# Investigation of Machinability of Composite Materials

*Author*
***Naeem Ahmed Awan***
*MS (Design and Manufacturing Engineering)*
*00000205456*

*Supervisor*
***Dr. Syed Husain Imran Jaffery***

*Department of Design and Manufacturing Engineering*
*School of Mechanical and Manufacturing Engineering (SMME)*
*National University of Sciences & Technology (NUST)*
*Islamabad, Pakistan*
*(July, 2021)*

# <u>Investigation of Machinability of Composite Materials</u>

*Author*
***Naeem Ahmed Awan***
*00000205456*

A thesis submitted in partial fulfillment of the requirements for the degree of

MS Design and Manufacturing Engineering

*Supervisor*
***Dr. Syed Husain Imran Jaffery***

Thesis Supervisor's Signature: ___________________

*Department of Design and Manufacturing Engineering*
*School of Mechanical and Manufacturing Engineering (SMME)*
*National University of Sciences & Technology (NUST)*
*Islamabad, Pakistan*
*(July, 2021)*

# ***Thesis Acceptance Certificate***

Certified that final copy of MS/MPhil Thesis Written by Mr. Naeem Ahmed Awan (Registration No: 00000205456), of School of Mechanical and Manufacturing Engineering (School/College/Institute) has been vetted by undersigned, found complete is all respects as per NUST Statutes/ Regulations, is free of plagiarism, errors and mistakes and is accepted as partial fulfillment for award of MS/MPhil Degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have also been incorporated in the said thesis.

Signature:_________________________________

Name of the supervisor: Dr. Syed Husain Imran Jaffery

Date: ____________________

Signature (HOD): ___________________________

Date: ____________________

Signature (Principal): ________________

Date: ____________________

**FORM TH-4**

# National University of Science and Technology

## MASTER THESIS WORK

We hereby recommended that the dissertation prepared under our supervision by **Naeem Ahmed Awan** (00000205456) titled: "***Investigation of machinability of composite materials*)**" be accepted in partial fulfillment of the requirements for the MS Design and Manufacturing Degree with (_) grade.

## Examination Committee Members

1. Name: Dr. Mushtaq khan Signature: ____________________

2. Name: Dr. M.Taqi Mehran Signature: ____________________

3. Name: Dr. Shahid Ikramullah Butt Signature: ____________________

Supervisor Name: Dr. Syed Husain Imran Jaffery

Signature: ______________________

Date: _______________

________________________________

Head of Department Date: _________________

## COUNTERSIGNED

______________________________________

Dean/Principal Date:_________________

# Declaration

I certified that this research work titled "Investigation of machinability of composite materials**)**" is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledge/referred.

Mr. Naeem Ahmed Awan

00000205456

## Proposed Certificate for Plagiarism

It is certified that MS Thesis Titled "Investigation of machinability of composite materials" by **Naeem Ahmed Awan (205456)** has been examined by us. We undertake the follows:

a. Thesis has significant new work/knowledge as compared already published or are under consideration to be published elsewhere. No sentence, equation, diagram, table, paragraph or section has been copied verbatim from previous work unless it is placed under quotationmarks and duly referenced.
b. The work presented is original and own work of the author (i.e. there is no plagiarism). No ideas, processes, results or words of others have been presented as Author own work.
c. There is no fabrication of data or results which have been compiled /analyzed.
d. There is no falsification by manipulating research materials, equipment or processes, or changing or omitting data or results such that the research is not accurately represented inthe research record.
e. The thesis has been checked using TURNITIN (copy of originality report attached) and found within limits as per HEC plagiarism Policy and instructions issued from time to time.

**Name & Signature of Supervisor**

**Dr. Syed Husain Imran Jaffery**

Signature: ________________

# COPYRIGHT STATEMENT

# ACKNOWLEDGEMENT

This Thesis work has been done at School of Mechanical and Manufacturing Engineering (SMME) at NUST, Islamabad under the project *"Investigation of machinability of composite materials"* and is submitted in partial fulfillment of the requirements for the degree of Master of Science program in Design and Manufacturing (DME) at SMME, NUST University.

I am grateful to my Project Supervisor: **Dr. Syed Husain Imran Jaffery** for his constant guidance, support, friendly behavior and encouragement for working had made me able to achieve this milestone. Their critical views were the most helpful thing while doing this dissertation workand the project.

Besides my advisor, I would like to thank the rest of my thesis committee: **Dr. Mushtaq Khan** , **Dr. M. Taqi Mehran** and **Dr. Shahid Ikramullah Butt** for their insightful comments andencouragement, but also for the hard question which incented me to widen my research fromvarious perspectives.

I also acknowledge the help and support in experimentation and CNC machine operators **Mr. Waseem**, **Mr. Akseer** along with MRC shop officials and operators for making the working in the laboratory a joy.

Last but not the least; I would like to thank my family for their never-ending support and encouragement through very difficult times to complete research work.

I am thankful to my class mates for their assistance, advices and group discussions. Their helpdirectly or indirectly was really supportive for this task completion.

# DEDICATION

*To my Beloved Parents & Wife,*
*without whom none of my successwould have been possible*

*&*

*To my Respected Teachers,*
*Who acted like compass that activated the magnets of*
*Curiosity, knowledge and wisdom in me*

# Abstract

The machinability of composite materials mainly depends on matrix properties , reinforcements, cutting tool geometry and cutting parameters. Composite developments are increasing day by day and for each new composite the experimental study must be needed in order to understand its behavior against machining process and thereby help manufacturers to established data base for machining. In this study investigation is conducted to results the effects of cutting parameters (feed, speed) during drilling of carbon fiber reinforced polymer sandwich with Glass fiber reinforced polymer. It was found that feed rate and the spindle speed have significant impact on delamination of laminate and results surface roughness. The effect of machining parameters on delaminated areas are significant. The optimum parameters result in almost less delamination and fine surface roughness.

# Table of Contents

# List of Figures

# NOMENCLATURE

| | |
|---|---|
| CFRP | Carbon Fiber Reinforced Polymer |
| GFRP | Glass Fiber Reinforced Polymer |
| N | Spindle Speed RPM |
| Ra | Surface Roughness |
| µm | Micrometer |
| mm/min | Millimeter per Minute |
| Mm | Millimeter |
| Fd | Delamination Factor |
| C | Cutting Speed |

# CHAPTER 1: “INTRODUCTION”

The Composite classification based on fiber reinforcement consist of Carbon Fiber Reinforced Polymer also known as CFRP composite and Glass Fiber Reinforced Polymer also known as GFRP are widely used in industrial areas of aerospace, automotive, sports and construction. The advantages of using CFRP and GFRP being heterogenous and anisotropic materials that don’t exhibit plastic deformation. The conventional materials have be replacing by use of Carbon Fiber Reinforced Polymer and Glass Fiber Reinforced Polymer and this replacement is increasing day by day because of better and enhanced strength properties, in-short they have less strength to weight ratio. Composite fabrications in different combinations with customized strength properties, high fatigue and high temperature resistance, toughness ,oxidation resistance capabilities sort out these fabricated laminated materials wise choice to be used in applications related to engineering . In excess of 50,000 material sorts being used in the area of planning and creating large scope of designing area (1). Some of these known materials range between those accessible even before hundreds of years (copper, cast iron, metal, and so on) and the as of late created progressed materials (composites, earthenware production, elite prepares, and so forth). The categorization of composite materials are as a mixture of at least two synergic miniature components, which differ in actual structure or compound creation (2). The construction of composite materials comprises of two parts, specifically grid and support, and the three-dimensional district with explicit qualities between these two components is known as the interphase locale. The boundary, then again, establishes the limit between the components with its two-dimensional construction. The two-staged construction of composite materials, comprising of the support stage encompassed with the network stage, empowers the use of the unrivaled attributes of the two materials. Frameworks include metallic, polymer, or artistic materials while fortifications are as strands, particles, or precious stone fibers (powder) (1). The framework of fiber-supported materials is picked among various types of resins (epoxy, vinyl ester, phenolic, polyester, and so forth) whereas the support is chosen among fibers widely used are glass, carbon, or aramid (keylar). By and large, fortifications (filaments) go about as the principal load-bearing component, though the framework encases the strands and ensures them the ideal way. Grids go about as burden move components between the strands and ensure the construction against brutal ecological conditions like high temperature and stickiness.

Many publications have covered the machining of CFRP, while little research work has been done on the machining of CFRP sandwich with GFPRs. Results relating to the machinability of CFRPs cannot be directly applied to sandwich laminate because of the differences in the mechanical properties of these two composites.

## 1.1 Research Aim

The majority of engineering aerospace are using composite materials. The experiments are carried out to investigate the machinability of composite materials which will help in stopping the de-lamination of laminates so that we can avoid majority of failures in aerospace industry due to delamination or damages caused by machining.

## 1.2 Research Objective

1. To investigate the de-lamination causes in composite materials due to machining operations.
2. To prevent the causes of de-lamination

## 1.3 Research Scope

This work of research is limited to the drilling of hybrid laminate of CFRP with GFRP (hybrid composite) using CNC. Two controllable input parameters are used with 5 levels each, so L-25 array of Taguchi design of experimentation is used to results the effect of chosen parameters on delamination formation in the drilled hole and surface roughness inside the hole. Cutting speed ranges from 50mm/min to 250mm/min and spindle speed 1000 to 5000 rpm, as low speed machining setups are easily available and more economical as compared to high speed machining setup.

# CHAPTER 2: "LITERATURE REVIEW"

Drilling process is capable of producing small delaminated areas and surface roughness. Carbon fiber and glass fiber which are used as the component for support, can include fired grid , metal framework , polymer lattice, or carbon network. Carbon fiber and glass fiber supported as fiber reinforced polymer composites have been mostly used in space, car and aero industries (3). The increase in need of aero plane and demands of high production rate of aero planes are emerging.in manufacturing of planes the use of CFRP is very evident. This much use of CFRP composite is mainly because of their high strength to weight ratio and high resistance in wear and tear (4). The mostly parts that uses CFRP and GFRP in manufacturing are plan doors, fuselage, longerons, moving surfaces like aileron The parts made of carbon fiber-supported fiber reinforced composite materials utilized in Airbus 350 airplane are displayed in Fig. (1) (4).

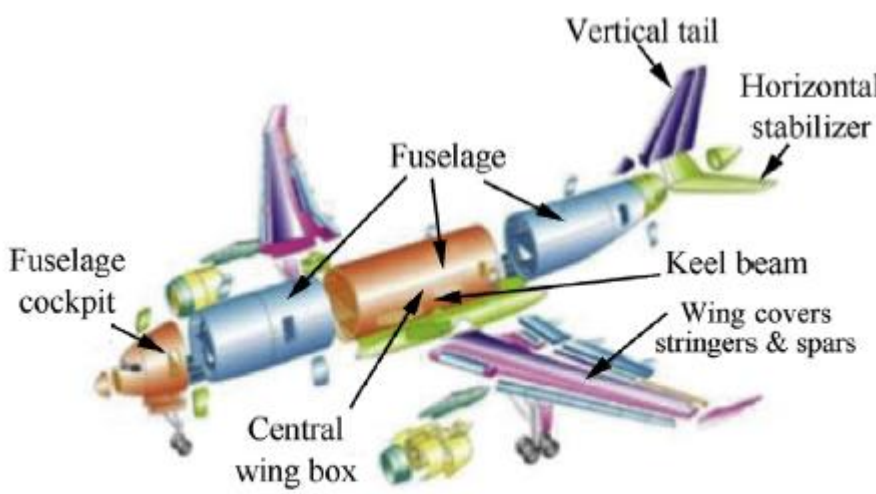



*Figure 1 CFRP in Airbus*

The limitation arises when from the machining of CFRP and GFRP composite materials the strength and weakness of component found. (5). The result of machining the CFRP and GFRP results like lattice spreading, fiber pull-out, delamination and fiber break brings about the rejection of various parts as per quality assurance. The prevailing rejection of components during the penetrating of machining process in composites is accounted for as delamination. Scientists, by and large, have tried to decide the ideal slicing boundaries to stay away from the disappointments, for example, fiber burst, gum fiber de-holding, stress fixation, miniature break development, and disfigurements around the penetrating locale, that happen during the boring of GFRP and CFRP materials.

## 2.1 Fiber Reinforced Composites Machining operations.

Fiber-supported in polymer matrix forming composite materials have been applied in a various fields of engineering for quite a long time. this usage is mainly because of their high strength to weight ratio and modulus of strength (6). Since the strength and firmness of a fiber reinforced composite fabrication rely upon the direction arrangement of the fibric layers, so as its mainly depends on layers directions so planning of this layer sequences is of utmost important. While the fibers in a unidirectional meaning that the fiber and epoxy run in one direction and respectively the stiffness and strength is also only in the direction of the fiber, on the other hand if the fiber in a bidirectional meaning that the fibers and epoxy run in two directions and the respectively the strength and stiffness are in two direction of the fiber. In order to counter axial loads the layers should require 0 degree plies, in order to resist the shear loads the layers should be ±45 degree plies, and to stop the side loads the layers should be 90 degree plies (Fig. 2). Since the requirement of strength is mainly needed and fulfilled as that they are a function of the applied ply orientation , hand lay-up sequence and load direction.

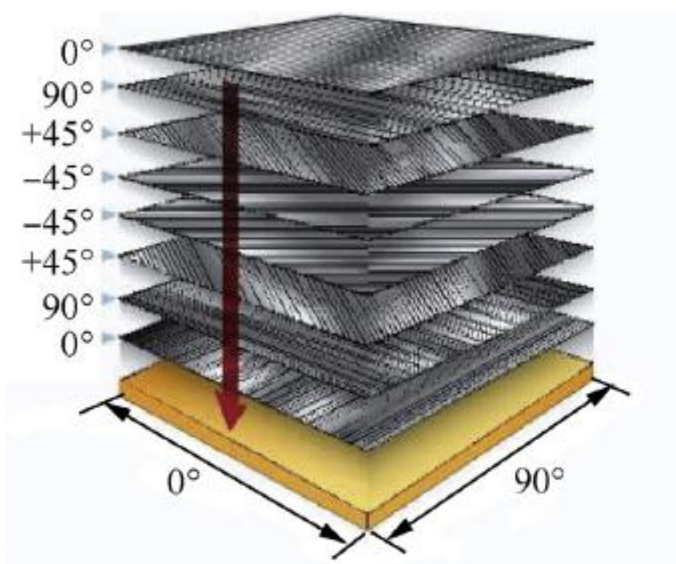



*Figure 2 Fiber orientation types*

In aerospace industry, the use of carbon fiber are related to many reasons but mostly reason for use of carbon fiber are due to their nature of less weight to high strength and due to this property of this fiber it is mainly use for weight reduction of many products

,beside reduction of weight it simultaneously gives high structure support in terms of strength. All of the reason for using carbon fiber results in better fuel and better mileage of airplanes. As for reducing weight it also provide large space for usage in aero industry. (7). With the increase in use of this material it is now obvious that machining operations need to be done it is revealed that there are more than hundred thousand fastening holes on a single small aircraft and for large one this number is more than a million (8). Hence for manufacturers' point of view, machining operation specially drilling process is of about 40% of all other machining operations during the assembly (riveted, bolted) of aero industry components (9) .Hence with so much of drilling in the production there have been rejection of parts due to, resin-fiber de-bonding, micro-crack formation ,surface irregularities, fiber rupture and deformations around drilling area are mostly been seen during the machining operation of drilling of CFRP and GFRP composite materials and the reason is because there are two or more boundaries or phases. So due to these failures , the machining processes of composite materials being differently from the machinability of rest of conventional materials. Such surface failures due to machining of CFRP and GFRP leads the researchers to perform study and eliminates these defects. (10). Many studies results that quality of surface after any machining process mainly depend on machining parameters like cutting tool geometry, cutting forces, cutting speed (10). Hence the optimum selection of parameters for cutting are essential in the machining of fiber reinforced polymer composites

The examinations on Carbon Fiber Reinforced Polymer and Glass Fiber Reinforced Polymer uncovered that the rejection of part that emerge during their machinability results in shorten the strength and weariness life of the product (5). In addition to assembly process the process of drilling is very challenging process.it is challenging because it causes un accepted failures if optimum parameters are not used for drilling. Among all the failures, most serious failure of product comes due to drilling of CFRP and GFRP composite materials is the delamination on surface of hole (Fig. 3). Studies of both theoretical and experimental shows us that the zones at the entry of drill and exit of the drill shows maximum delamination resulting in the most likely area for crack propagation. (11) (12).

### 2.1.1 Conventional methods used for Machining Operations of CFRP and GFRP

Composite reinforced polymer materials are viewed to be hard-to-machine materials because of their heterogeneous fabrication. Traditional machining techniques like turning, drilling, cutting, milling, boring and so on, are normally utilized in the machining of these sorts of polymer matrix materials (13). Because of anisotropic and heterogeneous fabrication of reinforced polymer composites materials, machining of such materials with customary machining measures regularly brings about material rejection, for example, fiber breakage, fiber pull-out, uncut-fiber and delamination (hole surface failure) (2). Disappointment practices don't just emerge from the heterogeneous and anisotropic construction, yet additionally from the machining techniques, machining parameters and their combine collaborations (14). Furthermore; because of their heterogeneous fabrication, machining of polymer composite materials with ordinary strategies brings about primary and wellbeing related issues like delamination, diminished instrument life, fiber pull out, lattice spreading, and unfortunate residue development (14). Notwithstanding their high hardness and abrasiveness (now and again much harder than a portion of the apparatus materials), because of their weak nature, smashing of strands is carried out by means of ordinary machining techniques, to turn away the plastic twisting of the device (15). The low machinability of CFRP and GFRP composite materials by and large prompts different machining results failures including delamination, peel-up, push out fibers and uncut fibers at the bottom of the hole.

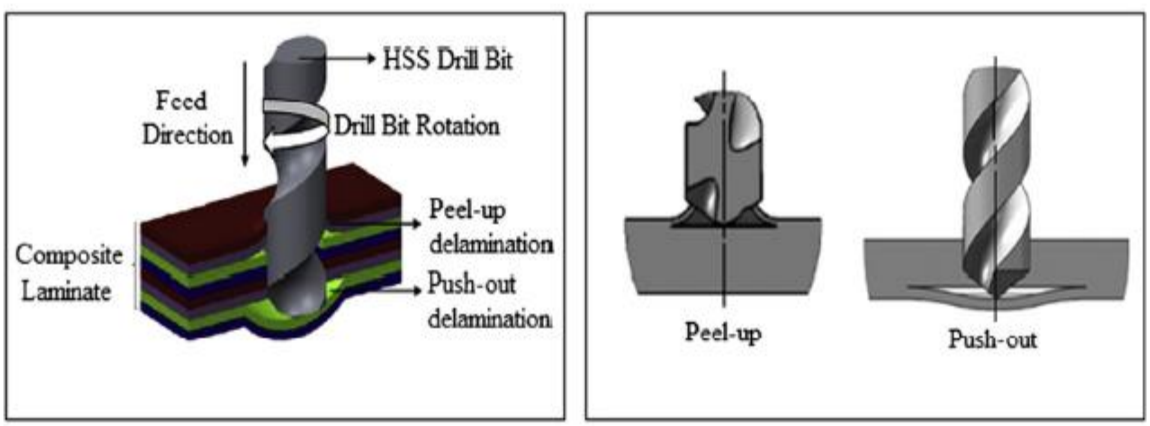



*Figure 3Illustration of delamination by drilling*

Usually the problems that are results due to machining of CFRP and GFRP with conventional solid machining tools are related to finishing and surface integrity-related problems.Fiber pull out at the bottom of hole, fiber break, matrix breakage and delamination are few types that result in failure of product as the product fails it strength and show weakness against loads end up with rejection of a lot of number of machined parts (10). In aerospace industry there are 60% cases reported that tends to rejection of parts due to delamination and surface roughness of the CFRP parts. (16) (17). Also,the limitation of using conventional size tools in deep and close spaces areas, which increase the machining time as time required to change the wear out tool increases. (17).

### 2.1.2 Machine Operation of Drilling on CFRP and GFRP

In research on damaged surface failures on CFRPs and GFRPs composite materials by machining operations and the impact of tool geometry being used and cutting parameters, Dur~ao et al.told that, the force in axial direction is lowered if the feed rate used is lowered, as the feed rate is low that results in reduction of delamination occurrences risk, so the low feed rate is hence more convenient for drilling of CFRPs. Dur~ao et al further told in research that to minimize the effect of delamination the tool geometry is important. The twist drill with 120 point of angle must be used for drilling in CFRPs and GFRPs (18). In the study of Ramirez et al research on wear criteria ,it is told that conducted drilling operation results in burr formation (19). Eneyew and Ramulu showed in their research that the feed rate increases the compressive force whereas increase in feed rate decrease the cutting force , by using PCD drill. Further many studies tells that generally a fine and smooth surface of hole is achievable with the use of low feed rate and high cutting speed. (20). Gaitonde et al. on the other hand tells that by using cementite carbide (K20) twist drill at high speed drilling process results in lessen delamination zones around hole. Gaitonde et al. approved the use of a low feed rate-point angle combination (2). Grilo et al. experiments the drilling operations with different drill bits (SPUR, R950, R415) and examined that on entry side of drilled hole no delamination , whereas at the bottom of holes at exit side uncut fibers were found. The best results obtained by using SPUR drill (21). Kılıçkap examined that, there is more than 30% difference in delamination quantity of hole top and bottom side.30% more is seen at the bottom of hole. Kılıçkap reported that less delamination factor was observed with low cutting speed and feed rate (22). According Ekici and Is¸ ık, the low rate of feed and high speed of cutting minimize the rejection factors. Their study also tells that cutting tool point angle and number of cutting edges also effect the failure factor, they explained that low the value of point angle and number of edges the less the failure factor.The minimum failure factor is at 90 m/min cutting speed and 0.06 mm/rev feed rate with60 degree point angle and two cutting edges (23). Abr_ao et al. showed that increasing the rate of feed also result in increasing the thrust force, the tool wear is also the cause of thust force so to minimized the thrust force the feed rate should be increased and tools used should wear less, it also explained that cutting speed has no significant effect on thrust (24) . fiber orientation is an important factor which is explained by Karpat et al..it is explained in working on mill operation carried out on CFRP material. Different fiber orientations (0, 45, 90 & 135 degrees) along with PCD milling tool were used. the results of testing of each orientations differs for example for 0 degree orientation, higher radial forces emerges while milling as compared to any other fiber orientation i-e 45 degree. Another force elements whose values are higher in 135 degree of orientation and lowest in 45 degrees called tangential forces. Those were relative results comparing 0, 45, 90 and 135 degree orientation only (25).

Examination about the damage of surfaces,Erkan and Is¸ ık's explained in their study that cutting speed directly decrease the roughness of surface with its value increasing, and feed rate directly increase the roughness of surface with its increasing value (26). Further explained that cutting direction was also a true parameter like channel milling at different orientations. Test results showed that surface roughness obtained by 45 degree channel milling were higher than obtained by 90 degree. (27). After their contour milling process Takmaz et al. explained about contour milling of CFRPs ,for surface roughness the best results depends on cutting edges following with cutting speed and rate of feed. the best average surface roughness was obtained with parameters like 6mm cutting depth(feed rate) 4 cutting edges at 60 m/min cutting speed, 0.08 mm/rev feed rate (28). Wang et al. work further helps out with another parameter referring to orthogonal cutting. Incorporating the effects on chip formations the results shows that fiber orientation directly affect the chip formation state (29).

## 2.2 Non-traditional methods for machining operation of CFRP and GFRP.

No delamination with smooth surface finish machining of CFRPs and GFRPs using general and regular machining methods like turning, boring, drilling and grinding is tough operation even with the very ideal working condition and best material state, because of the thermal resistance and heterogeneity of polymer matrix fiber reinforced polymer composite materials (30). Number of manufacturing techniques used for making of CFRP and GFRP to achieved best results, but after even getting best results from manufacturing when under go any conventional machining or non-traditional machining like WJM, AWJM,USM,ECM,EDM,LJM,CHM, their still left the defects like gaps, voids, unfilled epoxy gaps, burn epoxy, cracks with in fibers, tangled fibers,delamination, air tapped bubbles etc. As a rule the functioning standard of current machining techniques are characterized by specific energy and formation of chips. usually high energy is desired with low chip formation.The high quality of surface after machining , no burr formation on surfaces and less wear of tool are the main benefits of using such advanced methods of machining. (31)

# CHAPTER 3: "EXPERIMENTATION"

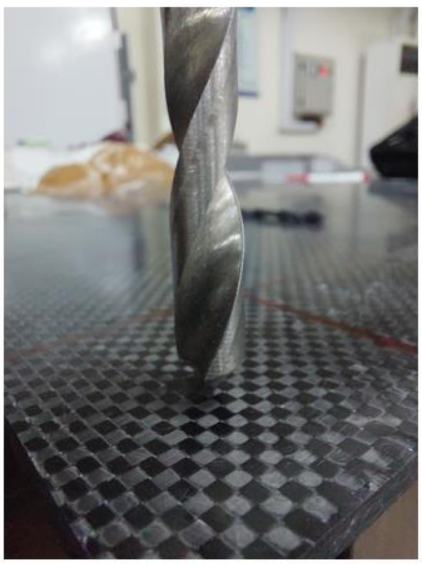
## 3.1 Materials used and methodology of tests.

In this research, the working procedure were limited to the drilling of a hybrid composite plate a combination of CFRPs and GFRPs. The material of test samples used were carbon fiber and glass fiber reinforced epoxy composite. The first step of the experiment involved the fabrication of the composite plate of 450mm x 450mm (Figure 4) having thickness of 4mm.the composite test sample plate is a mixture of fiber and epoxy, which are carbon fiber, glass fiber and epoxy resin. The specimen was fabricated on metallic mould, by mixing chemicals LY-3600 and LY-3600 by weight 100:33. In the first phase the standard hand lay-up process was carried out by applying 1 glass at 0 degree,14 carbon plies at 0 and 45 degree orientation(simultaneously) and on last one 45 degree glass fiber ply. Then the mould is closed and tightening with bolts which provides pressure during curing and then let the plate cured for 24 hrs. Using the samples fabricated in the step first, machining on the sample was then performed. The aim of these tests was to find out the optimum parameters like cutting speed and feed rate for this sample of CFRP and GFRPs results in less delamination and small surface roughness.

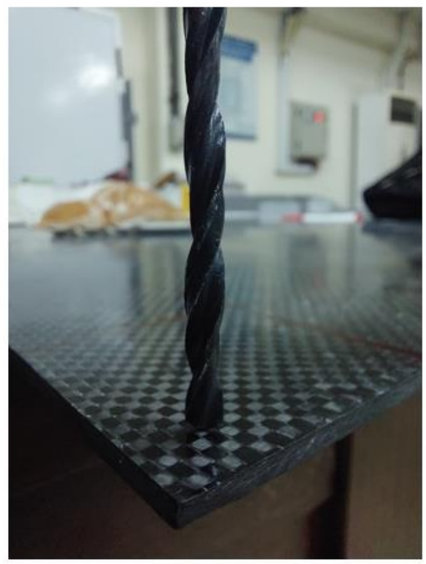
*Figure 4 Sample Plate 450x450mm*

## 3.2 Drilling Condition and Design of Experiment.

The Taguchi method of design of experiment widely used for most of machining operation so L25 array used for cutting speed and spindle revolution with five levels of each parameters.L25 array for each drill size is used, as depicted in Table 1. Taguchi method of DOE is good for obtaining max possible combination of design parameters with optimizing and accuracy in test results. There are two bit diameter size of 4mm and 8mm was used to analyses the damage response. The drill bits was made of HSS twist drills with 120 point angle(Fig 5).



(a)



(b)

*Figure 5 (a) 8mm HSS (b) 4mm HSS*

The machine used for drilling is CNC milling machine MV-1060 (figure 4) .The machine has specification of max STD 8000 rpm and bed side of 1060x630x630. The sample plate was clamped with 4 F-clamps from each side, on table of machine to reduce the disturbance cause in machining process of drilling by vibration and other machining forces.

*Figure 6 CNC milling machine MV-1060*

*Table 1Machining parameters*

| **Drilling Parameters** | | **Feed Rate** | **Cutting Speed** | **Spindle Revolution** |
|---|---|---|---|---|
| **Symbol** | | F | V | N |
| **L** | 1 | 0.05 | 50 | 1000 |
| **E** | 2 | 0.10 | 100 | 2000 |
| **V** | 3 | 0.15 | 150 | 3000 |
| **E** | 4 | 0.20 | 200 | 4000 |
| **L** | 5 | 0.25 | 250 | 5000 |
| **S** | | | | |
| **Units** | | mm/rev | mm/min | Rpm |

The drilling condition of dry machining is used through all the drilling  of holes. This is done because the wet drilling directly influence the structural integrity of sample plates. The use of liquid coolant as in general drilling known as wet machining was not encouraging while drilling with CFRPS, as it's the fiber that can absorb humidity caused by wet operation (Figure 7)

*Figure 7 Experimental Setup of drilling*

## 3.3 Analysis of Damage done Drilling and quantification of damage.

Delamination is the first factor that need to be measured right after drilling of CFRPs and GFRPS, after that the surface roughness of drilled holes were quantified. Other than these two major defects many other defect for sure can be seen after drilling are uncut fiber and minimal burrs formation defects. The area of delamination around the drilled holes, known as delamination damage zone(Fig 9(b)).this zone of the samples is seen by metallurgical microscope as it is a microscopic phenomenon. The delamination induced damage was quantified by delamination factor, which is defined by:

Fd = Dmax / Do

Therefore, it is observed and measured using an Metallurgical microscope . the sample is placed under the microscope and it is operated using 5x magnification lens with F200 fig(8)

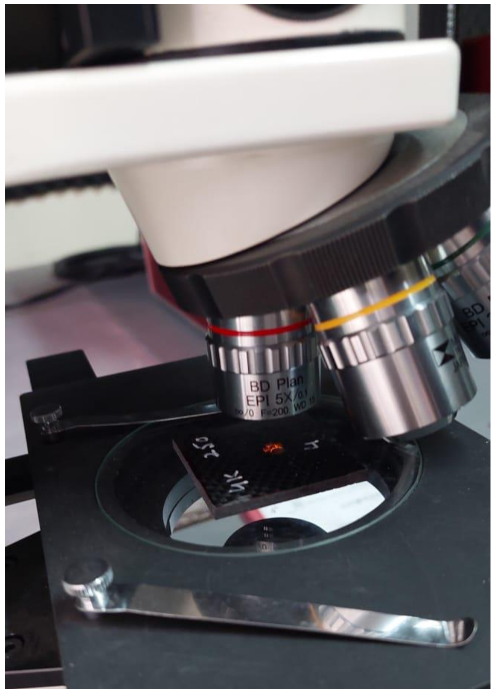


*Figure 8 Lens use for Delamination factor measure. 5X*

.

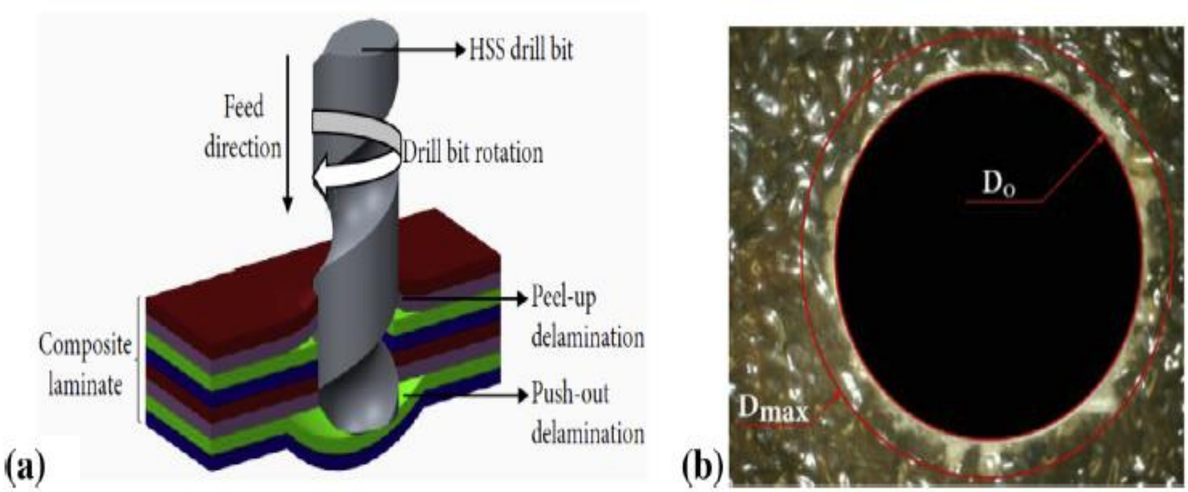



*Figure 9 (a)Drilling phenomena (b) delamination zone*

For using Metallurgical microscope the samples are further cut and reduce in size of 45mm x 45mm (Figure 10).The irregular shapes near the drill hole surface tells about the roughness. The hole walls in irregular shaped are measured in standard unit of roughness Ra. A special v shaped wedge is used to hold the samples and with help of Mitutoyo profilometer the Ra values of all samples drilled are performed. The probe used Stylus, with instruments results in value of roughness..

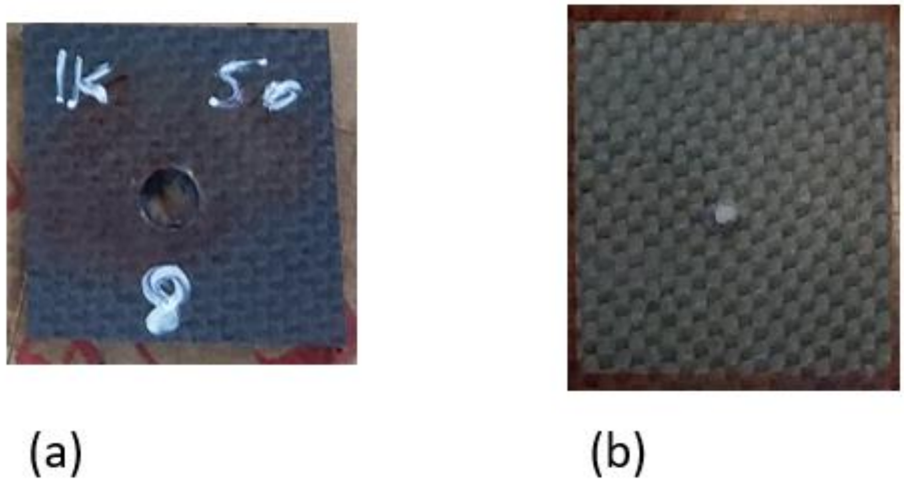



*Figure 10 (a) 8mm drill  Sample for microscope of 45x 45 (b) 4mm drill  Sample for microscope of 45x 45*

The surface roughness measurement of holes walls was carried along the direction of drilling. the different locations were measured which were all axially parallel to the direction of drill as described by ANSI standard. Each location was firmly checked using instrument. To ensure the best results of surface roughness, the samples are slice down into two equal parts. Cut the circle of holes in two semi circles as shown in Fig. 11(a). The need of semi-circles is required so that the probe STYLUS can easily measure the value of walls of hole Fig. 11(b)

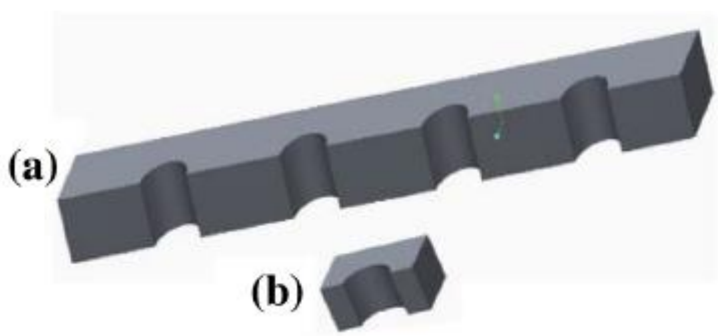



*Figure 11 (a)Semi circle samples for measuring walls roughness (b) single sample for roughness measurement*

Moreover, further moving in this research an effort is made to investigate the defects caused in materials with the method of non-destructive testing to ensure the fiber-uncut, fiber pull out, delamination area, burn epoxy areas, gaps with in layers. These all 45mm x 45mm small samples were seen again with metallurgical microscope but this time using lens f200 at 50x magnification(Fig 13). The microscope which is used for examinations of all samples was MEJI MT8530(figure 12) . The micrographic testing results achieved were shown in Fig.13 & 14.

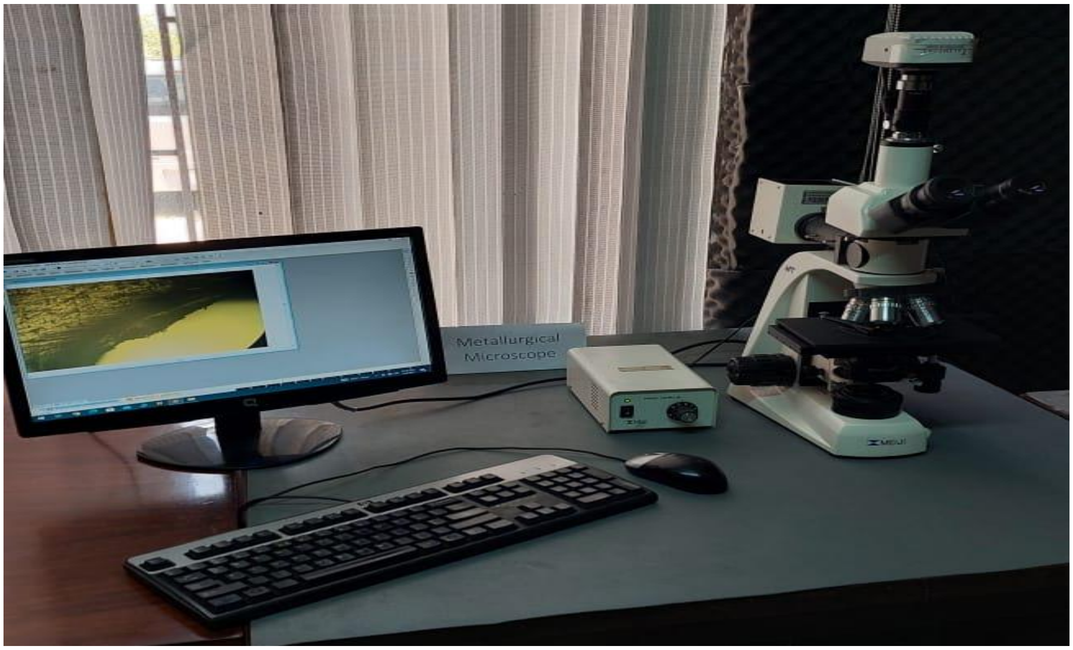
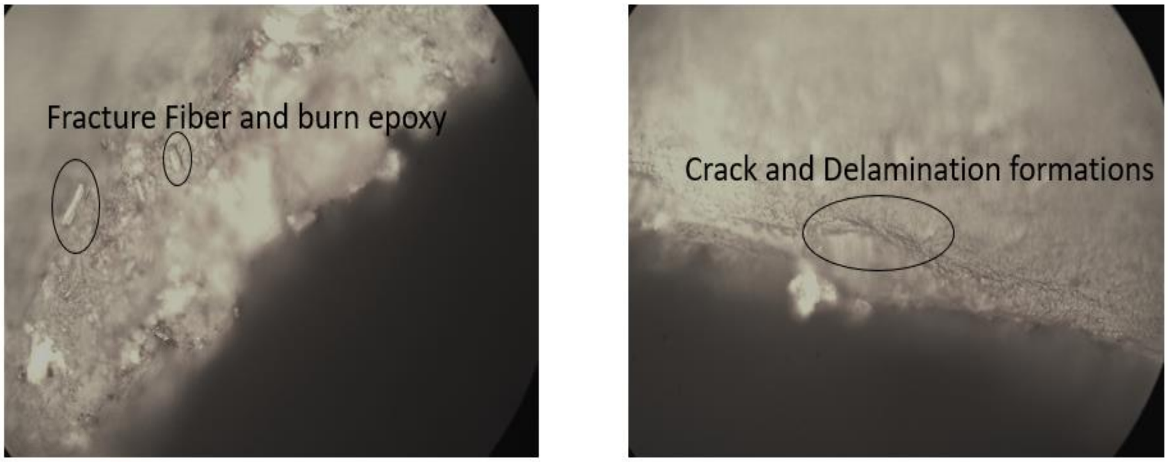



*Figure 12 MEJI MT8530*


*Figure 13 50 X lens F200*




(a) (b)

*Figure 14 (a) micrograph of sample @50 feed and @1000 RPM 4mm(b) micrograph of sample @250 feed and @5000 RPM 4mm*


(a) (b)

*Figure 15 Micrograph of sample @50feed and @1000 rpm 8mm (b) micrograph of sample @250feed and 5000rpm 8mm*

# CHAPTER 4: “Testing Results and Discussion”

## 4.1 Chips Examination.

The remaining of mostly machining operations results in formation of chips.it also formed in drilling operation of all samples. The types of chips formed by machining of CFRPs and GFRPs are discontinuous types of chips, powder and filaments forms fig(15).by analysis the chips types it is evident that chips creation by drilling laminated composites CFRP and GFRP are formed by serial process of fracture resulting in brittle facture, this phenomena is seen less in other metal materials after their making. Reinforced polymer under categorization of thermoset results in less plastic deformation than other thermoplastic polymers composite, resulting their formation of chips leads to fracture shortly. Inter laminated cracks can been seen in reinforced polymers when they processed through drilling process called delamination with in layers, which reveals the probability of causing crack propagation and lead to the failure of material when passes under any kind of load hence the reliability of products suffers having such delaminated zones present in materials.

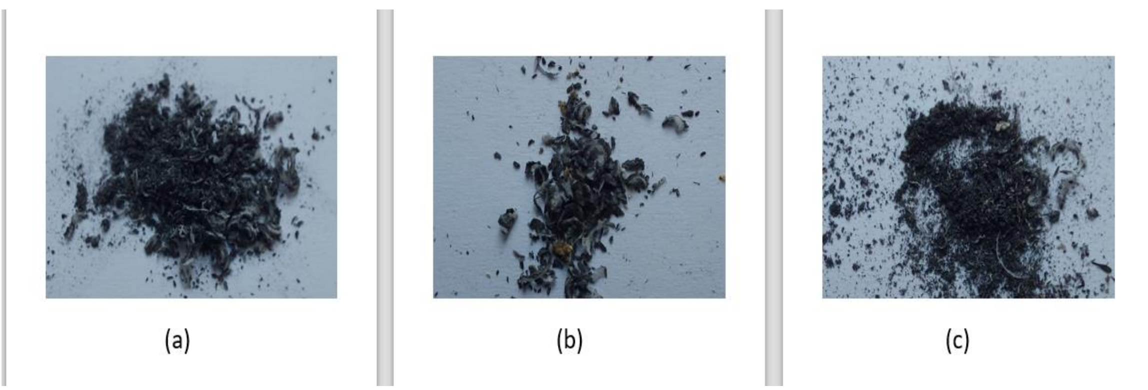
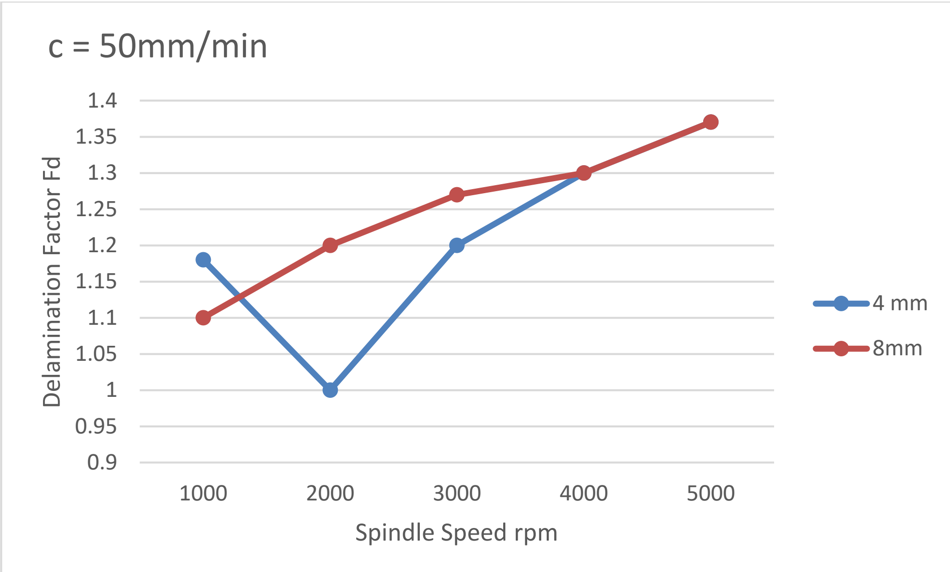
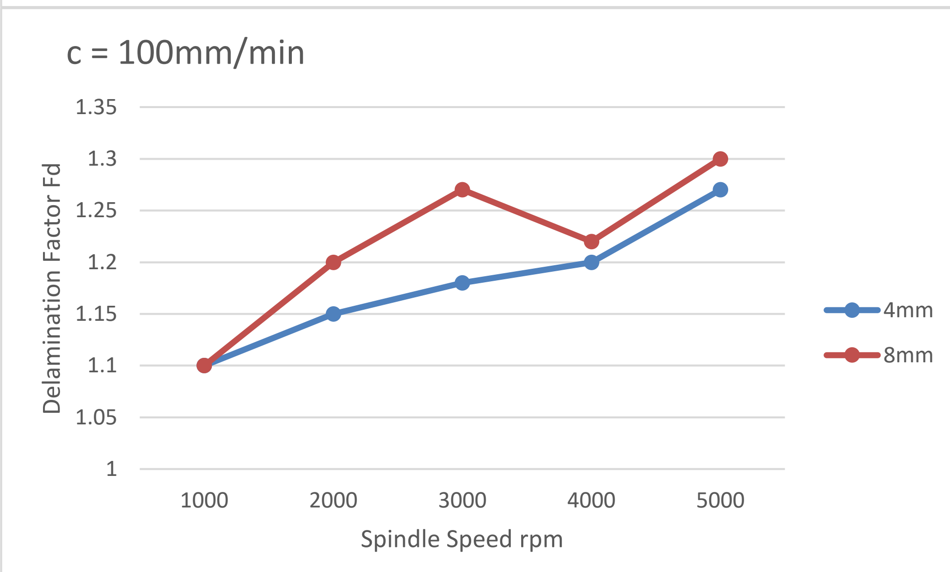



*Figure 16 Chip Formation(a) low feed and low rpm(filaments)(b) medium feed and rpm(chips)(c)high feed and rpm(powder)*

## 4.2 Delamination defect and surface roughness defect by Drilling.

The test results shows the phenomena of increasing in feed rate increases the both defects like delamination and surface roughness of all samples whereas by increasing the cutting speed this phenomena decreases in most of the samples, as showed in both Figures 16 and 17. The thrust force increases with increase in feed rate result in increases delamination area around hole. The test results shows that considering both drill sizes, the results are different.by looking at the figures 16 and 17 it is explained that for each size of drill bit there is an optimum feed rate and rpm which result in less delamination factor and smooth surface finish.



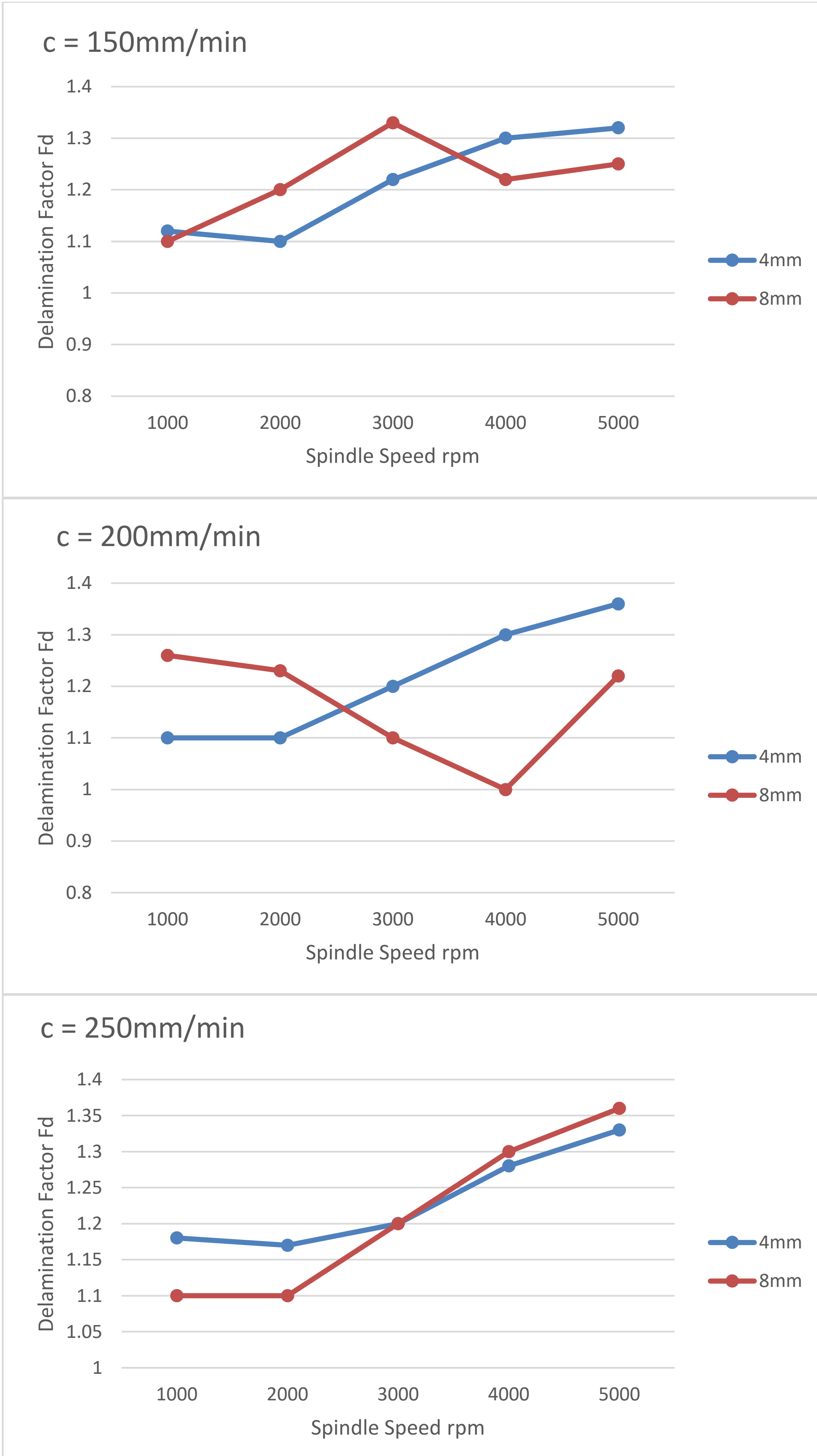
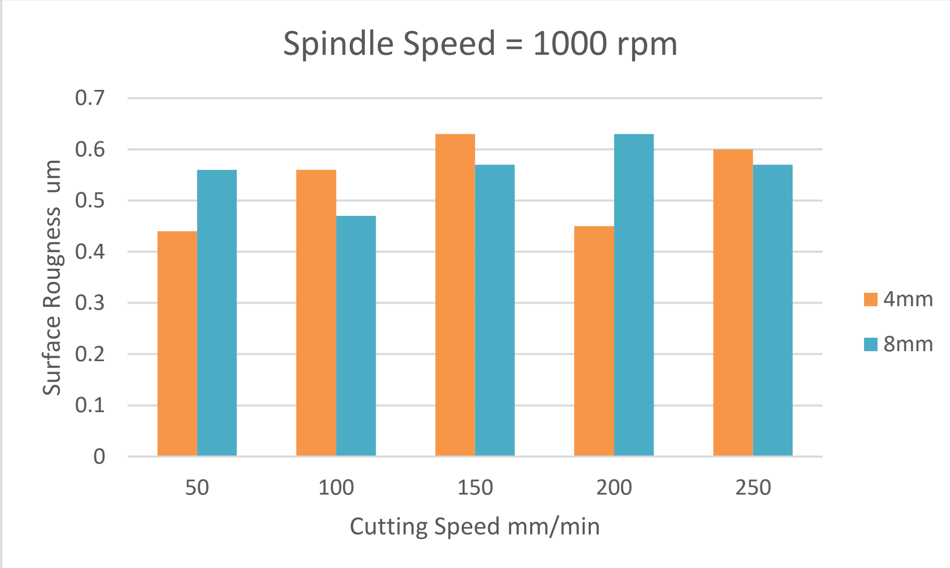
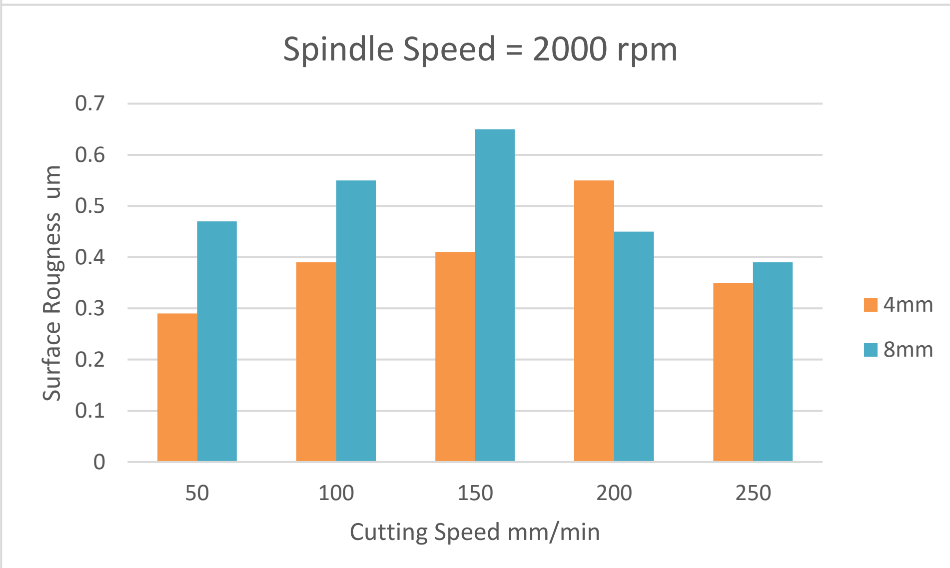
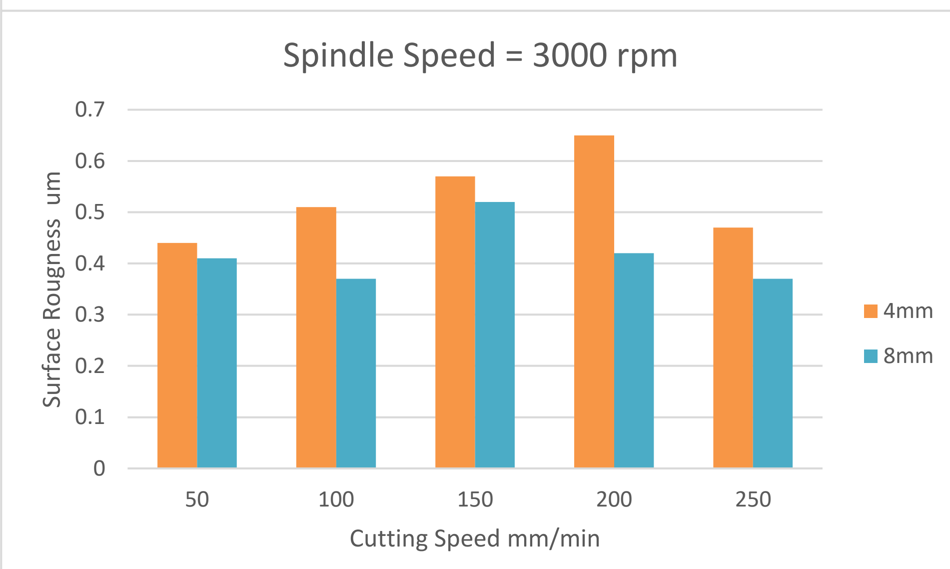



*Figure 17 Effect of drilling parameters on delamination*


Spindle Speed = 1000 rpm
Surface Rougness um
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50
100
150
200
250
Cutting Speed mm/min
4mm
8mm


Spindle Speed = 2000 rpm
Surface Rougness um
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50
100
150
200
250
Cutting Speed mm/min
4mm
8mm


Spindle Speed = 3000 rpm
Surface Rougness um
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50
100
150
200
250
Cutting Speed mm/min
4mm
8mm

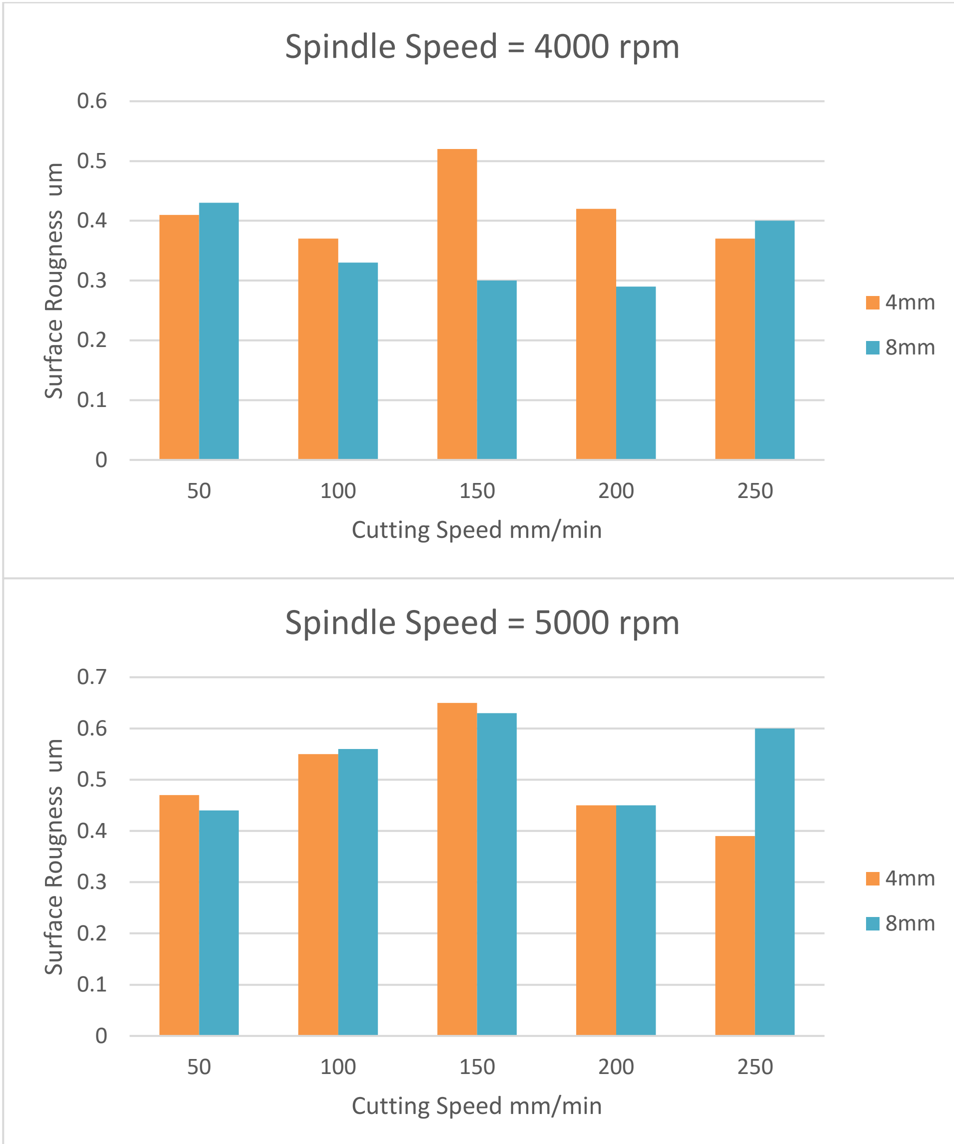



*Figure 18 Graphs of Surface roughness vs Cutting Speeds*

The brittle property of thermoset epoxy and reinforced polymer fiber shows defects like mini-fiber fracture, fiber pull-outs, thermoset burns and matrix cracking into pieces. It also shows that at depending on the drill size and thickness of plate the orientation in plies reflect the results, as coming close to optimum feed rate and rpm there is slightly decreases in defects like delamination and surface roughness whereas after achieving optimum feed rate and rpm this defects increase rapidly.

## 4.3 Effects of rate of feed and rpm of spindle.

Thoroughly analyzing all the results of all samples for both drill bit sizes at all 25 combination of parameters , it is clear that samples shows wide values. Generally it can be said that an increase in the cutting speed caused a gradual reduction in the delamination factor Fd. However, the delamination area of the all samples increased with an increase in the feed rate as shown in Fig. 16.

## 4.4 Metallurgical microscope results of delamination zones and quality of surface .

The images of metallurgical microscope at (Figs. 14 and 15) explains that surface roughness on walls of holes , damages in matrix and epoxy of materials are formed due to drilling operations. The black deep valleys of carbon layers and bright high peaks of glass fiber shows the uncut fiber and burned epoxy residuals. Furthermore cavities formed by shearing fiber depicts the high values of roughness and large area for delamination. These defects occurred prominently for a drill of 4mm at hole walls and entry surface at a low feed rate of 0.05 mm/rev and a spindle speed of 1000 rpm as well as at a high feed rate of 0.25 mm/rev and a spindle speeds of 5000 rpm(Fig. 14). Therefore, the cracks propagated in Fig. 14 occurred due to the high feed rate of 0.15 mm/rev and spindle speed of 5000 rpm used. In addition, feed rate increased with the thrust force. Therefore, both thrust force and feed rate are the responsible factors for the occurrence of the large gaps, cracks, internal laminates delamination and epoxy melting of the samples, as shown in Fig. 14. Moreover, Figs. 14 show big gaps and propagation of cracks in the reinforced polymer composite by delamination and de-bonding phenomena respectively. These defects occurred prominently for drill of 8mm at hole walls and entry surface at a low feed rate of 0.05 mm/rev and at spindle speed of 1000 rpm as well as at a high feed rate of 0.25 mm/rev and a spindle speeds of 5000 rpm(Fig. 15). Therefore, the cracks propagated in Fig. 15 occurred due to the high feed rate of 0.15 mm/rev and spindle speed of 5000 rpm used. In addition, feed rate increased with the thrust force. Therefore, both thrust force and feed rate are the factors for the occurrence of the large voids, cracks, internal laminate delamination and matrix melting of the samples, as shown in Fig. 15. Moreover, Figure 15 show large gaps and cracks propagated in the reinforced hybrid composite by delamination and de-bonding phenomena respectively.

# CHAPTER 5: “CONCLUSION”

This examination is done to discover the impact of various conditions on CFRP and GFRP hybrid composite laminate. The damage done by drilling process is analyzed, mainly defects of delamination and quality of surface after drilling reinforced hybrid composite samples, has been carried out experimentally. The following results concluded from the research.

i. Delamination and quality of surface is for sure induced in material due to drilling. The damage induced by drilling machine operation is most importantly at an increased feed rates of 0.05 and 0.25 mm/rev. the optimum parameter by this research for this hybrid composite laminate with 0 to 45 degree orientation of plies are 2000RPM and feed of o.05 mm/rev for 4mm drill hole and for 8mm drill hole the best optimum parameters are 4000rpm and 0,20mm/rev.

ii. Like all other materials the chips formation from machining of CFRPs and GFRPs were discontinuous chips ,types were of abrasive and powder-like in nature

iii. The most fine and smooth finish of surface and almost non delamination zones around holes for two different drill size 8mm and 4mm results from a feed rates of 0.05 mm/rev for 4mm and 0.20mm/rev for 8mm and spindle speed of 2000rpm for 4mm and 4000rpm for 8mm holes respectively. Therefore, the optimize drilling parameter, surface finish and hole quality on the samples appeared to depend on orientation of plies apply during manufacturing of reinforced polymer hybrid composite plate and hole size of drill.

# Recommendations

- Effect of riveting on surface roughness and burr formation of CFRP and GFRP
- Effect of built-in holes in formation of CFRP and GFRP plates
- Effect of different tool geometry on hybrid laminate

# Bibliography


1. **Ashby MF, Jones DRH.** *Chapter 1-engineering materials and their properties.* 2012.
2. *Analysis of parametric influence on delamination in high-speed drilling of carbon fiber reinforced plastic composites.* **V, Gaitonde.** 2008.
3. *Assesment of delamination on drilling of fiber reinforced Ploymer.* **., Bayraktar S¸.** 2016.
4. *Trimming of CFRP aircraft components.* **M., Hashish.** 2013.
5. *Effects of hole machining defects on strength and fatigue life of composite laminates.* **Persson E.** 1997.
6. *Study on drilling of reinforced plastics.* **Sakuma K.** 1984 : s.n.
7. *Investigations of delamination in GFRP material cutting using abrasive water jet.* **P, Unde.** 2015.
8. *effect of vibratory drilling on hole quality in polymeric composites.* **S, Arul.** 2006.
9. *Effect of tool wear on delamination in drilling composite materials.* **C, Tsao.** 2007.
10. *Experimental study of drilling glass fiber reinforced plastics (GFRP) manufactured by hand lay-up.* **JP, Davim.** 2004.
11. *Effects of feedrate and chisel edge on delamination in composite dirlling.* **S, Jain.** 1993.
12. *An analysis of delamination in drilling composite materials.* **Wong T.** 1982.
13. **Chouhan H.** Laser machining of Kevlar fiber reinforced laminates. 2016.
14. *Bonded repair of composite aircraft structures:a review of scientific challenges and opportunities.* **Katnam K.** 2013.
15. *The cutting process, chips, and cutting forces in machining CFRP.* **KoPlev A, Lystrup A, Vorm T.** 1983.
16. *Delamination in drilling GFR-thermoset composites.* **U., Khashaba.** 2004.
17. *A review of mechanical drilling for composite.* **Liu D, Tang Y, Cong WL.** 2012.
18. *Drilling tool geometry evaluation for reinforced composite laminates.* **Dur~ao LMP, Gonçalves DJS.** 2010.
19. *Tool wear monitoring and hole surface quality during CFRP drilling.* **C, Ramirez.** 2014.
20. *Experimental study of surface quality and damage when drilling unidirectional CFRP composites.* **ED, Eneyew.** 2014.
21. *Experimental delamination analyses of CFRPs using different drill geometries.* **TJ, Grilo.** 2013.
22. *delinmesinde olus¸ an deformasyona delme parametrelerinin etkisinin _Incelenmesi.* **E., Kılıçkap.** 2010.
23. *Experimental investigation of surface damage in drilling of glass fiber reinforced polymer composite materials.* **Ekici E.** 2009.
24. *The effect of cutting tool geometry on thrust force and delamination when drilling glass fibre reinforced plastic composite.* **A, Abrao.** 2008.
25. *Milling force modelling of multidirectional carbon fiber reinforced polymer laminates.* **Karpat Y.** 2012.
26. *Investigation of cutting parameter effects on surface.* **O, Erkan.** 2016.
27. *Precision drilling of composites with abrasive-waterjets.* **M., Hashish.** 1993.
28. **M, Hashish.** *Machining of advanced composites with abrasive-waterjets.* 1989.
29. *Peak stress reduction in the laser contouring of CFRP.* **MF, Zaeh.** 2017.
30. *A review on machining of fiber reinforced plastic using ABRASIVE WATERJET.* **S, Patel.** 2013.
31. *Nontraditional machining processes.* **M., Shukla.** 2013.
32. *Experimental Investigation on Machinability of Polypropylene Reinforced.* **Tran, Dinh Son.** 2020.
33. *Machining of carbon fiber reinforced polymer.* **Che D.** 2014.

# Thesis Naeem

*by* Syed Husain Imran

**Submission date:** 14-Jul-2021 10:56AM (UTC+0500)
**Submission ID:** 1619441829
**File name:** 12502_Syed_Husain_Imran_Thesis_Naeem_721563_906089336.pdf (1.14M)
**Word count:** 5781
**Character count:** 32670

Thesis Naeem

ORIGINALITY REPORT

| 15% | 8% | 14% | 4% |
|---|---|---|---|
| SIMILARITY INDEX | INTERNET SOURCES | PUBLICATIONS | STUDENT PAPERS |

PRIMARY SOURCES

| | | |
|---|---|---|
| 1 | Meltem Altin Karataş, Hasan Gökkaya. "A review on machinability of carbon fiber reinforced polymer (CFRP) and glass fiber reinforced polymer (GFRP) composite materials", Defence Technology, 2018<br>Publication | 6% |
| 2 | researchportal.port.ac.uk<br>Internet Source | 4% |
| 3 | Sikiru Oluwarotimi Ismail, Hom Nath Dhakal, Ivan Popov, Johnny Beaugrand. "Comprehensive study on machinability of sustainable and conventional fibre reinforced polymer composites", Engineering Science and Technology, an International Journal, 2016<br>Publication | 1% |
| 4 | Submitted to Jawaharlal Nehru Technological University Anantapur<br>Student Paper | 1% |
| 5 | Submitted to Universiti Putra Malaysia<br>Student Paper | <1% |

| | | |
|---|---|---|
| 6 | mafiadoc.com<br>Internet Source | <1 % |
| 7 | Submitted to University of Bradford<br>Student Paper | <1 % |
| 8 | Submitted to Embry Riddle Aeronautical University<br>Student Paper | <1 % |
| 9 | Submitted to International Islamic University Malaysia<br>Student Paper | <1 % |
| 10 | www.mdpi.com<br>Internet Source | <1 % |
| 11 | Liu, D.. "A review of mechanical drilling for composite laminates", Composite Structures, 201203<br>Publication | <1 % |
| 12 | Muhammad Harris, Muhammad Asif Mahmood Qureshi, Muhammad Qaiser Saleem, Sarmad Ali Khan, Muhammad Mahmood Aslam Bhutta. "Carbon fiber-reinforced polymer composite drilling via aluminum chromium nitride-coated tools: Hole quality and tool wear assessment", Journal of Reinforced Plastics and Composites, 2017<br>Publication | <1 % |
| | repository.tudelft.nl | |

| | | | |
|---|---|---|---|
| 13 | Internet Source | | <1 % |
| 14 | KM John, S Thirumalai Kumaran, Rendi Kurniawan, Ki Moon Park, JH Byeon. "Review on the methodologies adopted to minimize the material damages in drilling of carbon fiber reinforced plastic composites", Journal of Reinforced Plastics and Composites, 2018<br>Publication | | <1 % |
| 15 | journals.sagepub.com<br>Internet Source | | <1 % |
| 16 | Lalwani, D.I.. "Experimental investigations of cutting parameters influence on cutting forces and surface roughness in finish hard turning of MDN250 steel", Journal of Materials Processing Tech., 20080912<br>Publication | | <1 % |

| | | | |
|---|---|---|---|
| Exclude quotes | Off | Exclude matches | Off |
| Exclude bibliography | On | | |