	1.cfg			
Sampling rate [Hz]:	50			
Measuring time [s]:	5			
Delay time [s]:	0			

Cycle time [s]:	0			
Cycles:	1			
Samples per channel:	751			
Cycle interval:	0			
Channel enabled:	1	1	1	1
Cycle No:	1			
Time [s]	Fx	Fy	Fz	Ch4
0	0.90332	1.53809	0.292969	-4.24805
0.1	-2.44E-02	2.24609	0.610352	-2.14844
0.525	-2.83203	5.63965	7.83691	13.5742
0.975	5.88379	12.1338	0.90332	-9.76563
1	-1.83105	12.5977	5.22461	6.22559
1.575	-4.39453	7.49512	-1.66016	2.24609
1.975	-7.6416	8.83789	-0.12207	9.375
2	-3.41797	4.3457	9.27734	13.501
2.525	19.2383	19.5557	21.2158	-6.90918
2.975	-9.30176	24.5605	3.56445	19.873
3	13.1836	26.416	21.1914	7.34863
3.55	-4.56543	26.6602	-3.32031	8.10547
3.975	5.7373	27.9297	16.8213	12.0605
4	21.167	28.3691	22.1924	-6.03027
4.525	-0.56152	25.5371	-1.53809	-1.97754
4.975	18.75	5.81055	24.3652	-1.12305
5	16.2842	2.92969	13.3789	-9.5459

**Table 3.52 Different Parameters For Tungsten Carbide Drill**

Exp. No.	POINT ANGLE(deg.)	FEED (mm/rev.)	SPEED(rpm)
24	118	0.1	890



**Fig. 3.34 Graphical representation for feed .1mm/rev., speed 890 rpm and point angle 118°**

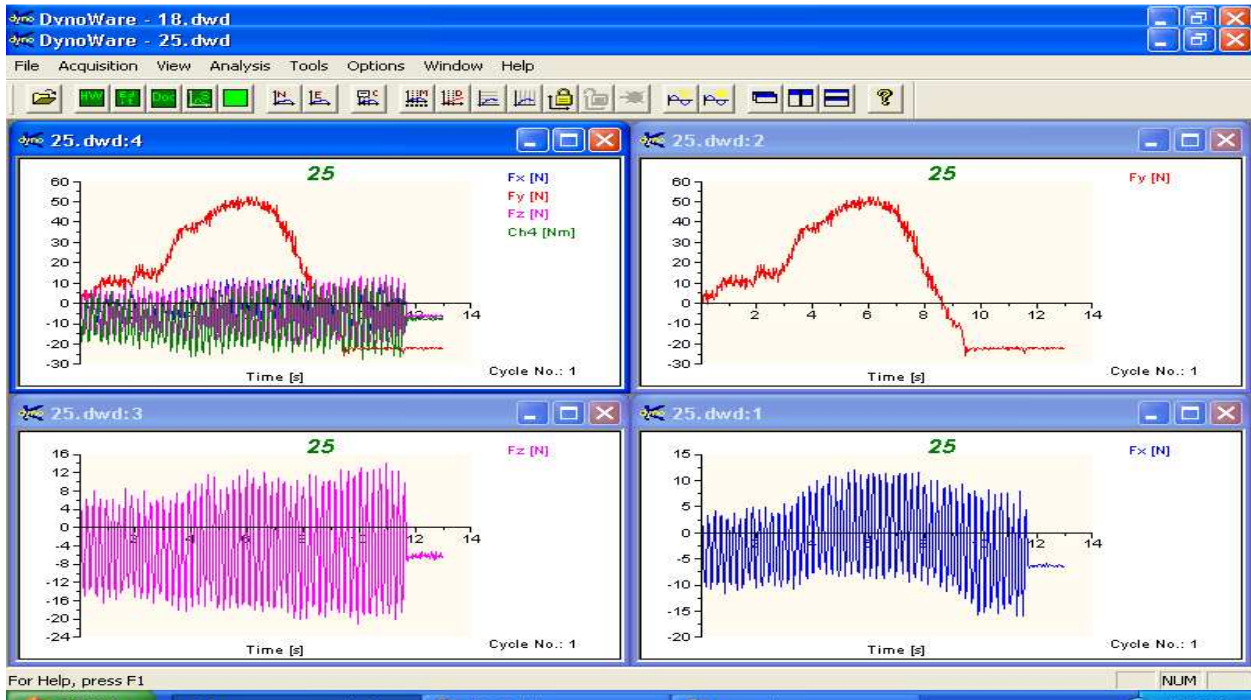
**Table 3.53 Different value of thrust forces and torque value for tungsten carbide drill**

File Type:				
Path	C:\Documents and Settings\STUDENT\Desk\carb,Manual\1\			
File name	1.dwd			
Config ID	1.cfg			
Sampling rate [Hz]:	50			
Measuring time [s]:	3			
Delay time [s]:	0			
Cycle time [s]:	0			
Cycles:	1			
Samples per channel:	751			
Cycle interval:	0			
Channel enabled:	1	1	1	1

Cycle No:	1			
Time [s]	Fx	Fy	Fz	Ch4
0	-3.07617	7.10449	8.34961	-8.00781
0.1	-8.49609	4.63867	11.9873	18.5791
0.2	-0.3418	3.90625	3.95508	-5.78613
0.4	1.63574	4.6875	-2.70996	8.05664
0.6	2.49023	3.83301	-1.87988	17.8955
0.8	-2.6123	4.05273	4.15039	21.3623
1	-7.37305	8.74023	14.2822	18.1396
1.2	-12.5977	15.9424	20.9473	10.9863
1.4	-12.4512	15.1855	21.0205	3.02734
1.6	-9.69238	21.8994	17.5537	-2.24609
1.8	-3.61328	20.8008	6.78711	-0.78125
2	1.53809	19.6777	1.48926	-0.19531
2.2	2.6123	25.3418	-2.41699	9.05762
2.4	2.56348	15.5029	-1.00098	18.4326
2.6	-0.19531	10.1318	2.56348	23.9258
2.8	-4.27246	-7.8125	10.6934	23.3887
3	-14.0381	-21.3623	20.2148	11.7188

**Table 3.54 Different Parameters For Tungsten Carbide Drill**

Exp. No.	POINT ANGLE(deg.)	FEED (mm/rev.)	SPEED(rpm)
25	118	0.2	244



**Fig. 3.35 Graphical representation for feed .2mm/rev., speed 244 rpm and point angle 118°**

**Table 3.55 Different value of thrust forces and torque value for tungsten carbide drill**

File Type:				
Path	C:\Documents and Settings\STUDENT\Desk\carb,Manual\1\			
File name	1.dwd			
Config ID	1.cfg			
Sampling rate [Hz]:	50			
Measuring time [s]:	13			
Delay time [s]:	0			
Cycle time [s]:	0			
Cycles:	1			

Samples per channel:	751			
Cycle interval:	0			
Channel enabled:	1	1	1	1
Cycle No:	1			
Time [s]	Fx	Fy	Fz	Ch4
0	-1.53809	3.58887	-2.09961	0.268555
0.5	4.24805	4.71191	7.93457	-12.915
0.966667	2.73438	10.3516	5.98145	-16.2109
1	-1.70898	12.6709	-1.02539	-20.1172
1.5	-10.6445	8.93555	-14.2334	-13.623
1.96667	-10.4492	11.4258	-15.1123	-11.1816
2	-7.37305	13.208	-13.1348	1.75781
2.5	0.219727	15.0146	-2.17285	-1.29395
2.96667	1.97754	15.2832	1.5625	-4.19922
3	5.54199	18.0908	6.73828	-14.3066
3.5	1.85547	34.0576	1.3916	-24.1699
3.96667	2.44E-02	37.5732	-1.95313	-26.123
4	-7.54395	35.2783	-13.3057	-15.3076
4.5	-7.12891	42.2363	-17.1875	-0.65918
4.96667	-6.54297	45.4102	-16.1621	4.6875
5	2.44141	44.8975	-2.36816	3.4668
5.96667	11.1816	50.0244	12.5244	-13.0127
6	3.00293	52.0508	2.00195	-21.3867
6.96667	-8.61816	45.4346	-17.5537	-10.2051
7	-6.71387	42.8711	-17.2852	2.46582
7.5	5.39551	35.5957	-1.46484	5.83496
7.96667	8.10547	15.2344	5.29785	2.70996
8	9.17969	14.4287	8.66699	-5.66406
8.5	-1.17188	4.22363	-2.56348	-21.582
8.96667	-5.76172	-7.44629	-7.20215	-22.2656
9	-10.0586	-8.66699	-16.4795	-11.7432
9.96667	-8.61816	-22.2168	-13.6719	8.22754
10	-1.58691	-22.4854	-4.07715	5.27344
10.5	7.2998	-22.4609	12.5732	-9.30176
10.9667	7.59277	-21.8506	14.0625	-14.0625
11	-1.41602	-21.9727	2.73438	-22.8516
11.5667	-9.375	-24.3896	-14.8682	6.20117

11.9667	-6.20117	-21.875	-6.34766	-7.49512
12	-6.49414	-21.9971	-5.9082	-8.71582
12.5	-6.32324	-21.9482	-6.88477	-7.27539
12.9667	-6.4209	-22.1191	-6.54297	-7.39746
13	-6.22559	-22.1924	-6.27441	-8.42285

**Table 3.56 Different Parameters For Tungsten Carbide Drill**

Exp. No.	POINT ANGLE(deg.)	FEED (mm/rev.)	SPEED(rpm)
26	118	0.2	580



**Fig. 3.36 Graphical representation for feed .2mm/rev., speed 580 rpm and point angle 118°**

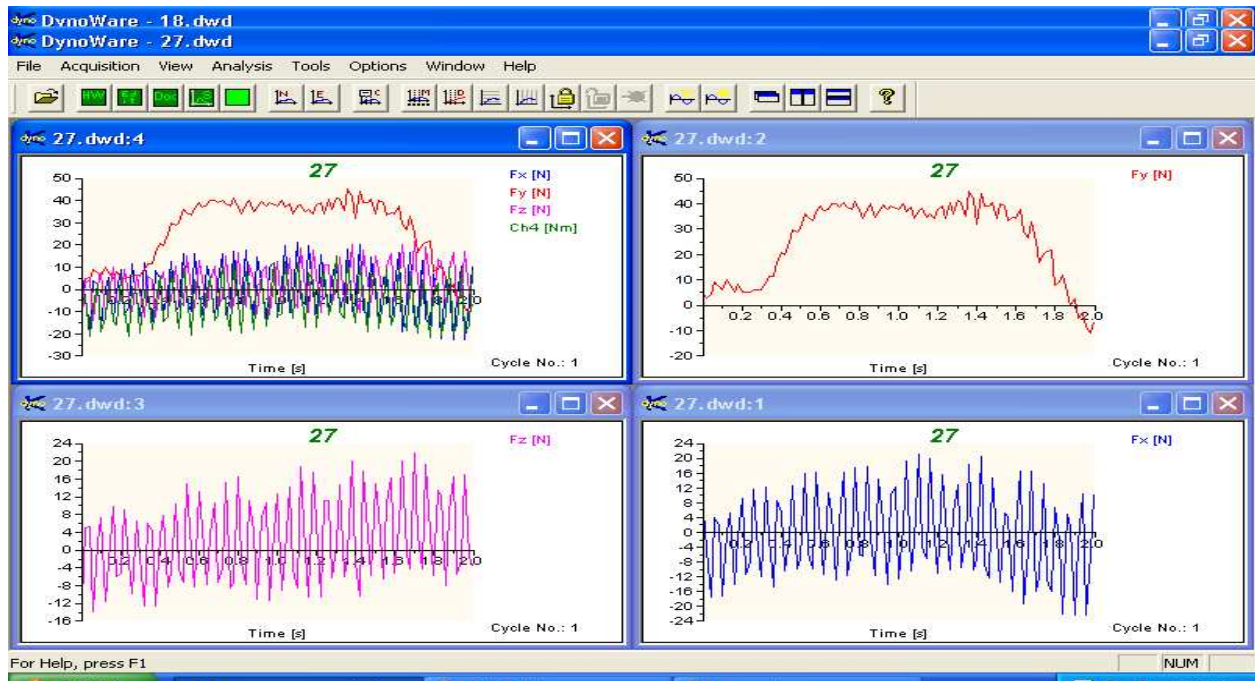
**Table 3.57 Different value of thrust forces and torque value for tungsten carbide drill**

File Type:	
Path	C:\Documents and Settings\STUDENT\Desk\carb,Manual\1\
File name	1.dwd
Config ID	1.cfg

Sampling rate [Hz]:	50			
Measuring time [s]:	4			
Delay time [s]:	0			
Cycle time [s]:	0			
Cycles:	1			
Samples per channel:	751			
Cycle interval:	0			
Channel enabled:	1	1	1	1
Cycle No:	1			
Time [s]	Fx	Fy	Fz	Ch4
0	4.24805	1.07422	16.5283	14.9658
0.2	4.78516	1.34277	15.0879	10.7178
0.4	6.29883	3.71094	16.4795	8.78906
0.6	8.91113	3.68652	13.3301	2.66113
0.8	10.9375	10.6689	12.8418	0.268555
1	11.3281	29.1016	12.0117	-0.3418
1.3	10.4492	43.6279	9.66797	0.244141
1.6	7.03125	44.1895	4.90723	1.02539
1.975	13.0615	39.8926	16.2598	7.51953
2	1.0498	39.2822	-0.58594	4.12598
2.2	-4.15039	34.7168	-5.51758	6.78711
2.4	-5.17578	36.7676	-7.54395	10.1807
2.65	4.73633	39.6973	16.1865	19.2871
2.85	7.27539	33.5938	17.7002	19.3115
3	-10.2783	24.6826	-8.10547	15.7959
3.2	-13.4277	10.5225	-8.25195	22.9248
3.4	-16.2598	6.86035	-10.2783	27.4658
3.65	10.6689	-10.9375	15.2588	1.68457
3.85	9.61914	-18.6768	10.7422	-2.44E-02
4	-18.3594	-27.0752	-0.70801	34.5459

**Table 3.58 Different Parameters For Tungsten Carbide Drill**

Exp. No.	POINT ANGLE(deg.)	FEED (mm/rev.)	SPEED(rpm)
27	118	0.2	890



**Fig. 3.37** Graphical representation for feed .2mm/rev., speed 890 rpm and point angle 118°

**Table 3.59** Different value of thrust forces and torque value for tungsten carbide drill

File Type:				
Path	C:\Documents and Settings\STUDENT\Desk\carb,Manual\1\			
File name	1.dwd			
Config ID	1.cfg			
Sampling rate [Hz]:	50			
Measuring time [s]:	2			
Delay time [s]:	0			
Cycle time [s]:	0			
Cycles:	1			
Samples per channel:	751			
Cycle interval:	0			
Channel enabled:	1	1	1	1
Cycle No:	1			
Time [s]	Fx	Fy	Fz	Ch4
0	5.76172	4.71191	-11.9141	-5.59082
0.1	-17.0654	6.03027	7.20215	-19.2627
0.2	9.05762	5.17578	-5.07813	5.27344
0.4	5.56641	20.7764	3.17383	5.81055

0.6	-2.22168	39.0137	13.2568	0.92773
0.8	-6.12793	37.207	16.6016	-5.85938
1	-12.4756	37.5732	12.6709	-12.1094
1.2	-11.1572	37.9395	6.5918	-17.0898
1.4	-7.00684	32.0313	-2.66113	-15.0879
1.6	0.78125	34.1797	-5.17578	-11.4746
1.8	6.83594	7.78809	-5.81055	-3.51563
2	10.2539	-6.4209	-3.68652	9.00879

### 3.14 SUMMARY OF ALL ABOVE GRAPHS TUNGSTEN CARBIDE GRAPH

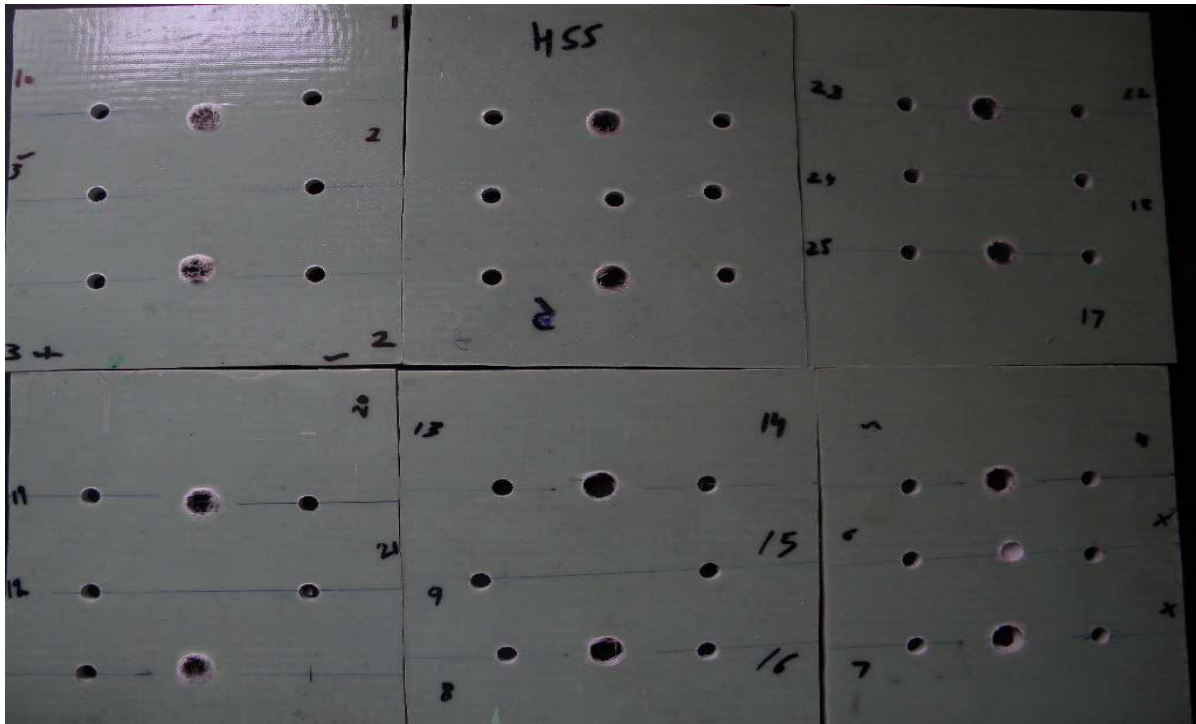
**TABLE 3.60 All values of thrust forces and torque value**

Experiment no.	Thrustforce $F_x(N)$	Thrustforce $F_y(N)$	Thrustforce $F_z(N)$	Torque (Nm)
1	7.9757	30.10	90.712	60.41248
2	-40.94653	10.281704	90.910	70.74962
3	-80.29291	40.511897	10.651	140.5223
4	-50.08791	170.36439	50.807	60.050856
5	-70.70617	-60.67923	110.781	150.4968
6	230.42368	30.756082	140.117	140.71892
7	60.31034	-30.86492	100.184	180.8382
8	-200.9988	40.020284	140.906	210.44267
9	-110.5911	4.8587	190.780	1.89267
10	10.417934	-20.18186	70.144	70.67743
11	60.613834	20.156034	60.628	5.21104
12	-50.42544	40.521306	20.535	80.452537

13	-20.60156	50.271958	50.781	30.315657
14	40.085044	-40.05176	40.093	30.840661
15	7.7479	9.43271	20.484	3.08909
16	-70.07178	-30.07069	20.943	90.62087
17	-4.3339	-70.38	10.965	20.800339
18	-80.12989	-90.24088	150.327	10.96096
19	-50.57668	130.11585	60.880	8.29364
20	-80.45074	100.32325	20.657	80.71381
21	90.30526	90.994301	40.768	50.171014
22	70.419613	140.25062	25.678	90.139791
23	50.925087	150.65852	60.678	20.035357
24	-30.93438	100.52278	90.789	70.896414
25	-20.20351	110.5072	120.679	80.02236
26	-20.02592	210.19641	122.657	140.51439
27	-0.70777	250.86054	130.987	50.17119

### 3.15 Experimental results of thrust forces and torque values for HSS drill

According to designed experiment by Taguchi design the experiment was performed for finding the values of thrust forces and torque values. Tungsten carbide drill bit is used for experiment, below is the composition shown for carbide drill bit.



**Fig. 3.38 Specimens drilled with hss twist drill**

**Table 3.61 All values of thrust forces and torque value**

Experiment no.	Thrustforce $F_x(N)$	Thrustforce $F_y(N)$	Thrustforce $F_z(N)$	Torque (Nm)
1	70.76216	90.2281	40.138	50.65919
2	20.26738	130.9598	50.983	10.157551
3	20.529167	90.387247	10.961	80.893208
4	10.933869	30.098522	10.594	10.59242
5	10.894059	8.3874	50.803	30.743227
6	30.713989	80.161929	20.928	10.921082
7	20.456942	40.16852	25.474	40.88836
8	80.308293	60.40118	15.584	30.140963

9	20.134487	130.6428	6.324	8.435
10	8.93322	160.85199	10.475	8.0198
11	60.550829	10.082357	10.379	8.93019
12	40.45471	90.157301	60.954	10.949152
13	40.067865	8.4039	9.267	20.35235
14	7.6388	50.65491	70.110	30.15094
15	20.11246	60.974715	6.104	20.91684
16	20.746954	20.82685	30.494	40.642001
17	10.355561	90.974895	10.858	50.4641
18	50.857159	2.2234	35.495	30.067295
19	10.637784	280.84947	7.672	30.72572
20	40.124063	240.06374	10.474	30.65057
21	20.273022	130.3944	10.433	70.36486
22	40.49105	40.869187	20.485	30.224927
23	40.29199	50.12696	30.066	80.789058
24	40.31101	100.19479	32.948	2.04307
25	80.345948	30.06399	30.494	8.84399
26	20.27865	120.13495	50.485	7.6846
27	9.509	50.383948	58.485	20.912984

### 3.16 Experimental results of thrust forces and torque values for M50 drill

According to designed experiment by Taguchi design the experiment was performed for finding the values of thrust forces and torque values. Tungsten carbide drill bit is used for experiment, below is the composition shown for carbide drill bit.



**Fig.3.39 Specimens drilled with M50 twist drill**

**Table 3.62 All values of thrust forces and torque value**

Exp. No.	Thrust forces (Fx)(N)	Thrust forces (Fy)(N)	Thrust forces (Fz) (N)	Torque (N/m)
1	8.91696	30.95619	20.30541	30.9664
2	30.52373	10.87133	7.59322	30.04818
3	10.88093	110.89229	10.954933	20.795167
4	20.85547	60.460393	20.634838	20.15948
5	30.383004	60.0954	20.65538	30.866958
6	40.20917	80.809427	20.790492	20.626768

7	2.59554	10.9172	4.9042	20.733362
8	20.06399	30.077734	60.705266	2.34757
9	5.4784	10.305024	40.333236	30.94209
10	60.874526	150.41597	50.74527	10.63207
11	10.38588	60.05036	40.80336	30.352185
12	40.629421	70.822585	20.189406	30.57308
13	20.550239	60.630464	20.964669	20.97657
14	10.23403	40.297824	50.009279	10.58678
15	60.411759	130.27223	50.54303	8.0451
16	70.79705	140.1908	1.3482	60.143381
17	6.4128	170.17438	60.956444	10.01366
18	60.688761	280.67873	10.21637	20.99497
19	20.056368	70.231735	2.82742	10.71215
20	30.01564	80.46675	10.98043	3.7419
21	10.500317	160.87026	10.65035	10.43605
22	2.7145	4.54255	10.295199	20.92453
23	20.167691	30.863107	20.00557	3.9608
24	10.91058	90.181613	40.188886	6.6374
25	10.68656	20.031244	50.47675	7.1217
26	20.684417	160.72494	59.8655	30.145678
27	40.042692	180.50361	70.7916	40.79767

**CHAPTER-4**  
**MATHEMATICAL MODELING**

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## 4.1 Introduction

The cutting forces and torque exerted by the cutting tool on the work piece during a machining action to be identified in order to determine the hole quality. Modeling of cutting force and torque in drilling is often needed in machining automation. The objective of this study is to predict the effects of cutting parameters on the variations of cutting forces and torque during drilling operation of Glass fiber reinforced plastic. Cutting forces and torque are measured by varying feed rates, cutting speed and point angle. The average cutting forces are determined at different feed rates in tangential, radial, and axial directions. A comparison between modeling and experiment is presented. Anova has been performed for different experiments to analyse the value of F-test whether it is increasing or decreasing for different factors.

## 4.2 Taguchi Method

Taguchi method is a scientifically disciplined mechanism for evaluating and implementing improvements in products, processes, materials, equipment, and facilities. These improvements are aimed at improving the desired characteristics and simultaneously reducing the number of defects by studying the key variables controlling the process and optimizing the procedures or design to yield the best results.

The method is applicable over a wide range of engineering fields that include processes that manufacture raw materials, sub systems, products for professional and consumer markets. In fact, the method can be applied to any process be it engineering fabrication, computer-aided-design, banking and service sectors etc. Taguchi method is useful for 'tuning' a given process for 'best' results.

## 4.3 ANOVA

In statistics, analysis of variance (ANOVA) is a collection of statistical models, and their associated procedures, in which the observed variance is partitioned into components due to different sources of variation. In its simplest form ANOVA provides a statistical test of whether or not the means of several groups are all equal, and therefore generalizes Student's two-sample  $t$ -test to more than two groups. ANOVAs are helpful because they possess a certain advantage over a two-sample  $t$ -test.

The purpose of the statistical analysis of variance (ANOVA) is to investigate which design parameter significantly affects the material removal rate and hardness. Based on the ANOVA, the relative importance of the machining parameters with respect to material removal rate and hardness is investigated to determine more accurately the optimum combination of the machining parameters.

Two types of variations are present in experimental data

1. Within treatment variability

## 2. Observation to observation variability

So ANOVA helps us to compare variabilities within experimental data. In my thesis ANOVA table is made with help of MINITAB 15 software. When performance varies one determines the average loss by statistically averaging the quadratic loss. The average loss is proportional to the mean squared error of Y about its target T. F-distribution as part of the test of statistical significance. Various formulas for ANNOVA are

- Sum of square

$$SS_A = \sum_{i=1}^{K_A} \left( \frac{A_i^2}{n} \right) - \sum_{i=1}^N \frac{Y_i^2}{N}$$

- Total sum of square deviation

$$SS_T = \sum_{i=1}^{K_A} Y_i^2 - \frac{\sum_{i=1}^N Y_i^2}{N}$$

## 4.4 Signal Noise ratio

Noise factors are those that are either too hard or uneconomical to control even though they may cause unwanted variation in performance. It is observed that on target performance usually satisfies the user best, and the target lies under acceptable range of product quality are often inadequate. If Y is the performance characteristic measured on a continuous scale when ideal or target performance is T then according to Taguchi the loss caused L(Y) can be modeled by a quadratic function as shown in equation (1)

$$L(Y) = K(Y - T)^2 \dots \dots \dots (1)$$

The objective of robust design is specific; robust design seeks optimum settings of parameters to achieve a particular target performance value under the most noise condition. Suppose that in a set of statistical experiment one finds a average quality characteristic to be  $\mu$  and standard deviation to be  $\sigma$ . Let desired performance be  $\mu_1$ . Then one make adjustment in design to get performance on target by adjusting value of control factor by multiplying it by the factor. Since on target is goal the loss after adjustment is due to variability remaining from the new standard deviation. Loss after adjustment shown in equation (2)

$$k(\mu_1/\mu)^2 \sigma^2 \dots \dots \dots (2)$$

The factor  $\mu^2/\sigma^2$  reflects the ratio of average performance (which is the signal) and (the variance of performance) the noise. Maximizing or S/N ratio therefore become equivalent to minimizing the loss after adjustment. Finding a correct objective function to maximize in an engineering

design problem is very important. Depending upon the type of response, the following three types of S/N ratios are employed in practice

- In my thesis work Thrust force is considered as smaller is better. Value of thrust force is measured by dynamometer which gives direct reading.
- Torque value is also considered as smaller is better. Torque values are also measured on dynamometer.

#### **4.5 Taguchi Orthogonal Array Design**

Orthogonal array used is L27 (3\*\*3) with three factors taken and number of experiments are 27 for one set. Three sets has been taken for different materials of drill.

Different Interactions AB, AC, BC has been taken for different parameters like point angle, feed rate and speed.

Where

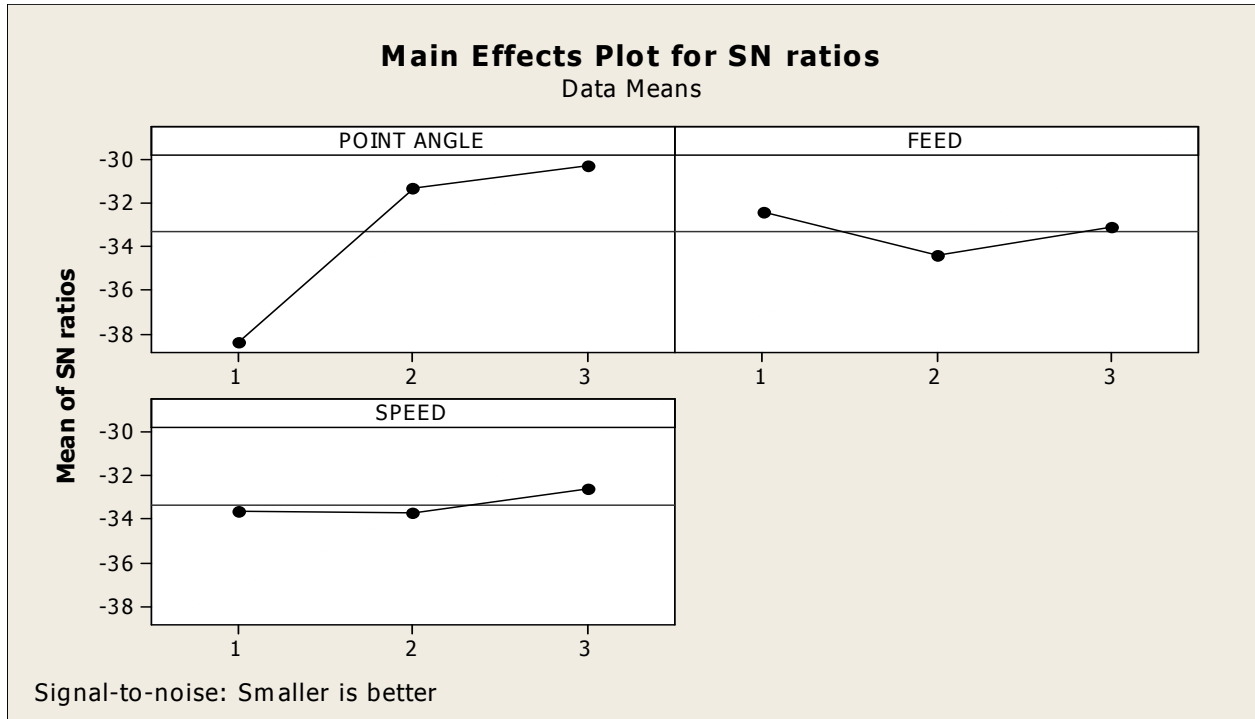
A is considered as point angle,

B is considered as feed rate,

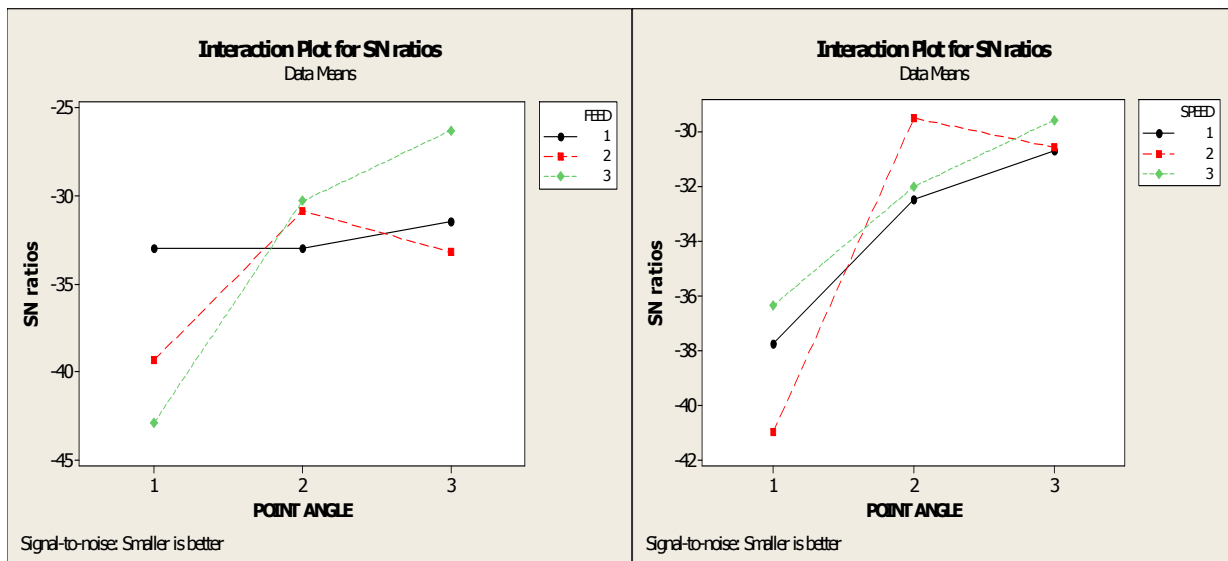
C is considered as speed

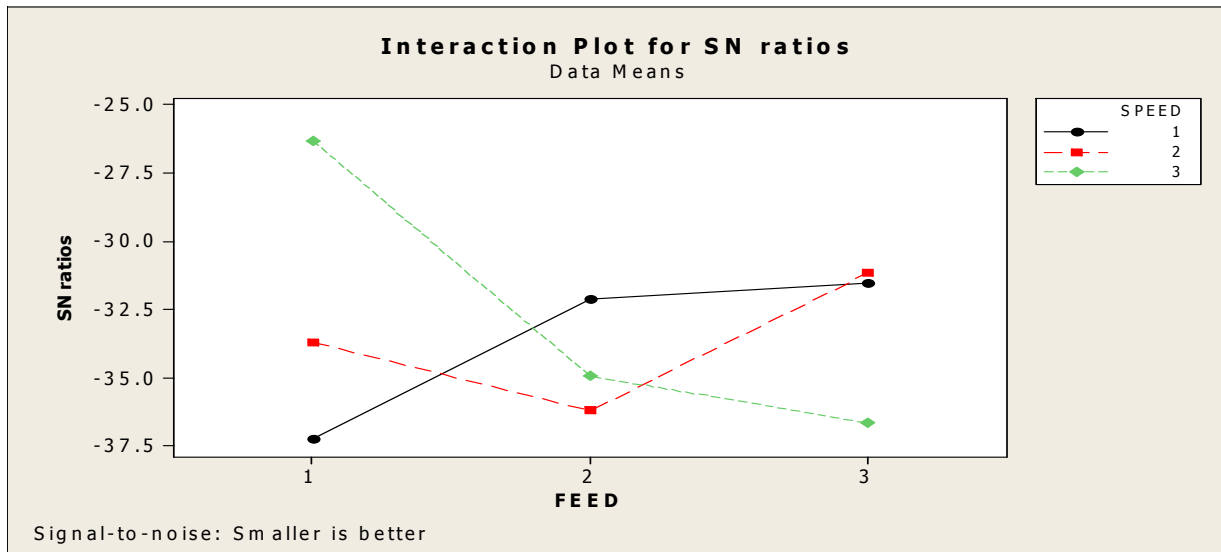
#### **4.6 Minitab results for THRUST FORCES AND TORQUE for Tungsten Carbide**

**For Thrust Forces**



**Graph 4.1 SN ratios for thrust forces of tungsten carbide tool**





**Graph 4.2 SN ratio for interaction of different parameters**

By using Minitab software we obtain some interactions if we look at the graph we will observed that with increase in point angle of twist drill the thrust forces increases but speed does not gives much effect. If we look alone at feed rate then it also does not pt much effect to thrust forces. By looking at graph 2 we will observe that interaction between point angle and feed, point angle and speed increases thrust forces but by looking at interaction between feed and speed, does not put much effect on thrust forces.

**Table 4.1 Estimated Model Coefficients for SN ratios**

Term	Coef	SE Coef	T	P
Constant	-33.325	1.498	-22.242	0.000
point angle 1	-5.0510	2.119	-2.384	0.044
point angle 2	1.9964	2.119	0.942	0.374
feed 1	0.8959	2.119	0.423	0.684
feed 2	-1.1014	2.119	-0.520	0.617
speed 1	-0.3176	2.119	-0.150	0.885
speed 2	-0.3657	2.119	-0.173	0.867
point angle*feed 1 1	4.5259	2.997	1.510	0.169

point angle*feed 1 2	0.1685	2.997	0.056	0.957
point angle*feed 2 1	-2.5049	2.997	-0.836	0.428
point angle *feed 2 2	1.6323	2.997	0.545	0.601
point angle *speed 11	0.9346	2.997	0.312	0.763
point angle *speed 12	-2.2681	2.997	-0.757	0.471
point angle *speed 21	-0.8353	2.997	-0.279	0.788
point angle *speed 22	2.1927	2.997	0.732	0.485
feed*speed 1 1	-4.5040	2.997	-1.503	0.171
feed*speed 1 2	-0.9107	2.997	-0.304	0.769
feed*speed 2 1	2.6063	2.997	0.870	0.410
feed*speed 2 2	-1.4081	2.997	-0.470	0.651

**Table 4.2 Analysis of Variance for T.F**

Source	DF	SS	MS	F	P
point angle	2	21852.1690	10926.0845	5.678	0.041
feed	6	11545.8819	1924.3136	1.223	0.340
speed	18	28329.2484	1573.8471		
Total	26	61727.2992			

By looking at ANOVA Table we will observe that F-Value is large for point angle which also show that it's only the point angle and somewhat feed rate which affecting thrust forces, whereas interaction of both also affects thrust forces.

**Table 4.3 Response Table for Signal to Noise Ratios Smaller is better**

Level	POINT ANGLE	FEED	SPEED
1	-38.38	-32.43	-33.65
2	-31.33	-34.43	-33.69
3	-30.27	-33.12	-32.65
Delta	8.11	2.00	1.05
Rank	1	2	3
Rank	1	2	3

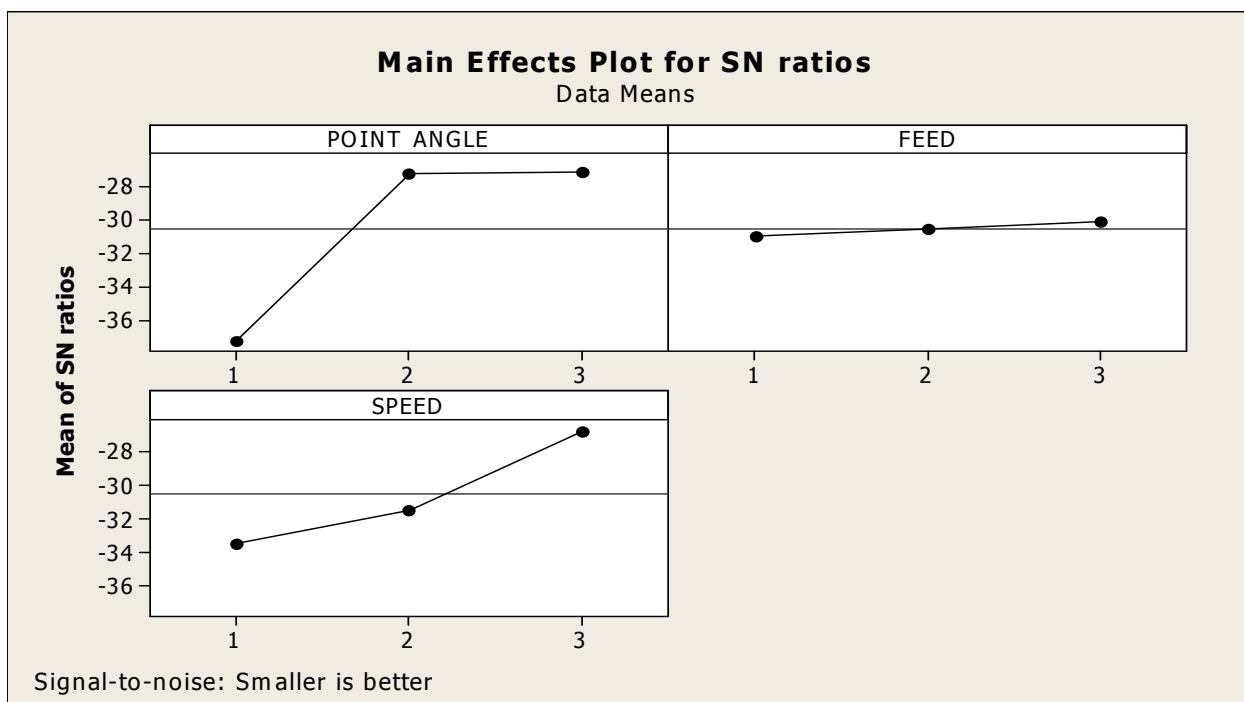
**Table 4.4 Analysis of Variance**

Source	DF	SS	MS	F	P
Regression	3	23103	7701	4.59	0.012
Residual Error	23	38624	1679		
Total	26	61727			

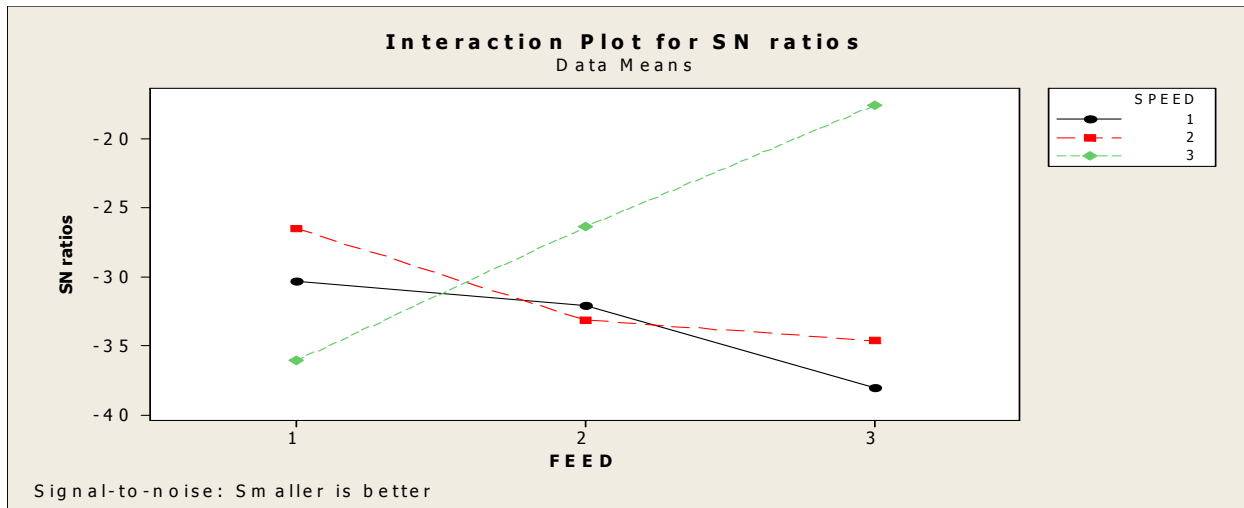
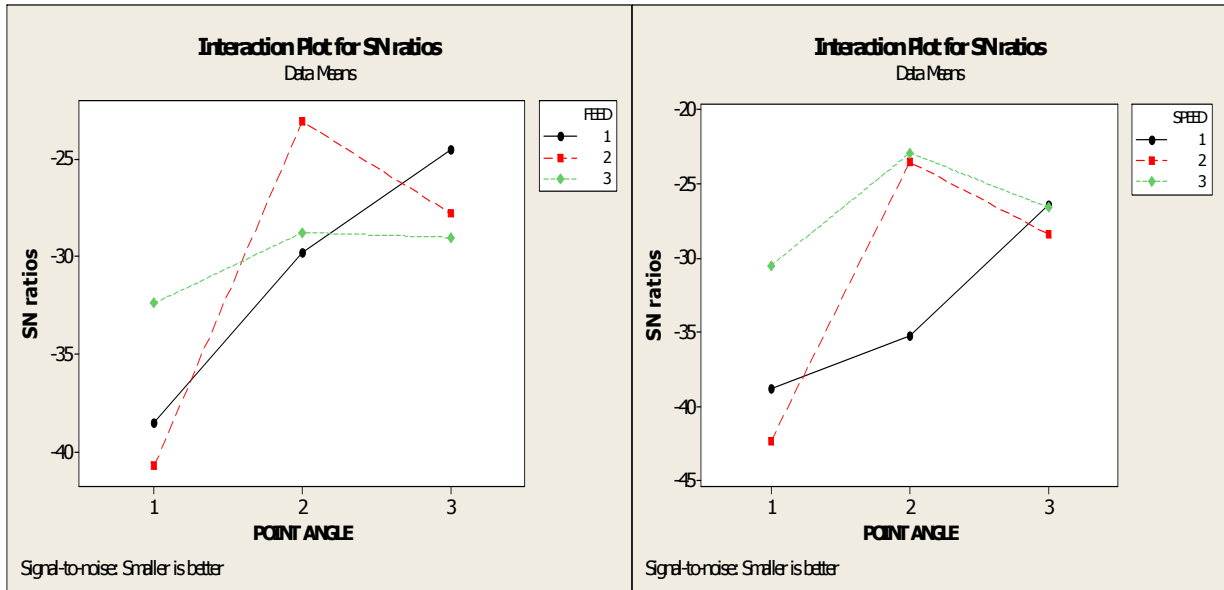
The regression equation is

$$T.F = 88.1 - 32.7 \text{ POINT ANGLE} + 12.0 \text{ FEED} + 8.31 \text{ SPEED}$$

**For Torque values**



**Graph 4.3 SN ratios for torque of tungsten carbide tool**



**Graph 4.4 SN ratio for interaction of different parameters**

By looking at above graphs we observe that alone feed rate does not put any effect on torque while speed has some effect on torque, here also point angle is affecting much to torque. Bt if we look at interaction then we can see with increasing point angle and feed rate or speed affect s to torque value.

**Table 4.5 Estimated Model Coefficients for Means**

Term	Coef	SE Coef	T	P
Constant	58.468	8.874	6.588	0.000
POINT ANGLE1	54.434	12.550	4.337	0.002

POINT ANGLE2	-20.361	12.550	- 1.622	0.143
FEED 1	-4.644	12.550	- 0.370	0.721
FEED 2	-3.821	12.550	- 0.304	0.769
SPEED 1	4.586	12.550	0.365	0.724
SPEED 2	4.807	12.550	0.383	0.712
point angle*feed 1 1	-17.698	17.749	-0.997	0.348
point angle *FEED 1 2	8.007	17.749	0.451	0.664
point angle *FEED 2 1	18.650	17.749	1.051	0.324
point angle *FEED 2 2	-12.871	17.749	- 0.725	0.489
point angle *SPEED 1 1	-17.054	17.749	- 0.961	0.365
point angle *SPEED 1 2	26.186	17.749	1.475	0.178
point angle *SPEED 2 1	21.178	17.749	1.193	0.267
point angle *SPEED 2 2	-23.964	17.749	- 1.350	0.214
FEED*SPEED 1 1	-11.949	17.749	- 0.673	0.520
FEED*SPEED 1 2	-24.866	17.749	- 1.401	0.199
FEED*SPEED 2 1	-17.244	17.749	- 0.972	0.360
FEED*SPEED 2 2	7.670	17.749	0.432	0.677

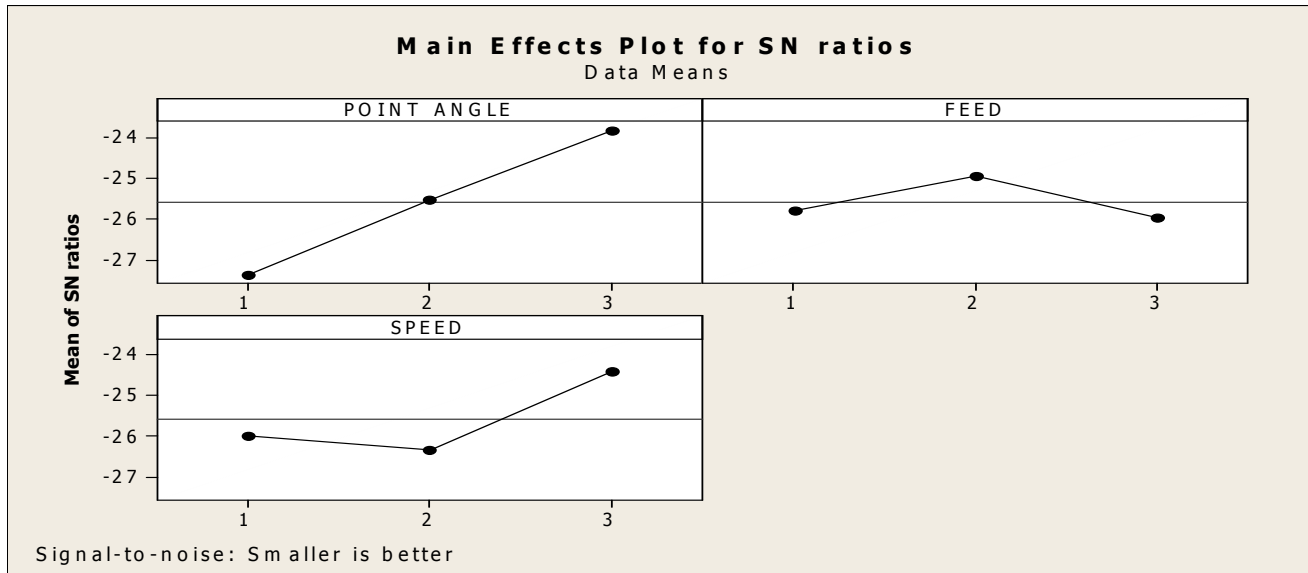
**Table 4.6 Analysis of Variance for Torque**

Source	DF	SS	MS	F	P
POINT ANGLE	2	40847.977	20423.98	29.570	0.001
FEED	6	4144.2350	690.70	0.294	0.932
SPEED	18	42253.443	2347.41		
Total	26	87245.655			

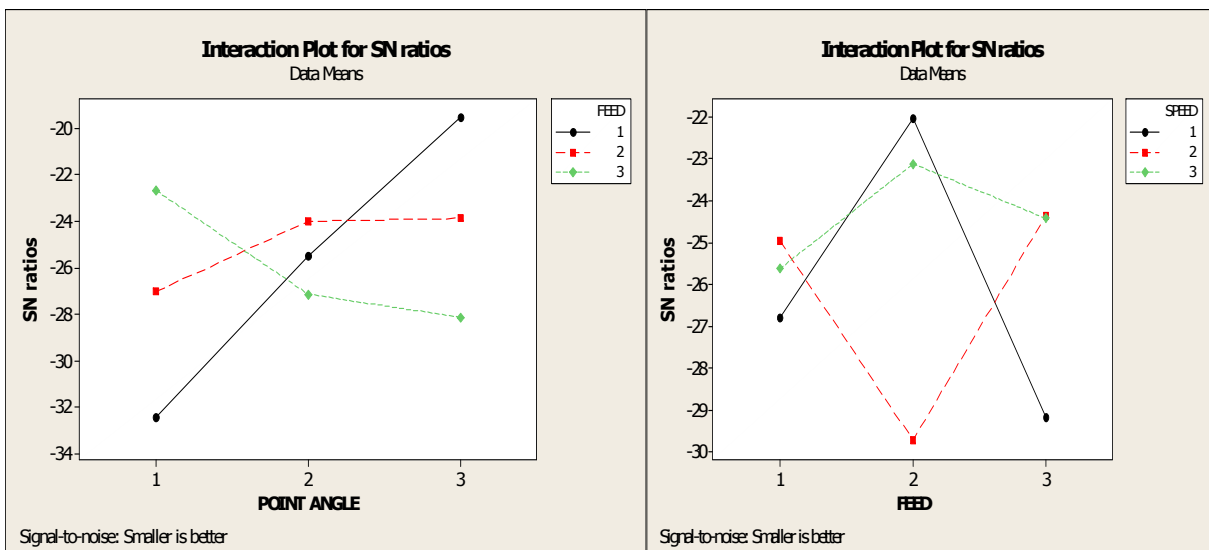
By looking at anova Table we observe that F-value show large value for point angle that's why point angle has much effect on thrust forces. Here F-value for feed rate also shows little value which also shows effect on thrust forces. Hence here again point angle shows the significant result towards thrust forces and torque value.

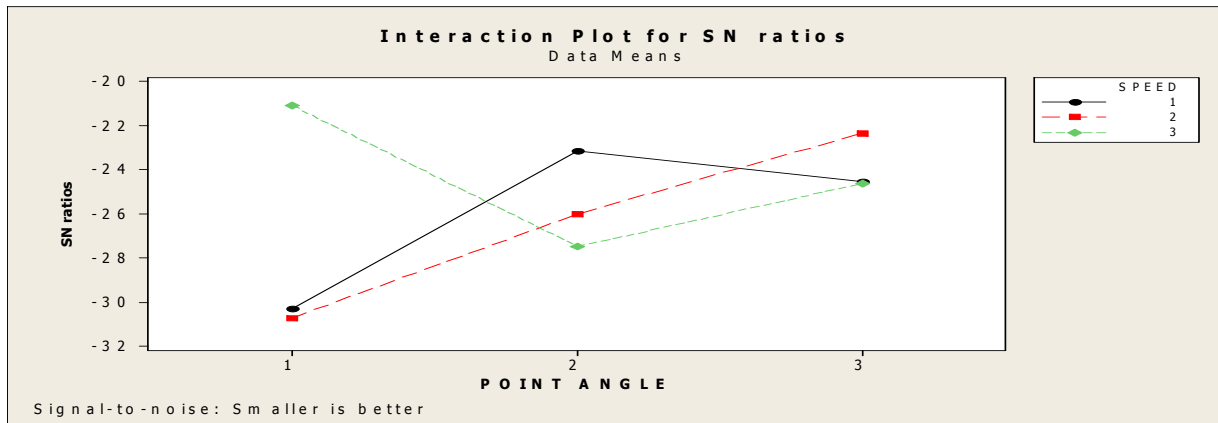
#### 4.7 Minitab results for Thrust Forces And Torque for HSS

##### For Thrust Forces



Graph 4.5 SN ratios for thrust forces of HSS tool





**Graph 4.6 SN ratio for interaction of different parameters**

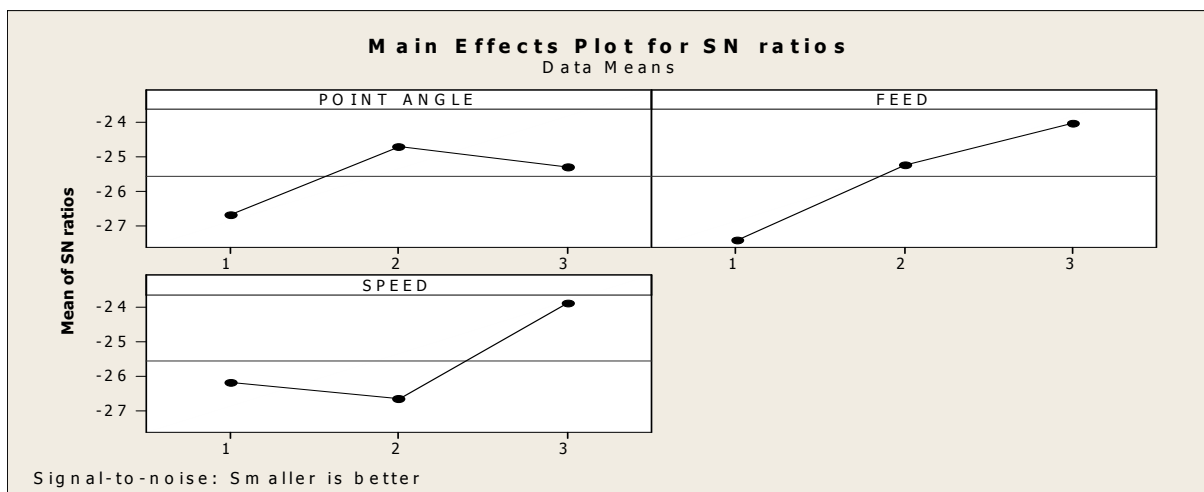
By looking at above graphs we observe that significant effect of point angle on thrust forces is there where as speed and feed does not have much effect as point angle. Interaction of point angle and feed, point angle and speed also have little effect on thrust forces.

**Table 4.7 Analysis of Variance for thrust forces**

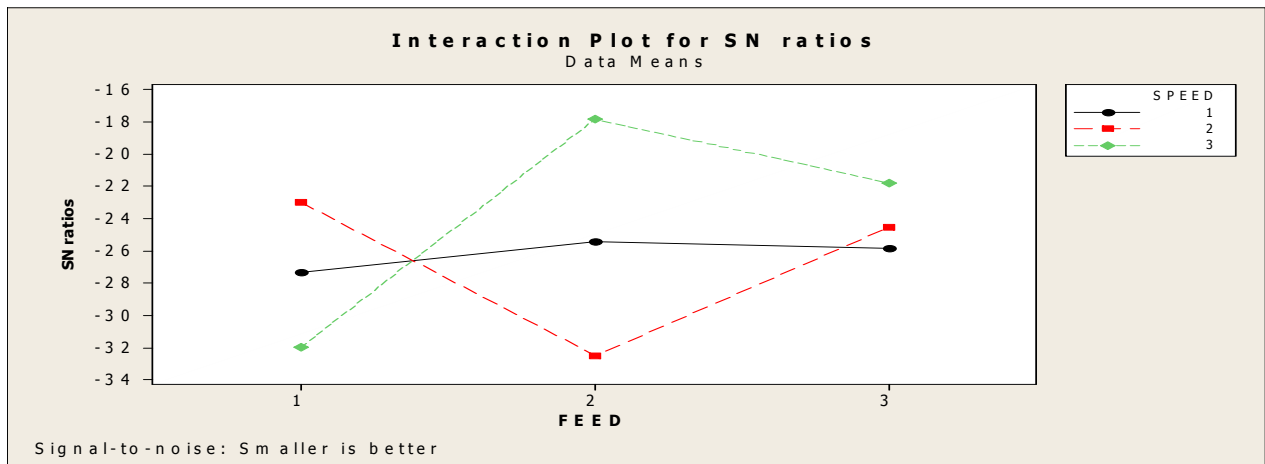
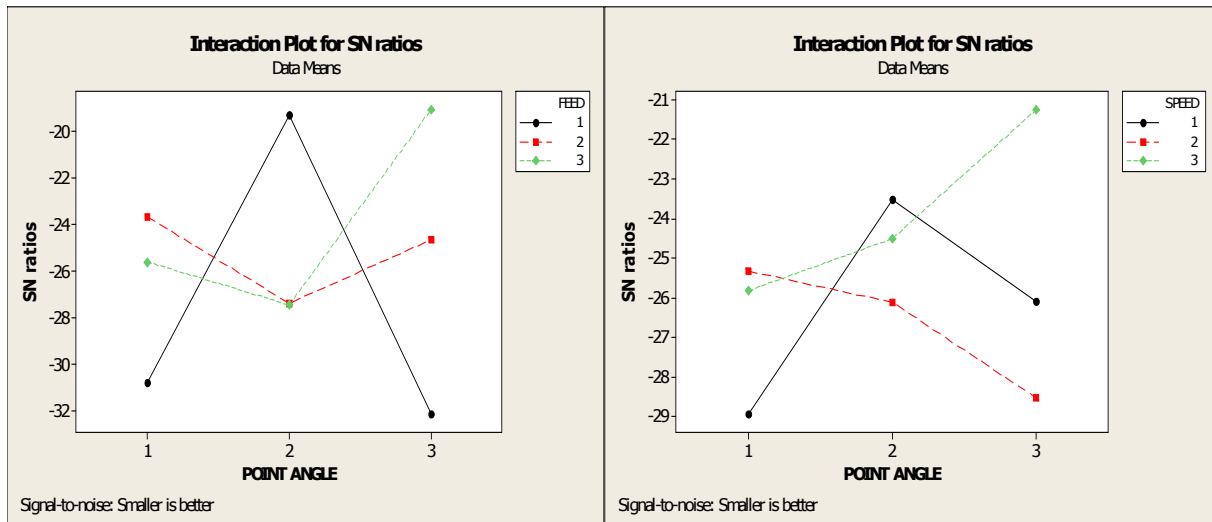
Source	DF	SS	MS	F	P
Point Angle	2	1500.1939	750.0969	1.069	0.401
FEED	6	4211.9417	701.9903	0.954	0.482
SPEED	18	13239.4645	735.5258		
Total	26	18951.6001			

By looking at anova Table we observe that F-value show large value for point angle that's why point angle has much effect on thrust forces. Here F-value for feed rate also shows little value which also shows effect on thrust forces.

**For Torque value**



**Graph 4.7 SN ratios for torque of HSS tool**



**Graph 4.8 SN ratio for interaction of different parameters**

By looking at above graphs we see that point angle does not have much effect as much feed rate, although point angle also has some effect. With increasing feed rate, torque value gets increases whereas interactions of different parameters do not have much effect on torque.

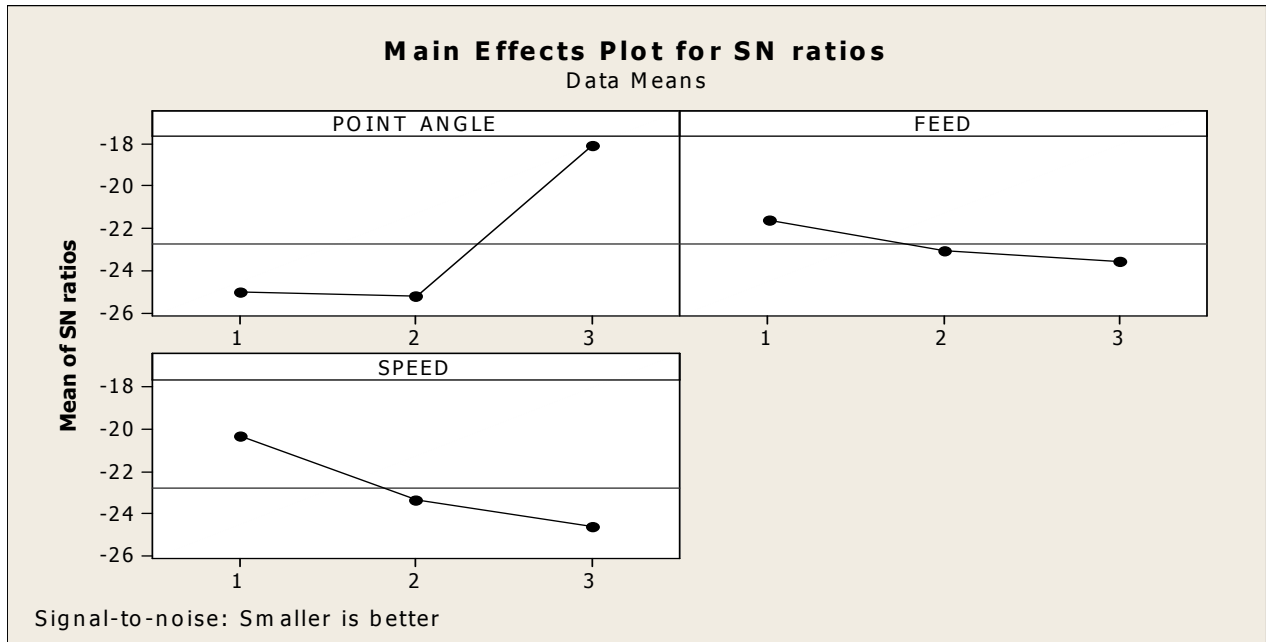
**Table 4.8 Analysis of Variance for torque**

Source	DF	SS	MS	F	P
POINT ANGLE	2	691.9835	345.9918	0.519	0.620
FEED	6	4000.7540	666.7923	1.560	0.216
SPEED	18	7695.6472	427.5360		
Total	26	12388.3847			

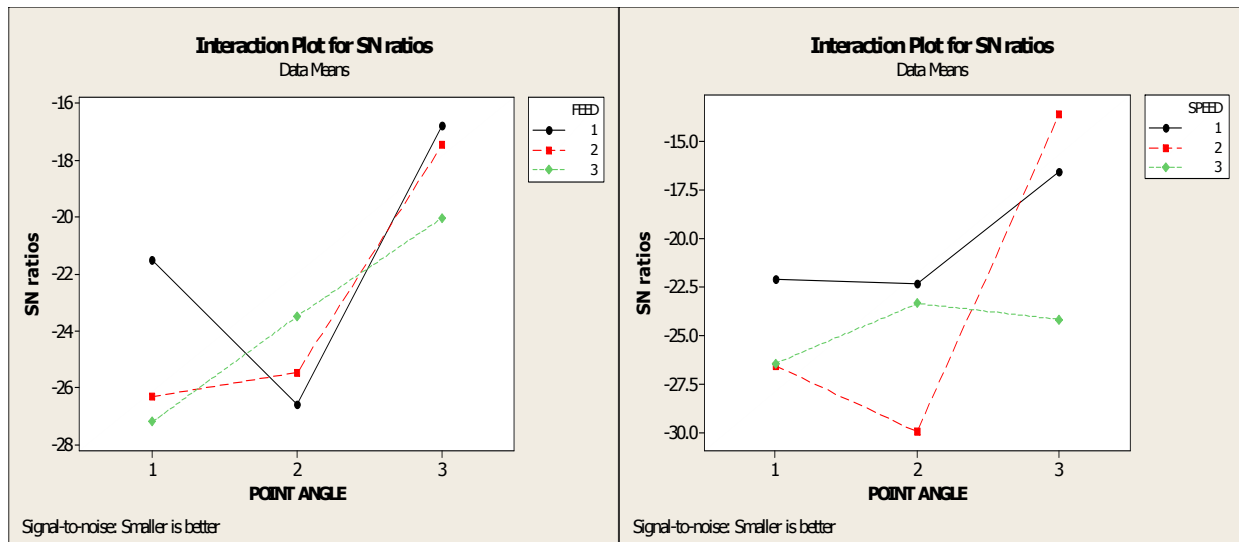
Here anova Table shows that F-value is large for feed but nearly half for point angle which shows that feed rate has large effect on torque value.

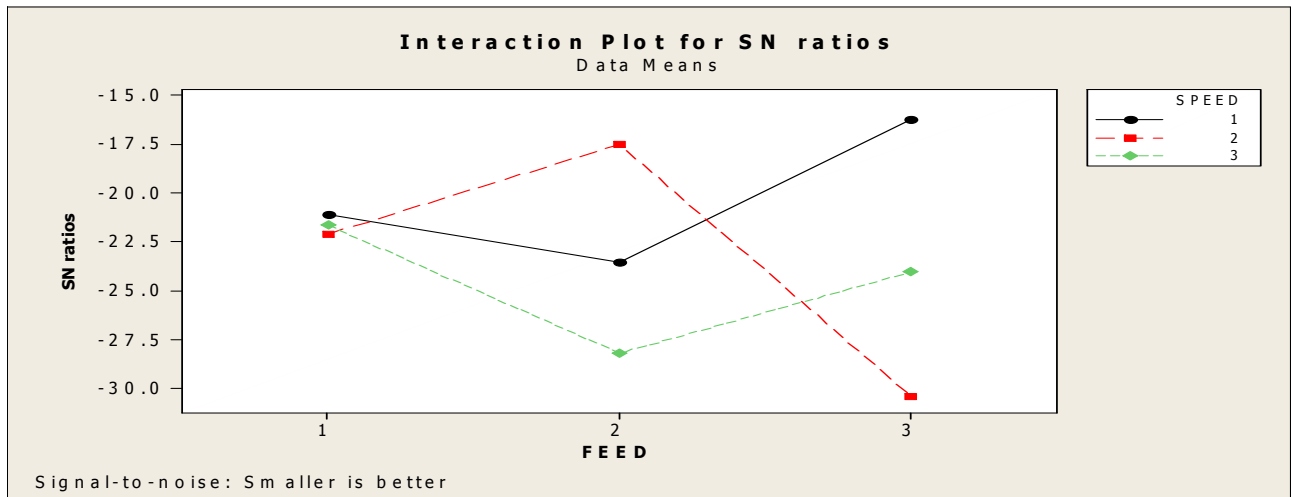
#### 4.8 Minitab results for Thrust Forces And Torque for M50

##### For Thrust Forces



Graph 4.9 SN ratios for thrust forces of M50 tool





**Graph 4.10 SN ratio for interaction of different parameters**

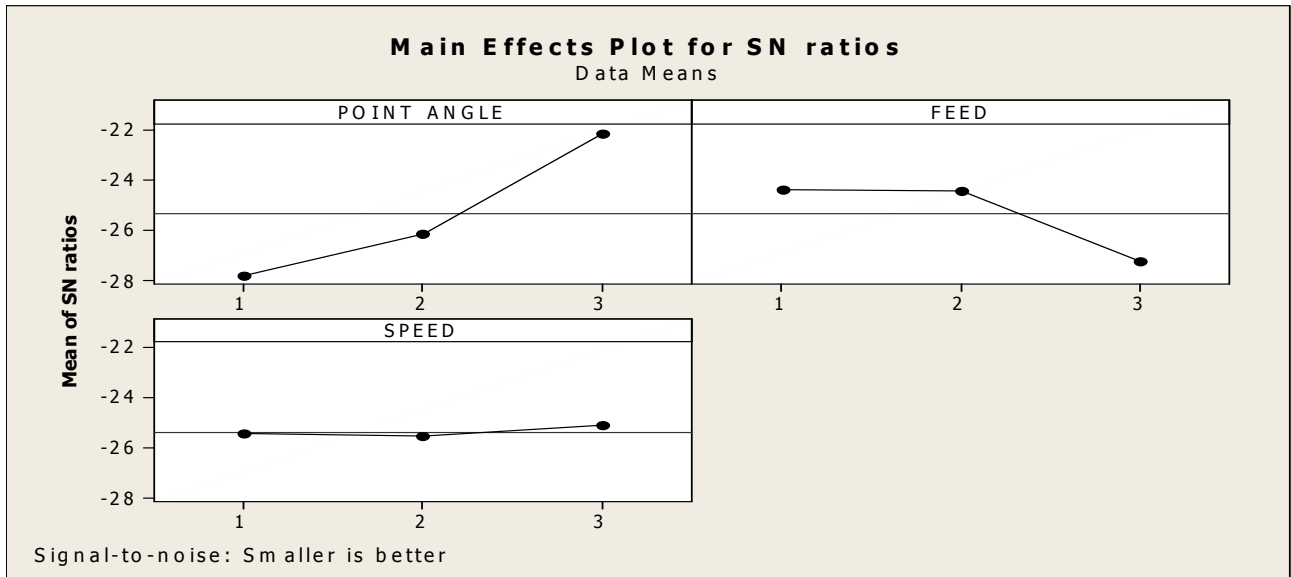
Above graphs shows that interaction of feed rate and point angle has significant effect on thrust forces whereas feed rate alone does not have much effect on thrust forces. Here point angle also have significant effect on forces.

**Table 4.9 Analysis of Variance for Thrust Forces**

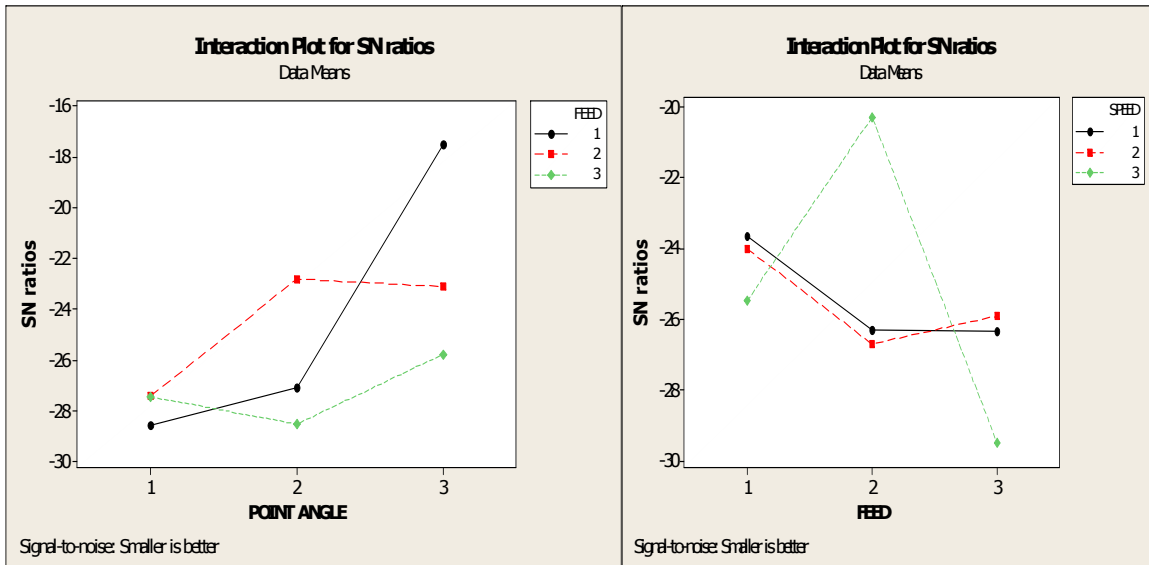
Source	DF	SS	MS	F	P
POINT ANGLE	2	697.8293	348.9147	2.147	0.198
FEED	6	975.1630	162.5272	0.644	0.694
SPEED	18	4540.6374	252.2576		
Total	26	6213.6297			

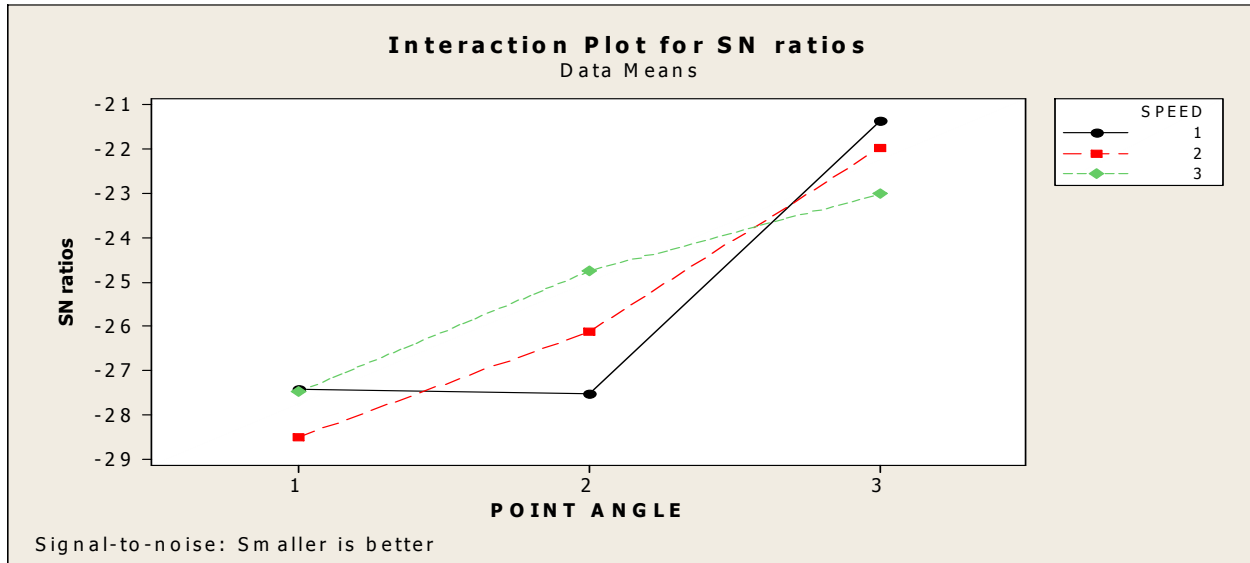
Above anova Table shows that F-value is large for point angle it means that with increase in point angle thrust forces also increases but F-value for feed rate also have less effect on thrust forces.

**For Torque Value**



**Graph 4.11 SN ratios for thrust forces of M50 tool**





**Graph 4.12 SN ratio for interaction of different parameters**

Here in above graph interaction of point angle and speed give significant effect on thrust forces but speed and feed does not put much effect on thrust forces. Interaction of feed and point angle also have little effect on thrust forces but interaction of feed and speed does not put much effect on torque.

**Table 4.10 Analysis of Variance for Torque**

Source	DF	SS	MS	F	P
POINT ANGLE	2	419.5294	209.7647	1.463	0.304
FEED	6	860.2384	143.3731	1.003	0.454
SPEED	18	2574.2382	143.0132		
Total	26	3854.0059			

By looking at anova Table we observe that F-value for point angle has large value that's why it has maximum effect on torque but feed rate also showing significant value of F- test which also show effect on torque value.

Hence it can be seen from above all graphs that with increasing point angle and feed rate, and interactions of two feed rate and point angle the thrust forces and torque value increasing significantly. From the predictions of anova table we can see that F-test value show significant results which show that its only the point angle which effect most to the thrust forces and torque value.

# CHAPTER-5

## FINITE ELEMENT ANALYSIS

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Computer-aided engineering (CAE) is the application of computer software in engineering to evaluate components and assemblies. It encompasses simulation, validation, and optimization of products and manufacturing tools. The primary application of CAE, used in civil, mechanical, aerospace, and electronic engineering, takes the form of FEA alongside computer-aided design (CAD)

### 5.1 Finite element analysis

In general, there are three phases in any computer-aided engineering task

- Pre-processing – defining the finite element model and environmental factors to be applied to it
- Analysis solver – solution of finite element model
- Post-processing of results using visualization tools

#### 5.1.1 Pre-processing

The first step in using FEA, pre-processing, is constructing a finite element model of the structure to be analyzed. The input of a topological description of the structure's geometric features is required in most FEA packages. This can be in either 1D, 2D or 3D form, modeled by line, shape, or surface representation, respectively, although nowadays 3D models are predominantly used. The primary objective of the model is to realistically replicate the important parameters and features of the real model. Once the finite element geometric model has been created, a meshing procedure is used to define and break up the model into small elements. In general, a finite element model is defined by a mesh network, which is made up of the geometric arrangement of elements and nodes. Nodes represent points at which features such as displacements are calculated. FEA packages use node numbers to serve as an identification tool in viewing solutions in structures such as deflections. Elements are bounded by sets of nodes, and define localized mass and stiffness properties of the model. Elements are also defined by mesh numbers, which allow references to be made to corresponding deflections or stresses at specific model locations.

#### 5.1.2 Analysis (computation of solution)

The next stage of the FEA process is analysis. The FEM conducts a series of computational procedures involving applied forces, and the properties of the elements which produce a model solution. Such a structural analysis allows the determination of effects such as deformations, strains, and stresses which are caused by applied structural loads such as force, pressure and gravity.

### **5.1.3 Post-processing (visualization)**

These results can then be studied using visualization tools within the FEA environment to view and to fully identify implications of the analysis. Numerical and graphical tools allow the precise location of data such as stresses and deflections to be identified.

## **5.2 Applications of FEA to the mechanical engineering industry**

A variety of specializations under the umbrella of the mechanical engineering discipline such as aeronautical, biomechanical, and automotive industries all commonly use integrated FEA in design and development of their products. Several modern FEA packages include specific components such as thermal, electromagnetic, fluid, and structural working environments. In a structural simulation FEA helps tremendously in producing stiffness and strength visualizations and also in minimizing weight, materials, and costs. The introduction of FEA has substantially decreased the time taken to take products from concept to the production line. It is primarily through improved initial prototype designs using FEA that testing and development have been accelerated. In summary, the benefits of FEA include increased accuracy, enhanced design and better insight into critical design parameters, virtual prototyping, fewer hardware prototypes, a faster and less expensive design cycle, increased productivity, and increased revenue.

## **5.3 Finite Element Modelling of Drilling**

The finite element method has been a fundamental analysis technique in widespread use in engg. Community. FEM is a computer-based numerical for calculating the strength and behaviour of engg. structures. It can be used to calculate deflection, stress, forces, vibration, buckling behaviour and many other phenomena. It can be used to analyze either small or larg-scale deflection under loading or applied displacement. It can analyse elastic deformation or permanently bent out of shape plastic deformation. In the finite element method, a structure is broken down into many small simple blocks or elements. The behaviour of an individual element can be described with a relatively simple set of equations.

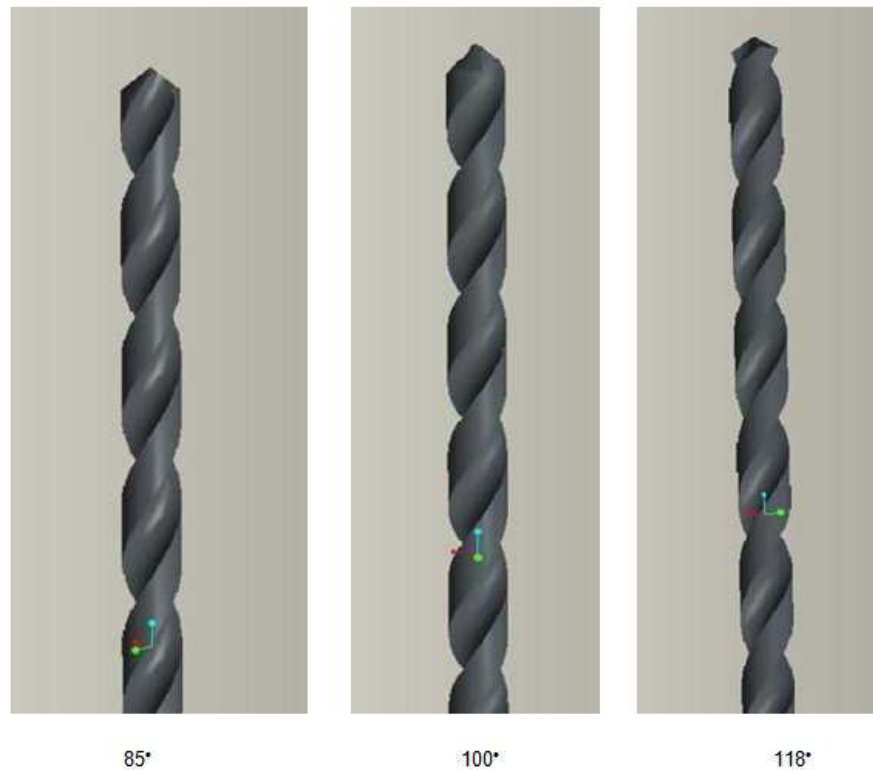
Planning the analysis is arguably the most important part of any analysis,as it helps to ensure the success of simulation. Oddly enough,it is usually the one analysts leave out. The purpose of an FE analysis is to model the behaviour of structure under a system a loads. In order to do so,all influencing factors must be considered and determined whether their effects are considerable or negligible on the final result. This finite modelling of drilling involved a great deal of complexity as the drill being a very complex tool and so is the process and chip geometry. So the pre-processing phase was done considering various parameters from element selection, boundary conditions, material properties and right selection of pre-processor and solver tool.

### **5.3.1 Finite element steps involved in modelling of drill bit**

#### **Drill bit modelling**

Using Pro/engineer, the simple twist drill of different point angle and by taking different materials has been made with drill bit diameter of 6mm then it was converted into IGES(inter graphic exchange system) format which is very common format to exchange data between different softwares.

By taking different point angle like 85,100 and 118 different bits has been modelled in pro-e. If the mesh is too coarse, then the element will not allow a correct solution to be obtained. Alternatively, if the mesh is too fine, the cost of analysis in computing time can be out of proportion to the results obtained. In order to define a relevant mesh, some idea of parameter distributions such as stress,temperature,pressure etc with in the component is required. Here the drill bit was considered to be a rigid body and so shell elements were used for meshing. Then the drill bit and composite plate was taken for meshing both meshed in denser manner. The meshing of workpiece plays a significant role in the simulation.



**Fig. 5.1 Modelling of drill bit with different point angle**

### **5.3.2 Element Definition**

**In this analysis work , Shell 181 was used for composite modelling which include 4node 3D shell element with 6 degrees of freedom at each node. Used for layered applications for modeling laminated composite shells or sandwich construction. (First order shear deformation)**

#### **Layer Definition**

- Total of 255 uniform/non uniform section layers
- Section commands rather than real constants.
- Supports generalized section definition

## Options

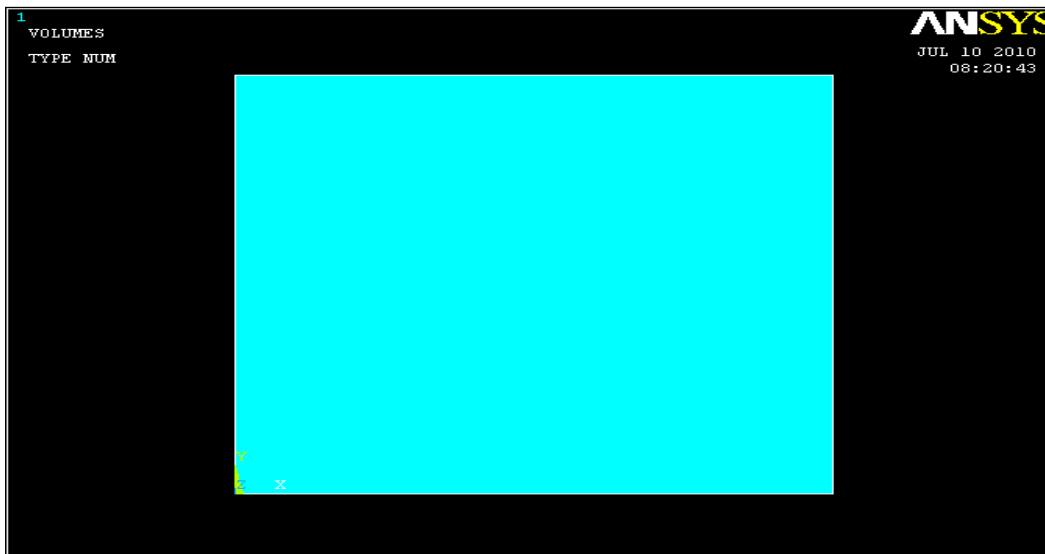
- Full nonlinear capabilities including large strain and material models
- Failure criteria is available via **FC** and other **FC xxx** commands.

## 5.4 Workpiece

After all the steps taken for modelling of drill bit then the modelling of composite sheet with layers upto 10 of lamina. Workpiece of dimension 14\*12 cm with thickness of 5 mm was modelled in ansys 11.0 by using workbench. With having different layers 10 in number and density of 3.2 gm/cm<sup>3</sup>.

**Table 5.1 Different properties of specimen material (GFRP)**

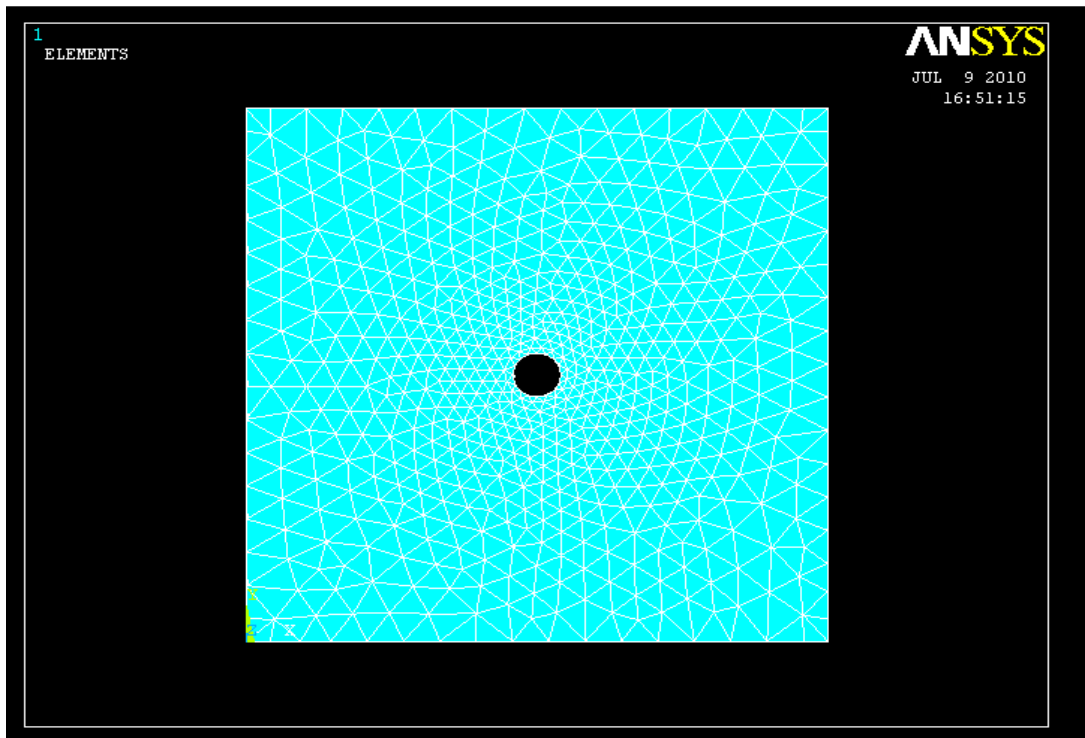
Modulus of elasticity (X-direction)	75 GPa
Allowable tensile stress (X-direction)	560 MPa
Modulus of elasticity (Y-direction)	13 GPa
Bulk modulus	5.0 GPa
Poisson's ratio	0.3
Allowable tensile stress (Y-direction)	37 MPa



**Figure 5.2 Modelling of workpiece with given dimension**

## 5.5 Meshing

Initially constructing the finite element workpiece model the solid elements were used to mesh the workpiece with uniform mesh density all over the workpiece. They had a disadvantage of increasing the computational time. The original mesh of workpiece as shown



**Figure 5.3 Meshing of workpiece**

## 5.6 Boundary conditions

Boundary conditions were simulated according to experimental set-up. The base and top face of the workpiece are constrained in all degree of freedom. The material property of workpiece was given as that of glass fiber reinforced plastic.

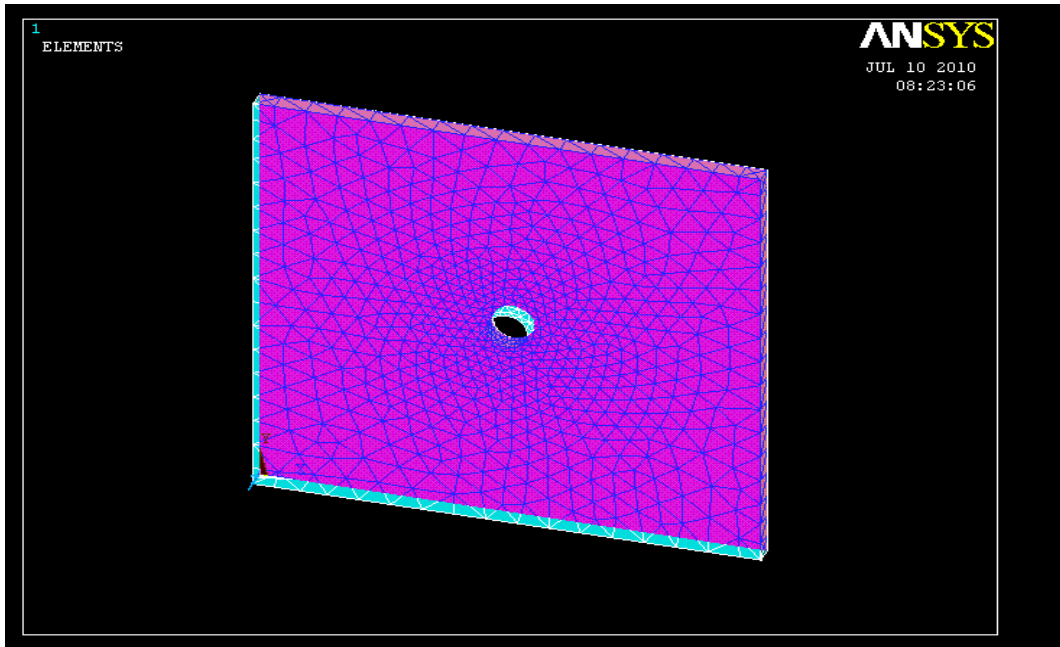


Figure 5.4 Applied boundary condition on workpiece

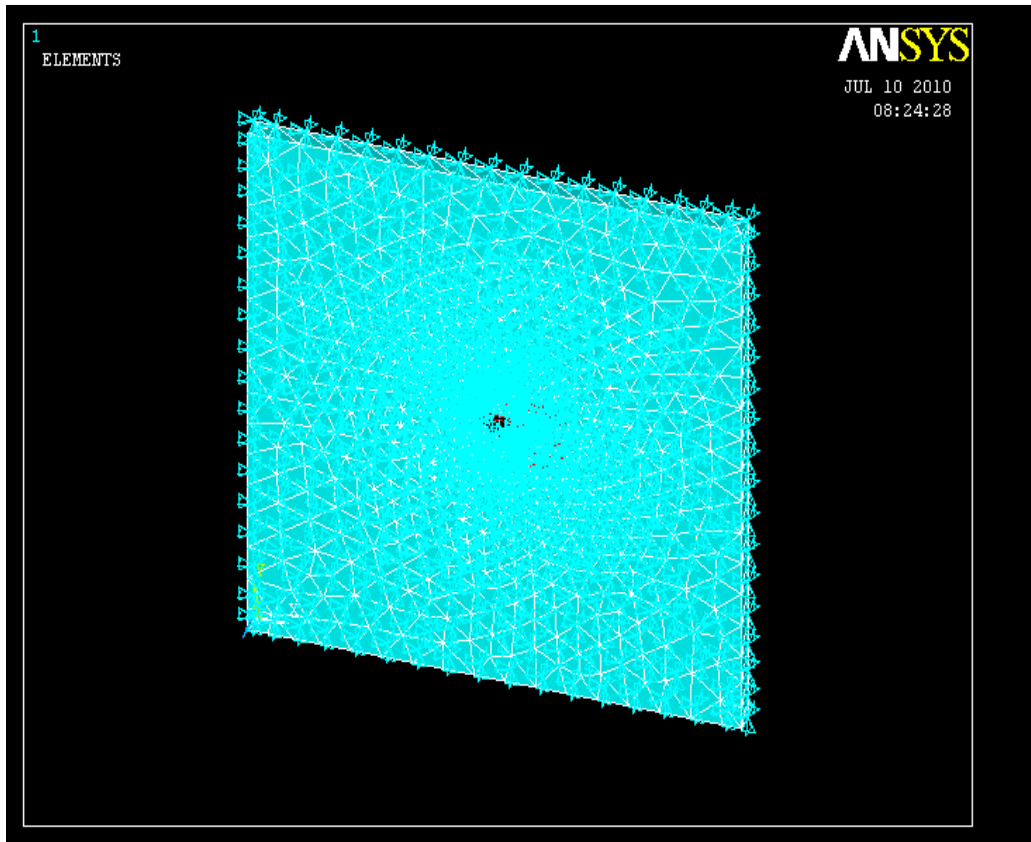
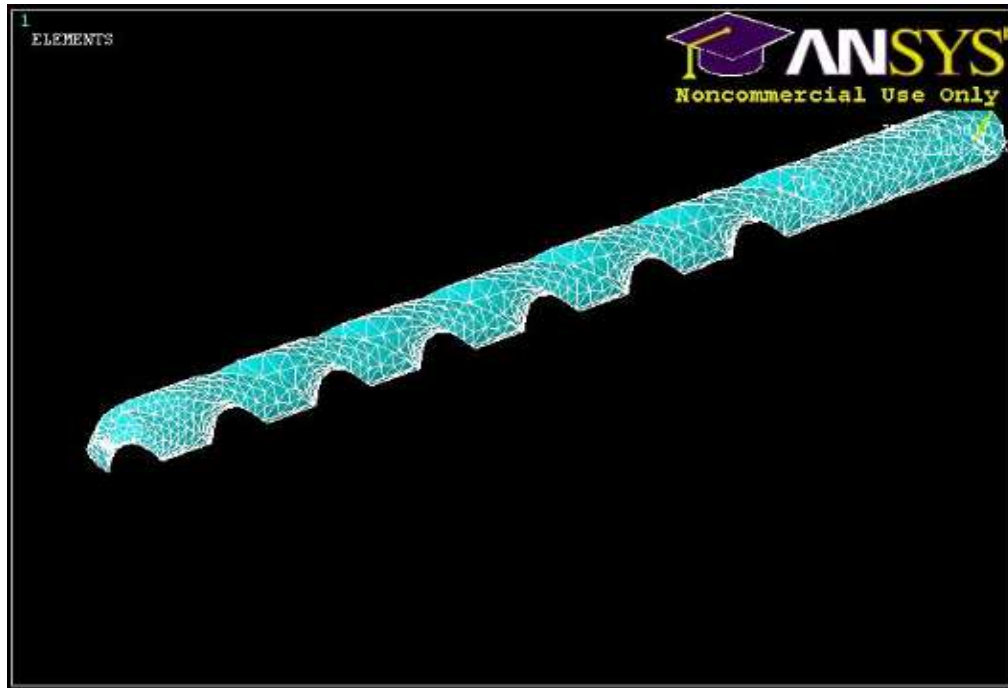


Figure 5.5 Constrained workpiece

## 5.7 Drill meshing

The meshing is the most important factor even in the initiation of chip evolution from the workpiece. With incorrect meshing there would be no chips formed even as the drill proceeds in to the workpiece. Different point angle and different materials of drill has been taken for the ansys.



**Fig. 5.6 Meshing Of Drill**

## 5.8 Layup of composite

As workpiece has 10 layers of glass fiber so appropriate model was constructed for modelling of different layer to make composite lamina. Different properties were given for layup process like orientation, different properties of different layers.

Orientation of different layers can be done by fiber orientation depending on the loading condition. Different fiber sheets can be made according to different loading conditions.

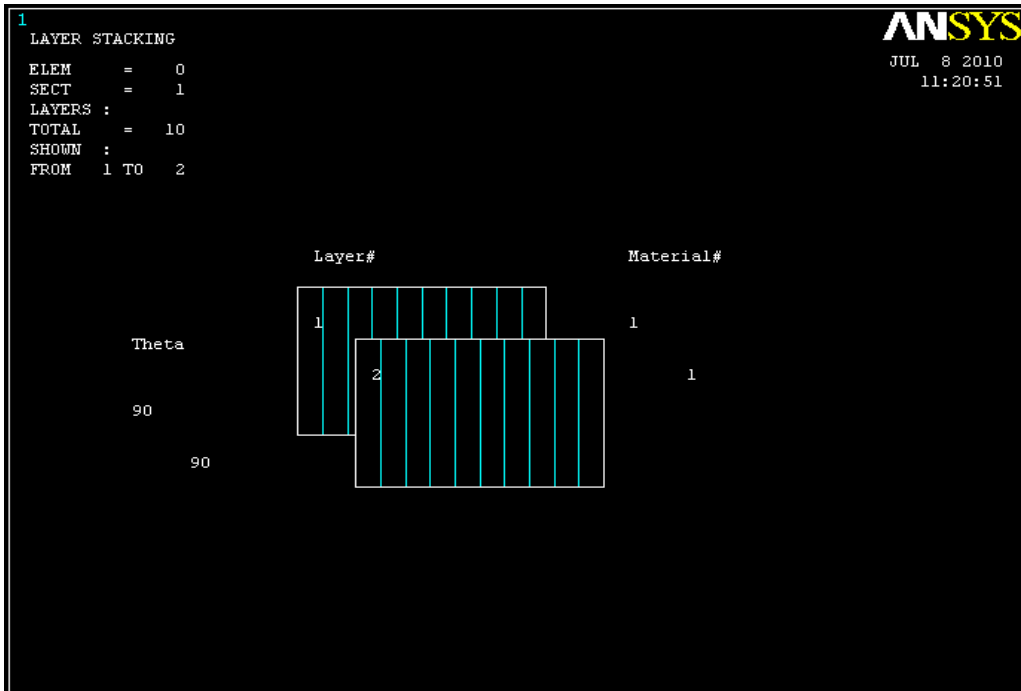


Figure 5.7 Layers of composite glass fiber plastic

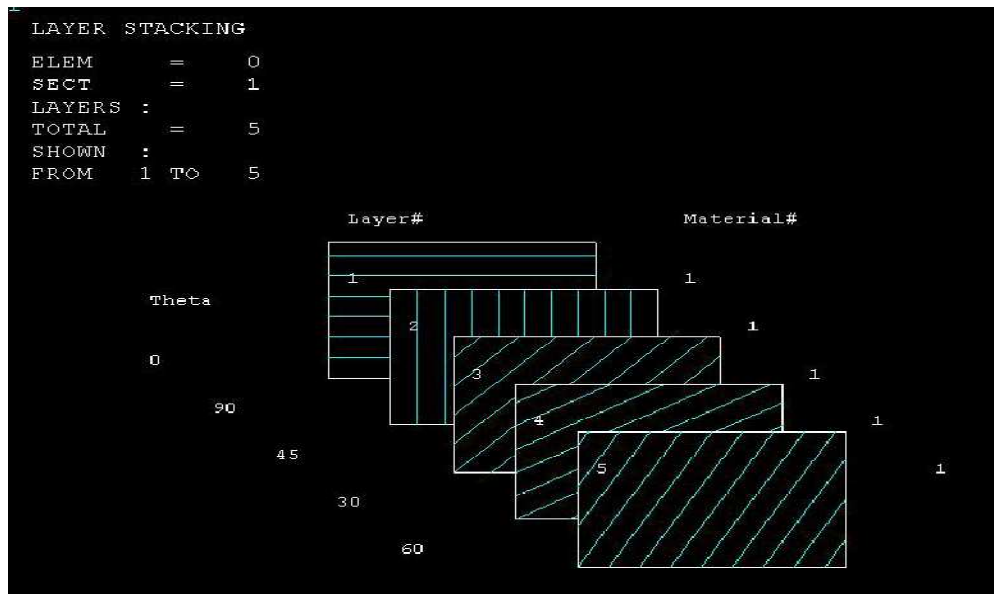
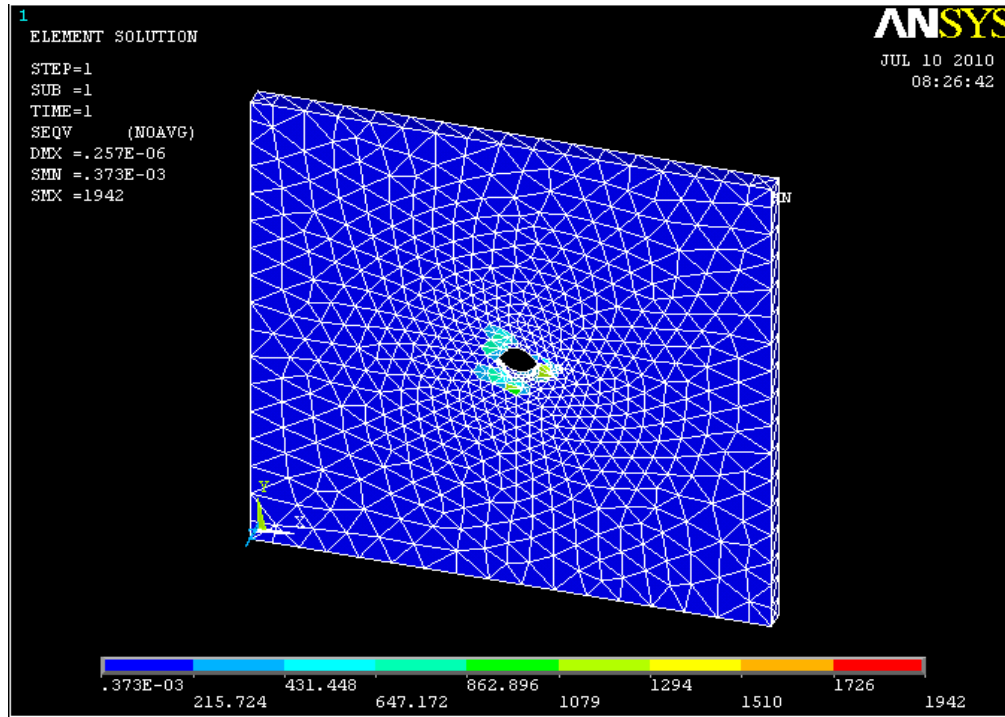


Figure 5.8 Different layers for making one layer of composite

### 5.9 Element solution

Below shown is element solution of the specimen after which failure criteria to be define, Tsai-wu failure criterion was chosen as for composite material. After this nodal solution is to be done for finding results.



**Figure 5.9 Elemental solution for analysing**

### 5.10 Failure criteria

To determine whether a laminate will fail due to applied loading, the program first calculates stresses across the different plies. It next applies a failure criterion based on these stress levels using a failure theory. A laminate is considered to fail when a first ply or a first group of plies fails.

Failure of composites occurs in multiple steps. When stress in the first ply or a first group of plies is high enough, it fails. This point of failure is the first ply failure (FPF) beyond which a laminate can still carry the load. For a safe design, laminates should not experience stress high enough to cause FPF. The point where the total failure occurs is termed the ultimate laminate failure (ULF). Failure of composites occurs on a micromechanical scale due to fiber damage, matrix cracking, or interface or interphase failure. These local failure modes cannot predict global laminate failure satisfactorily.

There are three theories available for laminate failure criteria are:

- Tsai-Hill Failure Criterion
- Tsai-Wu Failure Criterion
- Maximum Stress Criterion

In this work , Tsai-Wu Failure Criterion is applied for analysis of drilled damaged hole.

### **Tsai-Wu failure criterion**

The Tsai-Wu criterion is applied to composite shells. The Tsai-Wu failure criterion is a phenomenological failure theory which is widely used for anisotropic composite materials which have different strengths in tension and compression. This failure criterion is a specialization of the general quadratic failure criterion proposed by Gol'denblat and Kopnov and can be expressed in the form

$$F = F_1 \times S_{XX} + F_2 \times S_{YY} + F_3 \times S_{ZZ} + F_{11} \times S_{XX}^2 + F_{22} \times S_{YY}^2 + F_{33} \times S_{ZZ}^2 + F_{12} \times S_{XX} \times S_{YY} + F_{13} \times S_{XX} \times S_{ZZ} + F_{23} \times S_{YY} \times S_{ZZ} + F_{44} \times S_{YZ}^2 + F_{55} \times S_{XZ}^2 + F_{66} \times S_{XY}^2$$

where

$$\begin{aligned} F_1 &= (1/F_{Xt}) - (1/F_{Xc}), & F_2 &= (1/F_{Yt}) - (1/F_{Yc}), \\ F_3 &= (1/F_{Zt}) - (1/F_{Zc}), & F_{11} &= (1/F_{Xc}) \times F_{Xt}, \\ F_{22} &= (1/F_{Yt}) \times F_{Yc}, & F_{33} &= (1/F_{Zt}) \times F_{Zc}, \\ F_{44} &= (1/F_{SYZ})^2, & F_{55} &= (1/F_{SXZ})^2, & F_{66} &= (1/F_{SXY})^2 \end{aligned}$$

Here  $S_{XX}$ ,  $S_{YY}$ ,  $S_{ZZ}$  are the stress components in X, Y, Z directions.  $S_{XY}$ ,  $S_{YZ}$ ,  $S_{XZ}$  are the inter-laminar shear stresses.  $F_{Xt}$ ,  $F_{Xc}$  are the X-direction tensile and compressive failure stress, respectively.  $F_{Yt}$ ,  $F_{Yc}$  are the Y-direction tensile and compressive failure stress, respectively.  $F_{Zt}$ ,  $F_{Zc}$  are the Z-direction tensile and compressive failure stress, respectively.  $F_{SXZ}$ ,  $F_{SYZ}$ ,  $F_{SXY}$  are the shear failure stresses.

$F_{12}$ ,  $F_{23}$ ,  $F_{13}$  are determined by biaxial tests. When the value of the function reaches unity, failure of the composite material under combined loading is predicted.

This criterion considers the total strain energy (both distortion energy and dilatation energy) for predicting failure. It is more general than the Tsai-Hill failure criterion because it distinguishes between compressive and tensile failure strengths. For a 2D state of plane stress ( $\sigma_3 = 0$ ,  $\tau_{13} = 0$ ,  $\tau_{23} = 0$ ) that is assumed for the composite shells, the failure index is computed.

The program reports the factor of safety (FOS) as  $1 / (F.I.)$ . The FOS should be greater than 1 for laminates to be safe. The maximum stress and the maximum strain failure criterion represent the material failure in the principal direction only. The Tsai Wu Failure criteria take into account the interaction of the stress components in all directions. In this work, this criterion has been applied for finding the damage around the hole drilled with different drills. Therefore, it is a more realistic approach to predict failure than the maximum stress and strain theories.

## 5.11 Results of Ansys by Taking Drill Bit of Tungsten Carbide

### 5.11.1 Drill point angle 118°

After applying different element conditions and meshing steps the below shown results are shown for tungsten carbide drill. After applying Tsai-wu failure criterion we get the results below shown.

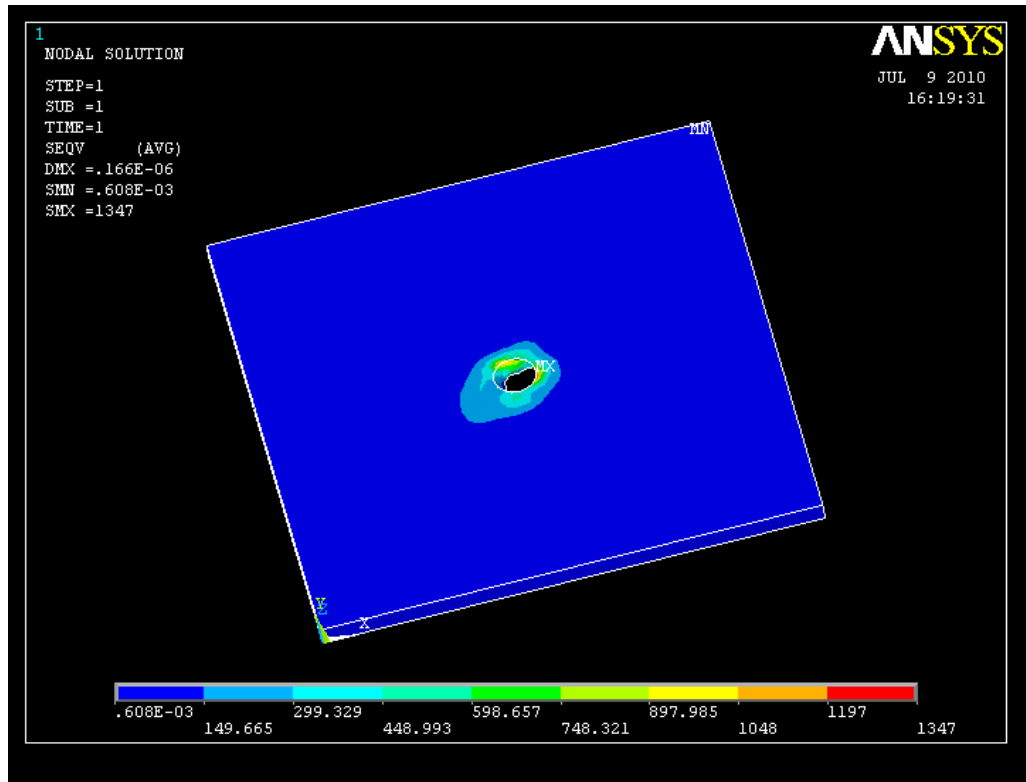


Figure 5.10 Drilled hole with 118° point angle by tungsten carbide drill

### 5.11.2 Drill point angle 100°

After applying different element conditions and meshing steps the below shown results are shown for tungsten carbide drill. After applying Tsai-wu failure criterion we get the results below shown.

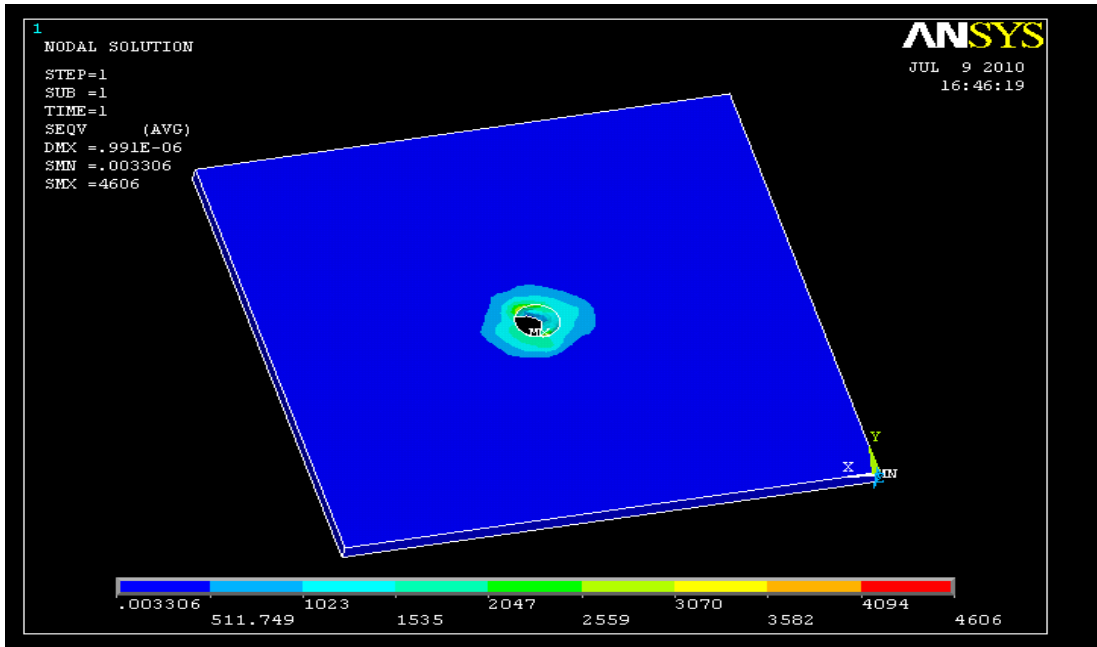


Figure 5.11 Drilled hole with 100° point angle tungsten carbide drill

### 5.11.3 Drill point angle 85°

After applying different element conditions and meshing steps the below shown results are shown for tungsten carbide drill. After applying Tsai-wu failure criterion we get the results below shown.

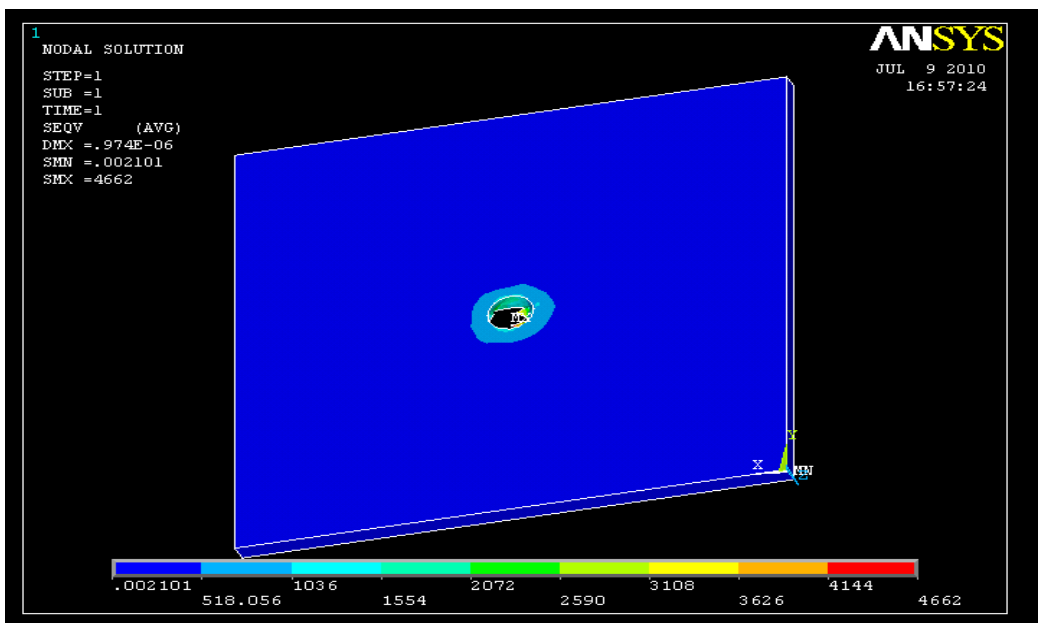
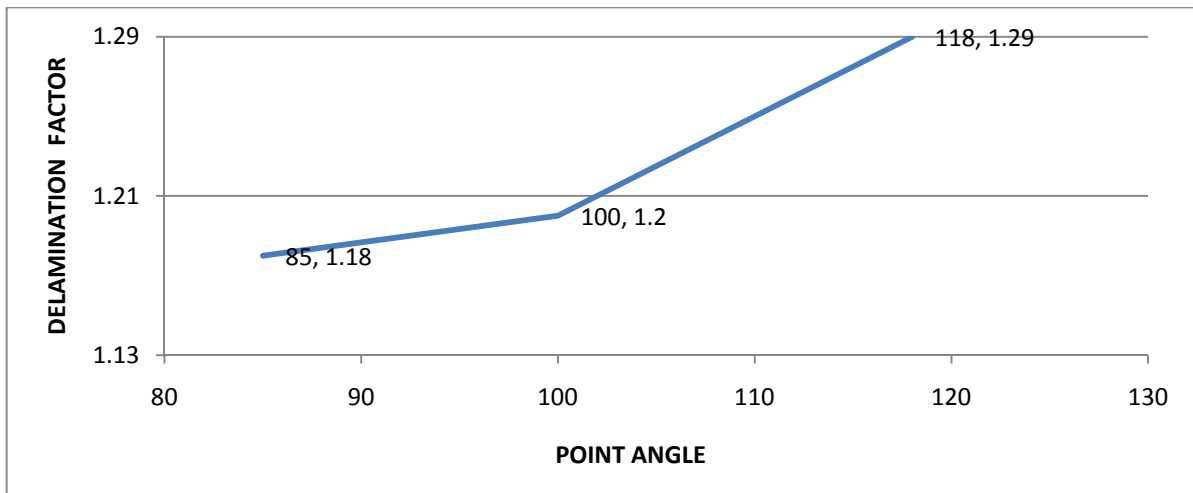


Figure 5.12 Drilled hole with 85° point angle tungsten carbide drill

Table 5.2 Delamination factor values of drilling GFRP using FEM of tungsten carbide

Drill point angle	118°	100°	85°
Delamination factor	1.24	1.20	1.18



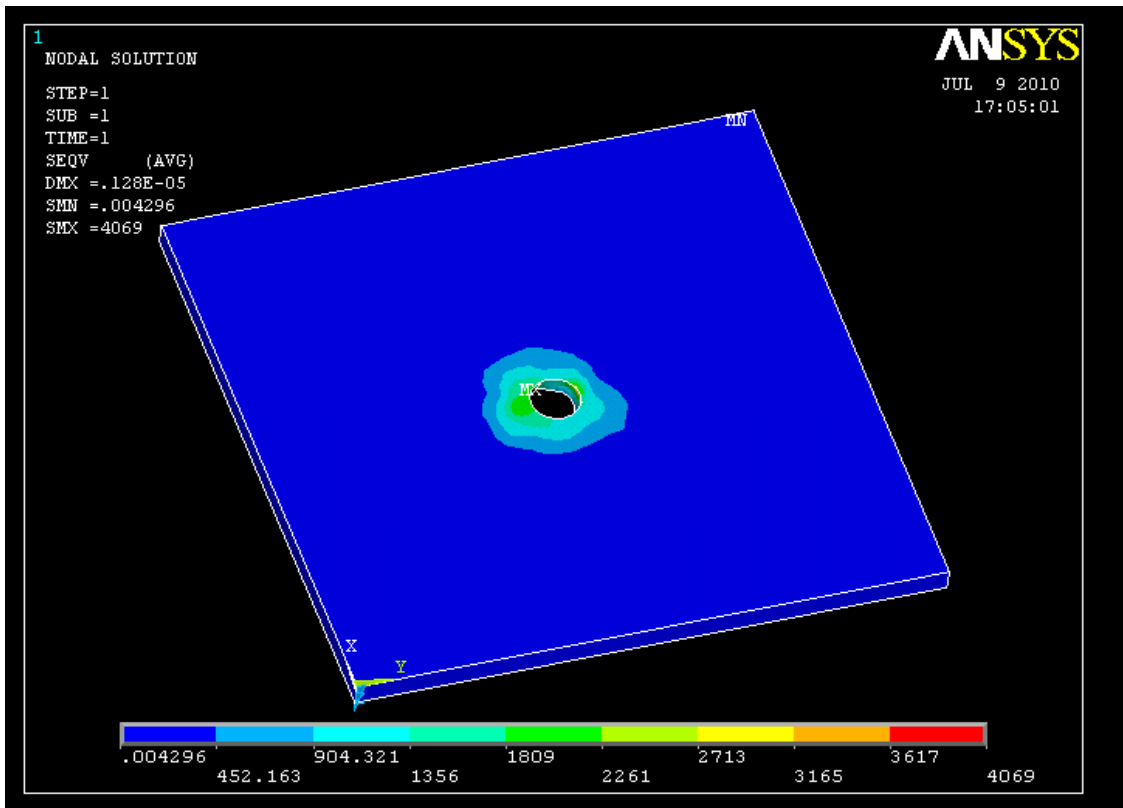
**Graph 5.1 Effect of diff. point angle on delamination factor for tungsten carbide drill**

It can be seen from above analysis with increase in point angle the delamination factor also increasing. As with point angle of 85 the delamination factor is of the range of 1.18 but if we look at point angle of 100 then the delamination factor also increasing of the range 1.2. with point angle of 118 the delamination factor increased by 1.29 which shows the result that with increase in point angle the damage around hole also increasing. Hence the delamination get effected most by increasing point angle.

## 5.12 RESULTS OF ANSYS BY TAKING DRILL BIT OF HSS

### 5.12.1 Drill point angle 118°

After applying different element conditions and meshing steps the below shown results are shown for tungsten carbide drill. After applying Tsai-wu failure criterion we get the results below shown.



**Figure 5.13 Drilled hole with 118° point angle HSS drill**

### 5.12.2 Drill point angle 100°

After applying different element conditions and meshing steps the below shown results are shown for tungsten carbide drill. After applying Tsai-wu failure criterion we get the result shown below.

Here we can observe that when there is change in point angle there is also increase or decrease in damage around the hole. In this case also point angle of 100 make change in damage area while in case of 118 there was more damage.

Hence whenever point angle increase or decrease there may be seen of damage area around the hole.

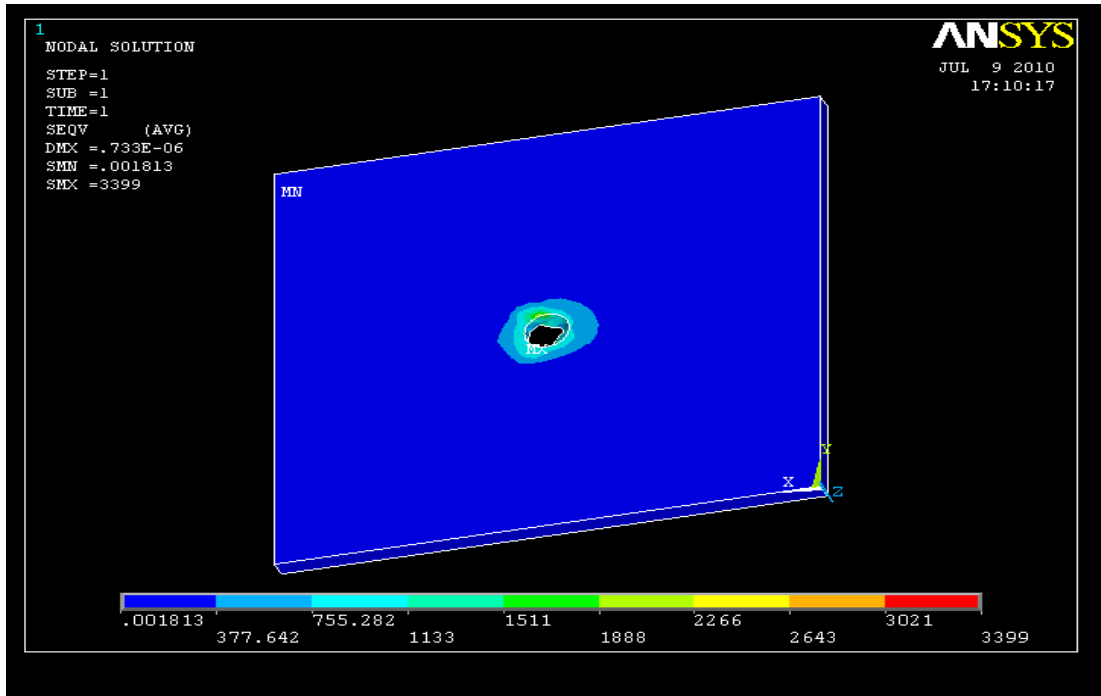


Figure 5.14 Drilled hole with 100° point angle HSS drill

### 5.12.3 Drill point angle 85°

After applying different element conditions and meshing steps the below shown results are shown for tungsten carbide drill. After applying Tsai-wu failure criterion we get the results

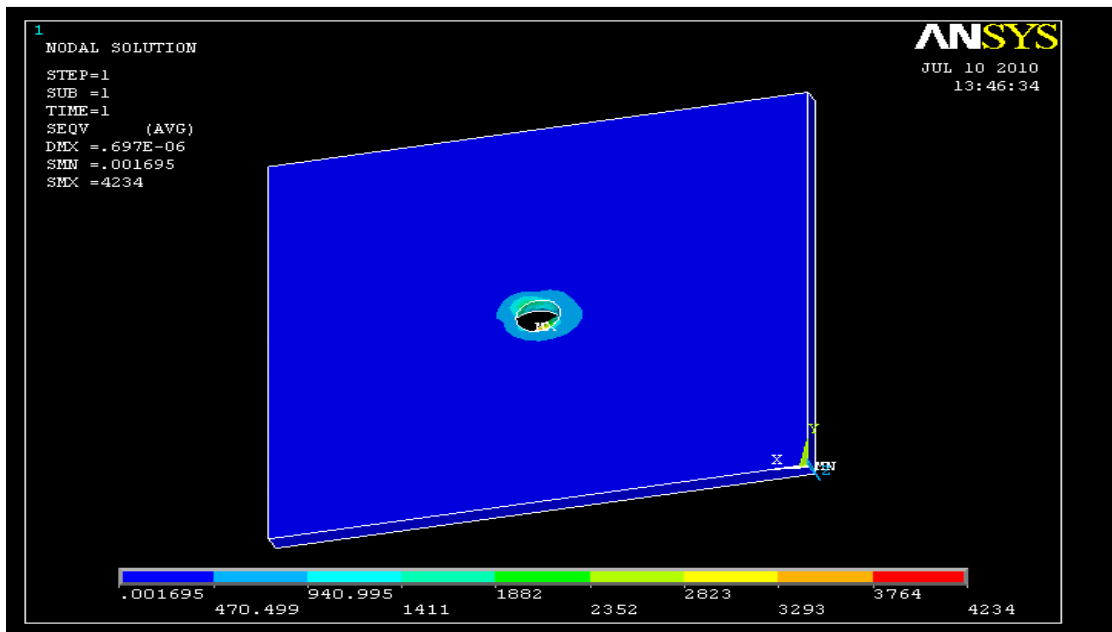
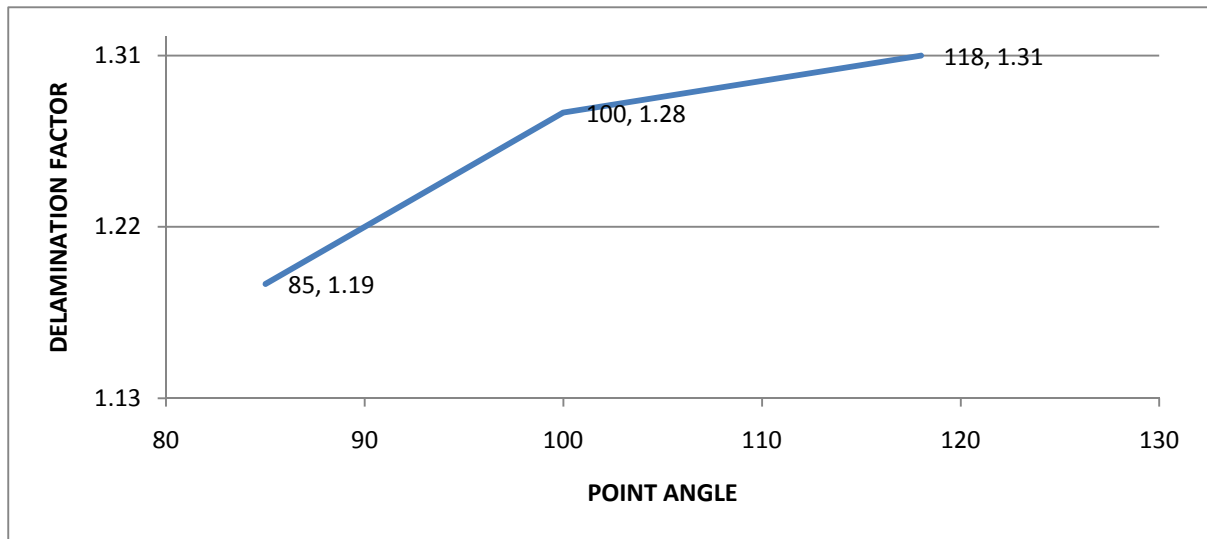


Figure 5.15 Drilled hole with 85° point angle HSS drill

**Table 5.3 Delamination factor values of drilling GFRP using FEM of HSS**

Drill point angle	118°	100°	85°
Delamination factor	1.31	1.28	1.19



**Graph 5.2 Effect of different point angle on delamination factor for HSS drill**

It can be seen from above analysis with increase in point angle the delamination factor also increasing. As with point angle of 85 the delamination factor is of the range of 1.19 but if we look at point angle of 100 then the delamination factor also increasing of the range 1.28. with point angle of 118 the delamination factor increased by 1.31 which shows the result that with increase in point angle the damage around hole also increasing. Hence the delamination get effected most by increasing point angle.

### **5.13 Results of Ansys By Taking Drill Bit of M50**

#### **5.13.1 Drill point angle 118**

After applying different element conditions and meshing steps the below shown results are shown for tungsten carbide drill. After applying Tsai-wu failure criterion we get the results below shown

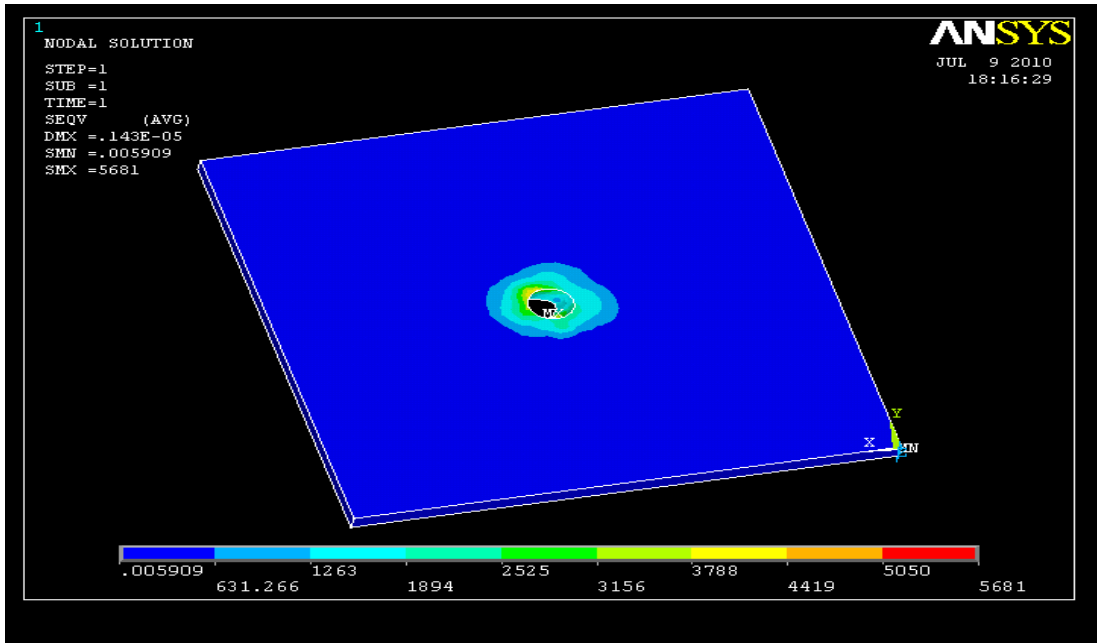


Figure 5.16 Drilled hole with 118° point angle M50 drill

### 5.13.2 Drill point angle 100°

After applying different element conditions and meshing steps the below shown results are shown for tungsten carbide drill. After applying Tsai-wu failure criterion we get the results below shown.

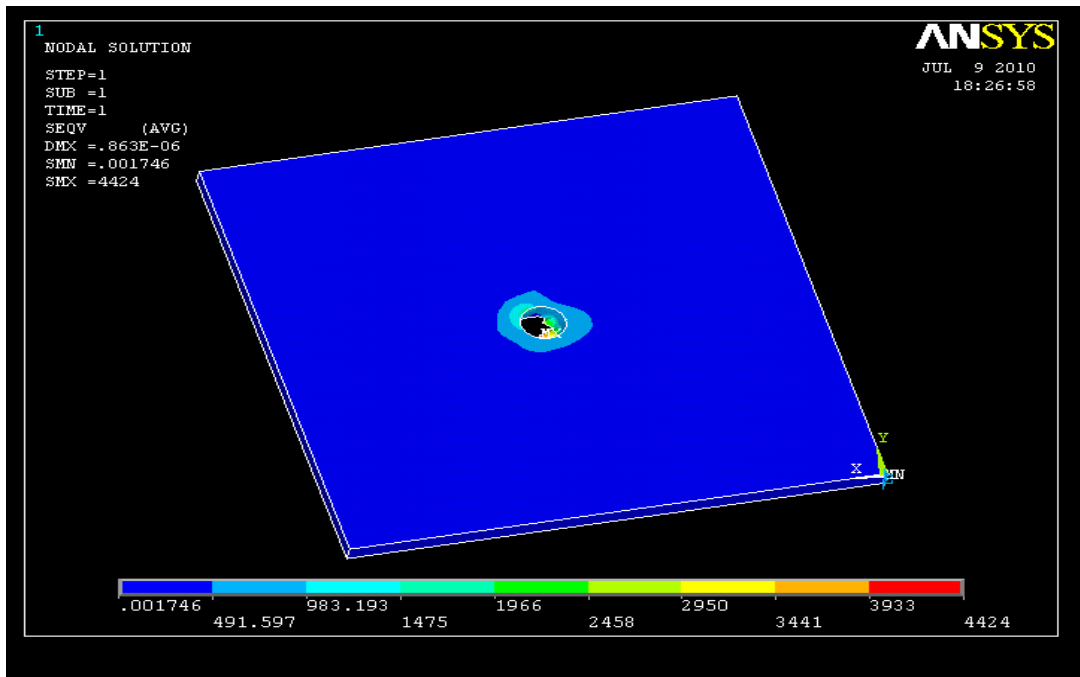


Figure 5.17 Drilled hole with 100° point angle HSS drill

### 5.13.3 Drill point angle 85°

After applying different element conditions and meshing steps the below shown results are shown for tungsten carbide drill. After applying Tsai-wu failure criterion we get the results below shown.

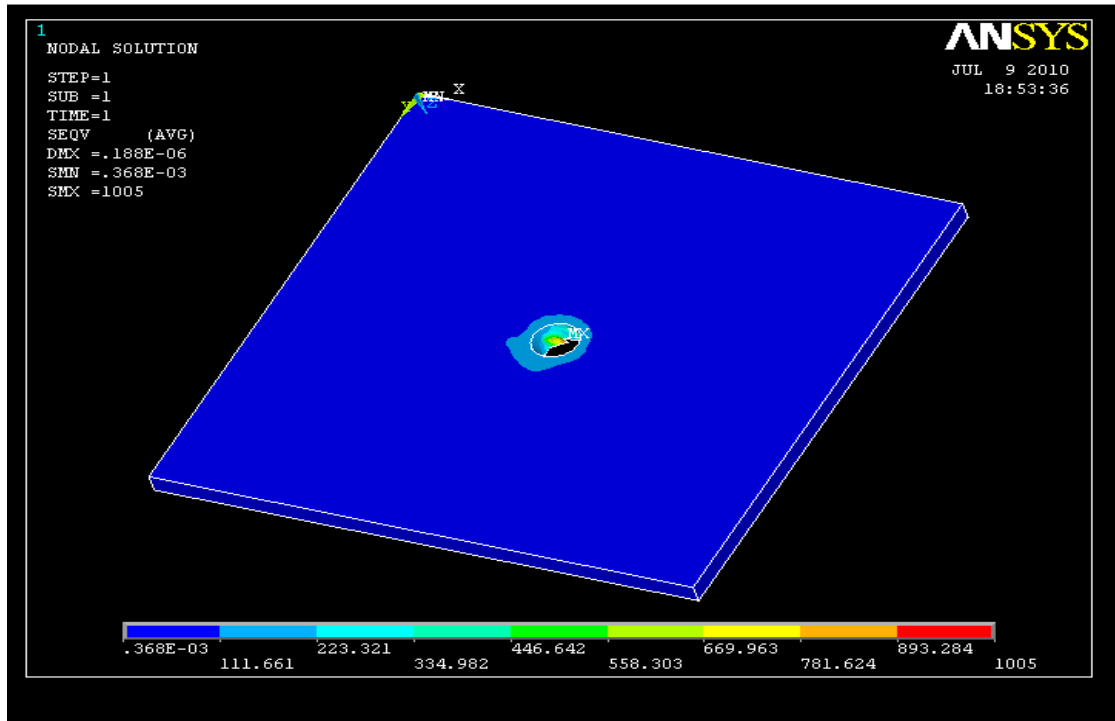
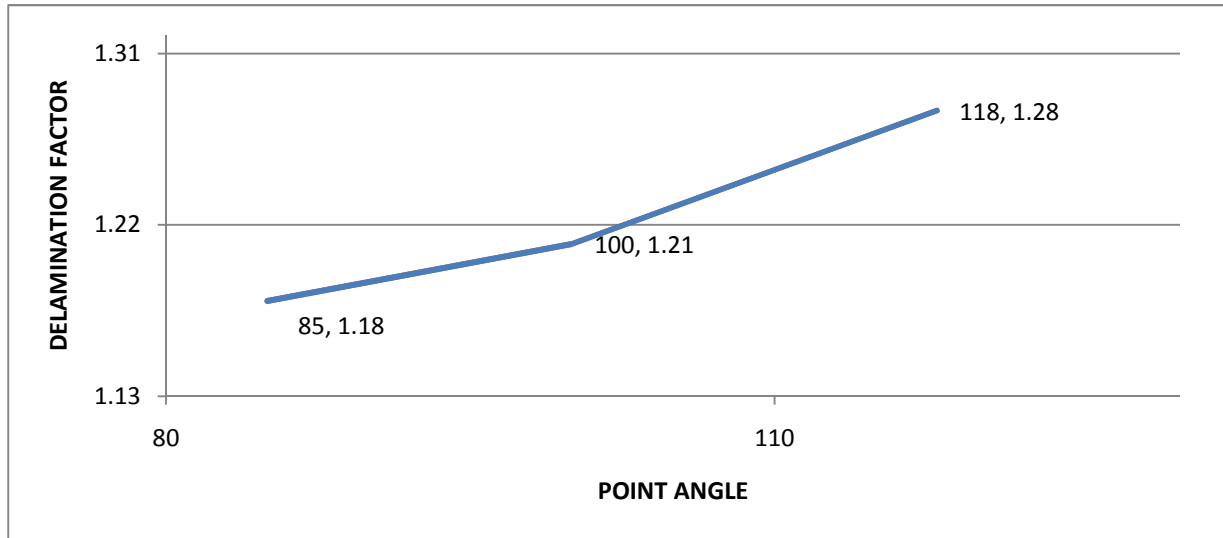


Figure 5.18 Drilled hole with 85° point angle M50 drill

Table 5.4 Delamination factor values of drilling GFRP using FEM of M50

Drill point angle	118°	100°	85°
Delamination factor	1.29	1.21	1.18



**Graph 5.3 Effect of different point angle on delamination factor for M50 drill**

It can be seen from above analysis with increase in point angle the delamination factor also increasing. As with point angle of 85 the delamination factor is of the range of 1.18 but if we look at point angle of 100 then the delamination factor also increasing of the range 1.21. with point angle of 118 the delamination factor increased by 1.28 which shows the result that with increase in point angle the damage around hole also increasing. Hence the delamination get effected most by increasing point angle. It is also seen that Tsai Wu failure goes on increasing with the increase in point angle. From the Tsai Wu failure theory the material is assumed to fail if the Tsai Wu failure value exceeds one. From the failure plots shown it is assumed that the regions around the hole whose Tsai Wu index is above one are assumed to be damaged.

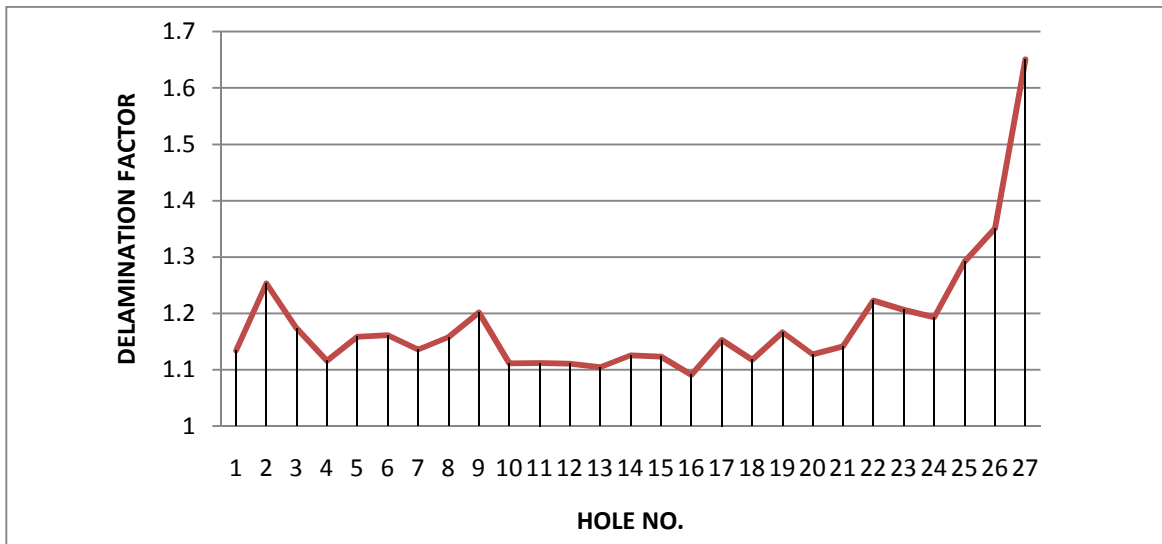
## CHAPTER-6

### RESULTS AND DISCUSSIONS

The results obtained through experiments have been presented in the graph and is represented between delamination factor and number of holes drilled by different drill bits. All the graphs has been represented by considering all different tool drill bit material.

#### 6.1 Delamination factor for tungsten carbide drill

By taking Tungsten Carbide as tool material the below shown graph has been represented between delamination factor and hole number. Below shown graph has slope increasing towards in end number of holes.



**Graph 6.1 Delamination factor and no.of holes drilled by tungsten carbide drill**

**Table 6.1 Thrust force and delamination factor for tungsten carbide as drill material**

Hole Number	Actual Diameter (mm)(D)	Observed Diameter (mm)(D <sub>MAX</sub> )	Thrust Forces(N)	Delamination Factor(D <sub>MAX</sub> /D)
1	6	6.805	90.712	1.13416
2	6	6.956	90.910	1.25933

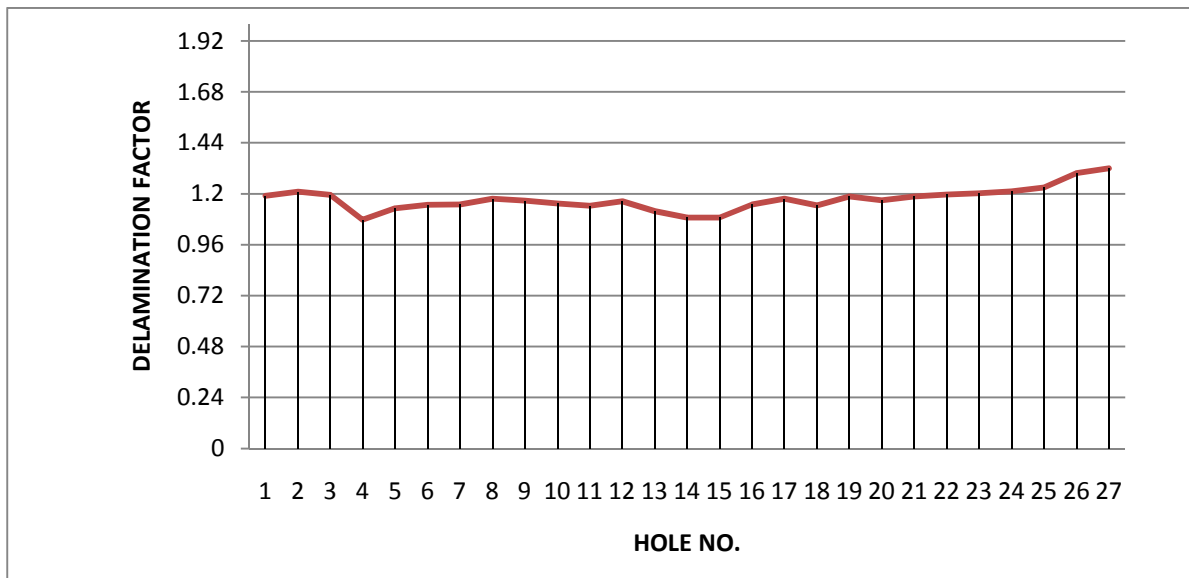
3	6	7.043	10.651	1.17383
4	6	6.694	50.807	1.11566
5	6	6.950	110.781	1.15833
6	6	6.967	140.117	1.16116
7	6	6.815	100.184	1.13583
8	6	6.949	140.906	1.15816
9	6	7.209	150.780	1.2015
10	6	6.667	70.144	1.11116
11	6	6.671	60.628	1.11183
12	6	6.664	20.535	1.11066
13	6	6.628	50.781	1.10466
14	6	6.753	40.093	1.1255
15	6	6.739	20.484	1.12316
16	6	6.544	20.943	1.09066
17	6	6.917	10.965	1.15283
18	6	6.705	150.327	1.1175
19	6	6.997	60.880	1.16616
20	6	6.764	20.657	1.12733
21	6	6.849	40.768	1.1415
22	6	7.337	25.678	1.22283
23	6	7.585	60.678	1.20641
24	6	6.859	90.789	1.19316
25	6	7.750	120.679	1.29166
26	6	8.106	122.657	1.351

27	6	9.904	130.987	1.65066
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By observing above graph and Table of tungsten carbide twist drill we see that with increasing thrust forces the damage area around hole also get increase, which is called delamination but the reason behind it is only the point angle and feed rate or interaction between these two factors. If we look at graph from left to right then there is increase in slope of graph, moreover point angle has significant effect on thrust forces which increases delamination factor. By looking at hole no. 22,23, 24, 25, 26,27 we see that delamination occurred is maximum due to large point angle of 118 and also due to with increasing feed rate.

### 6.2 Delamination factor for HSS drill

By taking HSS as tool material the below shown graph has been represented between delmaination factor and hole number.



**Graph 6.2 Delamination factor and no. of holes drilled by HSS drill**

**Table 6.2 Thrust force and delamination factor for HSS as drill material**

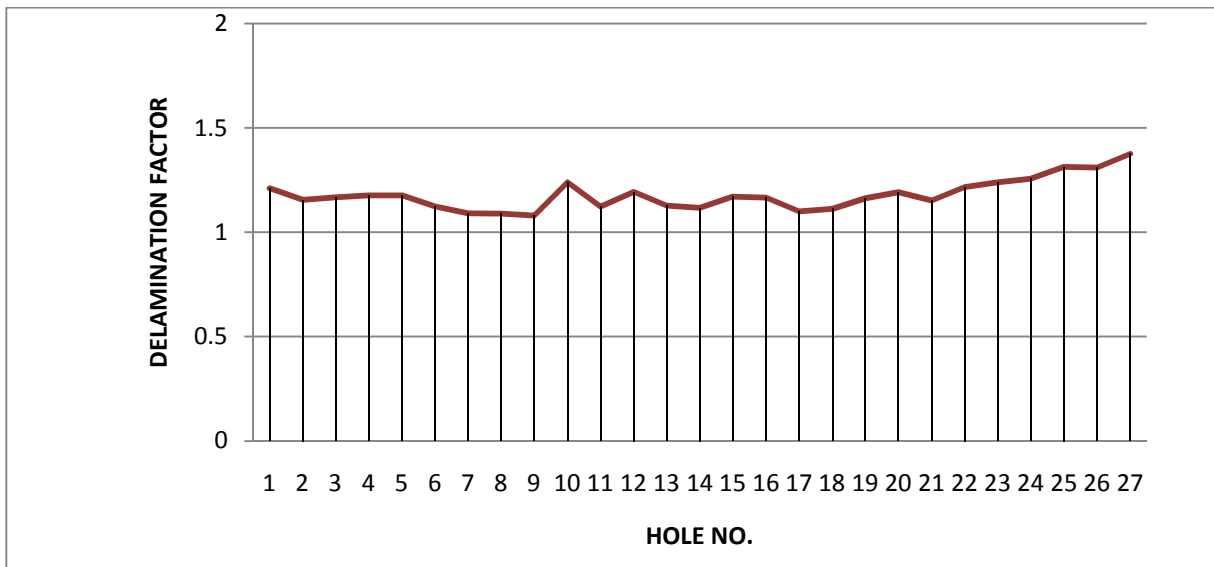
Hole Number	Actual Diameter (mm)	Observed Diameter(mm)	Thrust Forces(N)	Delamination Factor( $D_{MAX}/D$ )
1	6	7.145	40.138	1.19083
2	6	7.256	50.983	1.20933
3	6	7.168	10.961	1.19466
4	6	6.459	10.594	1.0765
5	6	6.793	50.803	1.13216
6	6	6.888	20.928	1.1480
7	6	6.900	25.474	1.1500
8	6	7.063	15.584	1.17716
9	6	7.004	6.324	1.16733
10	6	6.923	10.475	1.15383
11	6	6.865	10.379	1.14416
12	6	6.991	60.954	1.16516
13	6	6.706	9.267	1.11766
14	6	6.653	70.110	1.0883
15	6	6.529	6.104	1.08816
16	6	6.900	30.494	1.1500
17	6	7.057	10.858	1.17616
18	6	6.873	35.495	1.1455

19	6	7.128	7.672	1.1880
20	6	7.013	10.474	1.16883
21	6	7.002	10.433	1.1670
22	6	6.519	20.485	1.0865
23	6	6.555	30.066	1.0925
24	6	6.427	32.948	1.07116
25	6	6.659	30.494	1.10983
26	6	6.447	50.485	1.0745
27	6	6.964	58.485	1.16066

By observing above graph and Table we see that with increasing point angle and feed rate the delamination was increasing but in case of tungsten carbide it was sharp effect of increasing point angle but in this case of HSS there is increase in delamination but not that much significant effected by point angle and feed rate.

### 6.3 Delamination factor for M50 drill

By taking **M50** as tool material the below shown graph has been represented between delmaination factor and hole number.



**Graph 6.3 Delamination factor and no.of holes drilled by M50 drill**

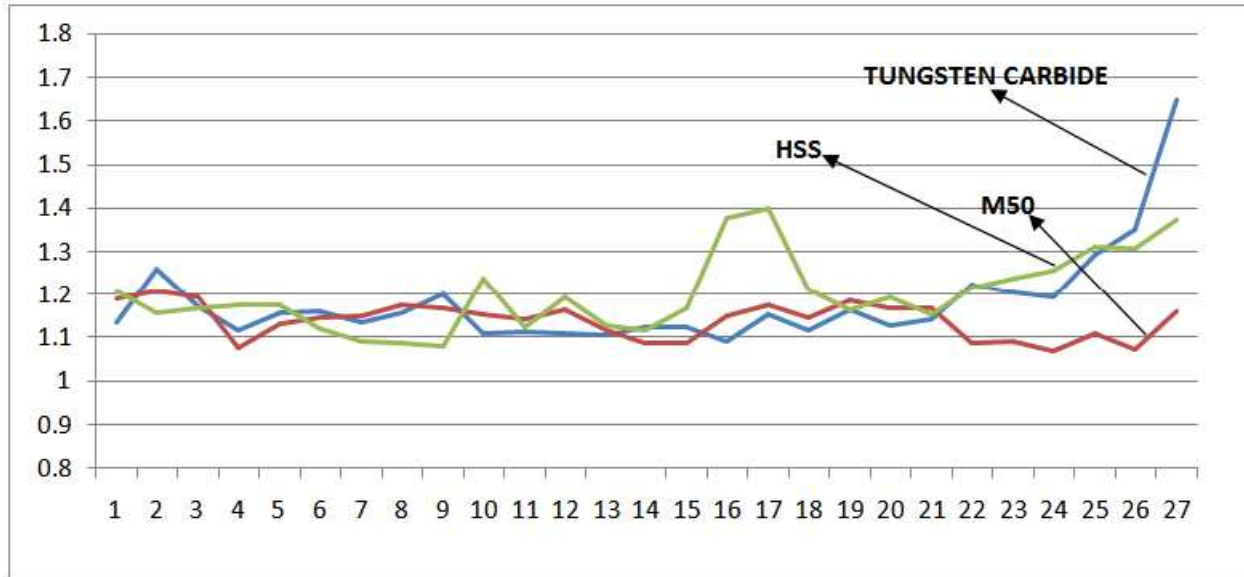
**Table 6.3 Thrust force and delamination factor for M50 as drill material**

Hole No.	Actual Diameter(mm) (D)	Observed Diameter(mm) $D_{MAX}$	Thrust Forces(N)	Delamination Factor( $D_{MAX}/D$ )
1	6	7.259	20.30541	1.20983
2	6	6.934	7.59322	1.15566
3	6	7.007	10.954933	1.16783
4	6	7.064	20.634838	1.17733
5	6	7.064	20.65538	1.17733
6	6	6.733	20.790492	1.12216
7	6	6.544	4.9042	1.09066
8	6	6.536	60.705266	1.08933
9	6	6.478	40.333236	1.07966
10	6	7.439	50.74527	1.23983
11	6	7.337	40.80336	1.12283
12	6	7.161	20.189406	1.1935
13	6	6.765	20.964669	1.1275
14	6	6.701	50.009279	1.11683
15	6	7.022	50.54303	1.17033

16	6	8.257	1.3482	1.37616
17	6	8.402	60.956444	1.40033
18	6	7.269	10.21637	1.2115
19	6	6.981	2.82742	1.1635
20	6	7.155	10.98043	1.1925
21	6	6.915	10.65035	1.1525
22	6	6.521	10.295199	1.21683
23	6	6.412	20.00557	1.23866
24	6	6.759	40.188886	1.2565
25	6	6.768	50.47675	1.313
26	6	6.657	59.8655	1.3095
27	6	7.055	70.7916	1.37583

In this case of M50 there is slightly increase in graph from right side due to increase in delamination factor which indirectly get affected by point angle or due to thrust forces or may be due to torque. Hence in this case also there is slightly change in delamination factor due to change in point angle or due to combination of both feed rate and point angle.

## 6.4 Delamination of all drill materials



**Graph 6.4 Delamination factor vs hole no. for all drill materials**

Hence by observing the graphs we see that in all the three cases only two parameters effect delamination factors significantly. In spite of different drill bit material there is seen that very less change in delamination factor is there. It is observed in all graphs that when ever there is increase in value of thrust force there is also significant change or increase in delamination factor. Two of factors has been seen which effect much to thrust forces and torques values are point angle and feed rate. These two factors significant increase the thrust forces which directly increase delamination factor. From above shown graph we can observe that tool drill bit material is not effected much to delamination factor. However its tungsten carbide drill bit which effect somewhat large to delamination factor and HSS and M50 drill bit also gives more or less same results for delamination factor.

## CHAPTER-6

### CONCLUSIONS

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The objective of this thesis work was to predict delamination generated in composite sheet when drilling with conventional twist drills. The experiments and finite element simulations were carried out on glass fiber sheet after doing holes to study the effect of cutting forces and torque value. Predictions of cutting forces help designers to design tools without having to conduct experiments. This cut down the time and money involved in product development life cycle. The cutting forces exerted by the cutting tool on the work piece during a machining have been identified in order to control the delamination. Modelling of cutting force in drilling is often needed in machining automation. The aim of study is to predict the effects of cutting parameters on the variations of cutting forces during drilling operation of composite materials.

The experiment has been performed by various twist drills of different materials on glass fiber composites under varying parameters according to the design of experiments. The critical analysis of results shows that with variations of different parameters, thrust forces and torque values increase. It has been calculated that when speed is varied the variation in thrust forces and torque value is not much affected. Finally the mathematical results show the same variation according to the parameter dealt during experimentations. From the results it was concluded that a thrust value and torque varies throughout the work piece during machining.

From the experiment it has been concluded that when cutting force and torque value is high then delamination factor is also large.

- Thrust forces and torque value increase when the point angle of twist drill increases
- Feed rate parameter also shown significant result on Thrust forces and torque values
- The interaction between feed rate and point angle with increasing rate also shown significant increase in thrust forces and torque values.
- Delamination factor increases when thrust forces and torque values increase.
- Delamination factor values were increasing with tungsten carbide twist drill with variation of point angle and interaction between point angle and feed rate
- A finite approach is used to study the effect of drill point angle on drilling induced damage while drilling cross-ply glass fiber composite laminate. It was observed that lower the point angle, better are the results in terms of delamination.

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