Faculty of Manufacturing Engineering

OPTIMIZATION OF DRILLING PARAMETER FOR CARBON FIBER REINFORCED POLYMER CFRP MATERIAL USING RSM

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Master of Manufacturing Engineering
(Manufacturing System Engineering)

2019

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A thesis submitted
in fulfillment of the requirements for the degree of Master of Manufacturing Engineering (Manufacturing System Engineering)

Faculty of Manufacturing Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2019

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TAJUK: **Optimization Of Drilling Parameter For Carbon Fiber Reinforced Polymer CFRP Material Using RSM.**

SESI PENGAJIAN: **2018/2019**

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DEDICATION

To my beloved mother Hajjah Rukiah Binti Arpan for her endlessness loves and support and to my late father Haji Abdul Rahim Bin Yusof even could not see the completion of this thesis as well as my lovely wife Ani Liza Binti Abd Rahman.

ABSTRACT

In today's scenario, composite like Carbon Fiber Reinforced Polymer (CFRP) is a standout and the most alluring and profitable material among all the designing materials. The reason for using these composite laminates is their superior properties and their influential application in aerospace industries, aircraft structural components, and others. The present learning about drilling of CFRP composites is in a moving stage for its ideal usage in different fields of uses despite being composite overlays are viewed as difficult for machine materials. Drilling process is highly depended on the drilling parameters (i.e. Feed, Speed). This becomes more important when a new product design , shape and hole dimension is critical inwhich high surface finish, accuracy of dimensional tolerances and high material removal rate are required. Therefore, the application using Ultrasonic and Non Ultrasonic is proposed to get the optimization of machining parameters in improving the product quality, as well as its productivity. Effects of input variable of drilling process (Spindle speed, feedrate) using Ultrasonic and Non Ultrasonic on the machining output; entrance and exit hole accuracy also surface roughness were studied. The optimum values of machining parameters can be obtained is Spindle Speed = 2500 rpm , Feed rate = 0.09 mm/tooth and Ultrasonic Assisted Drilling.

ABSTRAK

Dalam senario hari ini, komposit seperti Polimer Diperkukuh Serat Karbon (CFRP) adalah yang paling menonjol di antara bahan yang paling menarik dan menguntungkan di kalangan semua rekabentuk bahan.Sebab menggunakan laminates komposit ini adalah ia bersifat unggul dan aplikasi berpengaruh mereka dalam industri aeroangkasa, komponen struktur pesawat, dan lain-lain. Pembelajaran terkini tentang penggerudian komposit CFRP berada di peringkat yang bergerak untuk kegunaan idealnya dalam bidang penggunaan yang berbeza. Begitu juga, lapisan komposit dilihat sebagai sukar untuk bahan mesin. Proses penggerudian sangat bergantung pada parameter penggerudian (iaitu Feed, Speed). Ini menjadi lebih penting apabila reka bentuk produk, bentuk dan lubang dimensi baru adalah kritikal di mana selesai permukaan yang tinggi, ketepatan toleransi dimensi dan kadar penyingkiran bahan yang tinggi diperlukan. Oleh itu, penggunaan ultrasonic dan bukan ultrasonic dicadangkan untuk mendapatkan pengoptimuman parameter pemesinanagar ianya dapat meningkatkan kualiti produk, serta produktiviti. Kesan pemboleh ubah input proses penggerudian (Spindle speed, feedrate) menggunakan ultrasonic dan bukan ultrasonic pada output pemesinan; ketepatan lubang masuk dan keluar juga kekasaran permukaan dikaji. Nilai optimum parameter pemesinan boleh didapati ialah Spindle Speed = 2500 rpm, Kadar suapan = 0.09 mm / gigi dan pengeboran bantuan ultrasonic.

ACKNOWLEDGEMENTS

"Bismillahirrahmanirrahim"

"In the name of Allah, The Most Beneficent, The Most Merciful"

Alhamdulillah, first praise to Allah S.W.T, the Almighty whom ultimately we depend for sustenance, guidance and blessing of healh, strength and spirit in completion of this dissertation. I would like to take this opportunity to extend my gratitude to my supervisor, PM Dr. Raja Izamshah Bin Raja Abdullah and Assistant Engineer Mr Mohd Hanafiah Bin Mohd Isa from the Faculty of Manufacturing Engineering UniversitiTeknikal Malaysia Melaka (UTeM) for he essential supervision, support and encouragement towards the completion of this thesis .

Special thanks dedicated to my wife, my parents and all my family members for their love, support and guidance where, I would not able to complete the study without their unimagine support and guidance. I also would like to express my appreciation to all the staff, assistant engineer and lecturers at Fakulti Kejuruteraan Pembuatan, Universiti Teknikal Malaysia Melaka (UteM) for all their assistance and sharing of knowledge in completeing this dissertation.

Finally, I would like to extend my special thanks to all my classmates at Politeknik Muadzam Shah for their help and their support. For all their time, advice, ideas, comment and information sharing was greatly appreciated.

CHAPTER 1

INTRODUCTION

1.1 Background

The concept of reinforcement fiber material was found with the use of straw as reinforcement for the brick produced in 800 BC in Israel. While in the United States, the use of short glass fiber reinforcement for cement mixtures has been introduced since 1930 and the material with a fiber-reinforced resin matrix (composite that we know today) has been developed since 1940s. In this research, the term composite is used will be referred to the polymer reinforced with fibers or commonly referred to as FRP (Fiber Reinforced Polymer).

Since the use of composite expanded in the '60s, a lot of development and exploration have been achieved. The amount and number of composite materials have been increased in parallel with the rapid development of new market demand and dominance. Development is not merely focused on improvement of the existing composite system, but also included in the development technology and the potential range of sources of raw materials to be used as ingredients composite foundation.

Composites use in the aerospace industry is expanding, with carbon fibre reinforced plastics (CFRP) arguably at the forefront for replacing more conventional workpiece materials such as aluminium and steel in aircraft structural components. The nature of CFRP products still often necessitates the use of various machining processes in order to fulfil performance and design requirements. Of these, hole drilling is one of the most widely used operations as a mean to facilitate mechanical joining of composite parts with other elements. Despite considerable developments in tooling and machine tool technology as well as improved process capability over the past decade, innovations are constantly being pursued by industry to obtain greater productivity and improved surface quality/integrity.

While there is a significant body of research on the drilling of CFRP, the vast majority of publications deal (understandably) with fixing holes in the region of 5 – 6 mm diameter, there is also a need for data relating to the machinability of smaller diameter holes (< 3 mm), for example in relation to acoustic panels, where sections can incorporate up to 100,000 of such holes. More recently, multilayer metallic/composite stack materials consisting of CFRP, titanium and/or aluminium have also seen a surge in demand/use, particularly for aerospace structures subjected to high mechanical loads during service. Challenges faced when drilling such structures include not only the marked anisotropy/in- homogeneity, lack of plastic deformation and abrasive characteristics for the CFRP composites but also the dissimilar mechanical/physical properties for the stack materials. These aspects impact on selection of appropriate operating parameters, fluid supply, swarf evacuation etc. with consequent adverse effects on tool life and workpiece quality.

1.1.1 Fiber Reinforced

Fiber is an important element in the composite. Many research and development has been done on the effects of fiber in the type, volume fraction, the design and orientation. Fibers generally occupy 30% - 70% of the volume in the composite matrix. The fibers can be chopped, woven, sewn and / or braided. This type of fiber is most commonly used in advanced fiber reinforced polymer composites for structural applications is Glass fiber, aramid and carbon. Glass fiber is the most inexpensive, while carbon is the most expensive. Aramid fiber price is almost equal to the price of low-quality carbon fiber.

Glass fiber is divided into three classes, namely E-glass, S-glass and C-glass. C-glass intended for use in electrical applications, S-glass is used for high strength and E-glass is used for high corrosion resistance. Of the three fibers, E-glass is the most common reinforcing materials used in civil structures. E-glass is made of lime-alumina-borosilicate which can be easily obtained from the abundance of raw materials such as sand. Strength and modulus of glass fiber will decrease with the increasing temperature. Therefore, the glass material can undergo creep in continuous loads. Glass fiber itself is considered as an isotropic material and has a thermal expansion coefficient that is lower than of steel.

1.1.2 Carbon fibre reinforced plastic (CFRP) composites

1.1.2.1 Manufacturing of CFRP

As mentioned previously, various methods can be used for the manufacture of advanced composite components including vacuum bag moulding (oven cured), autoclave moulding, filament winding, press moulding, pressure bag moulding, thermal expansion moulding and pultrusion (Sheikh-Ahmed, J. Y et.al 2009) . However, oven and autoclave curing processes were the only methods used to fabricate workpieces for the current work.

1.1.2.2 Properties of CFRP

Carbon fibre reinforced plastic has relatively low thermal conductivity especially across the fibre direction (maximum of 1 W/mK as opposed to ~80 W/mK along the fibre direction) (Shim, H., Seo et.al 2002). Table 2.4 details the sample mechanical properties for a UD and woven carbon fibre composite laminate manufactured by the oven cured vacuum bag process. The unidirectional lamina has a 60% Vf while the value is 55% for the fabric woven data. It is evident that the UD laminate has superior properties as compared to the woven material. Table 1.1 details various mechanical properties for the most commonly used CFRP composites against equivalent of GFRP and AFRP composites.

Table 1.1 : Mechanical properties for carbon fibre laminate (Anon et.al 2009)

		283 gsm 3k HTA5131
Tensile modulus (GPa)	128.9	62.6
Tensile strength (MPa)	2159	927
Compression modulus	123.2	59.4
Compression strength	1330	729
Flexural modulus (GPa)	121.9	57.1
Flexural strength (MPa)	1958	1181
* gsm is the fibre areal density in grams per square metre 12k indicates 12,000 fibres in each tow		

1.2 Problem Statement

Conventional machining of fiber-reinforced composites is difficult due to diverse fiber and matrix properties, fiber orientation, inhomogeneous nature of the material, and the presence of high-volume fraction (volume of fiber over total volume) of hard abrasive fibers in the matrix. A variety of machining operations are performed on these materials and drilling is one of the major methods used in industries.

In the aerospace industry or other industry, fiber reinforced plastics (CFRP) are primarily used in structural components as a replacement for metal alloys, allowing for weight reduction. As structural materials, these materials must be drilled in order to connect them with other material components, and the bolt joining efficiency and quality depend critically on the accuracy of the machined holes (Ishida et al., 2014).

However, when machining carbon fiber composite materials, delamination at the edge of machine is the major problem due to multi ply composite material orientation that was constructed by lay in anisotropy and inhomogeneity form (Ishida et al., 2014). This is supported by Huda et al., 2016 where delamination, fibre and matrix pull-out, matrix cracking and smearing, and rapid tool wear are the most commonly problems reported when machining CFRP.

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 caused by drilling, delamination is recognized as the most critical. Many researchers over the past years have tried to study the machinability of composites using traditional machining methods and reported considerable improvement in dimensional and performance characteristics like surface roughness, hole quality and tolerance.

Even though this is so, drilling-induced delamination is among the major concerns of applying this material in various industries. To investigate the damage effects of drilling an optimization technique is employed. Appropriate control parameters are chosen to narrow the scope of study such as cutting speed, feed rate using ultrasonic / non utrasonic drilling and the main outputs investigated are surface roughness and hole accuracy (error entrace and exit).

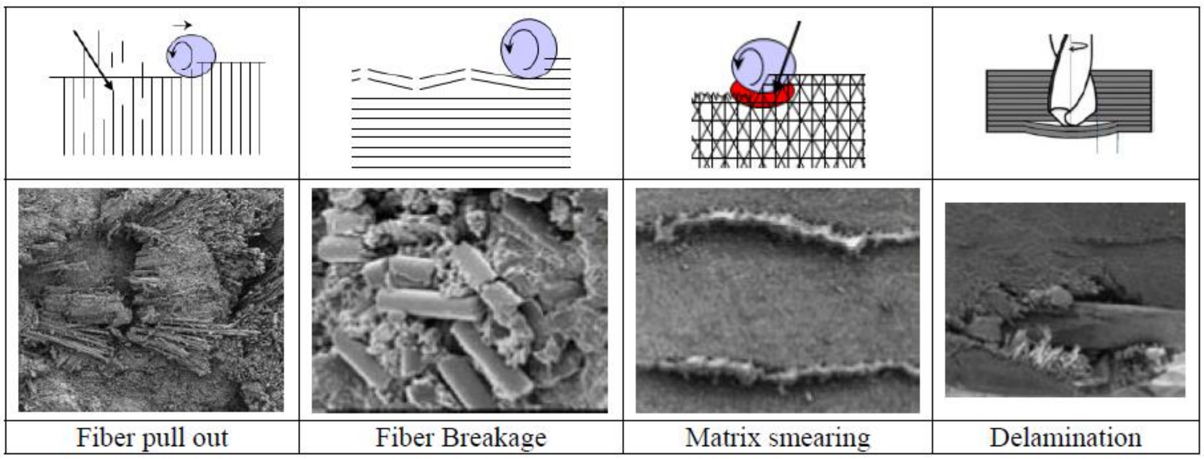

Figure 1.1 Potential problems machining CFRP using solid tools (Photos by Miller et.al. 2013)

1.3 Objective

1. To investigate the effects of drilling parameter (speed, feed) on hole performances using conventional drilling and ultrasonic assisted drilling of Carbon Fiber Reinforced Polymer (CFRP) Composite.
2. To optimize the drilling parameters to obtain the best results of hole accuracy (error entrance and exit) and surface roughness.
3. To validate the effectiveness of the optimized parameter

1.4 Scope

The scopes of this project are listed as below :

In this research, Parameters being evaluated to obtain the hole accuracy (error entrance and exit) and surface roughness are cutting speed and feed rate using non ultrasonic drilling and ultrasonic drilling. Where, all the value spindle speed and feed rate is varied.

1.5 Significance Of Study

This research aims to enrich the understanding and knowledge regarding the drilling parameters towards the accuracy hole (error entrance and exit) and surface roughness of work piece. The following contributions gotten from the research are as listed ;

i. Analysis of the most influential parameters contribute towards surface roughness and hole accuracy

ii. Selecting the drilling parameter value using non ultrasonic drilling and ultrasonic that will yield towards better surface roughness and easy hole accuracy.

iii. No trial and error process required for getting expected surface raughness and hole accuracy value

iv. Mathematical equation for prediction of surface roughness and hole accuracy can be used in future.

1.6 Thesis Organization

The chapters of the thesis are organised as follows:

In Chapter 1, background Carbon Fiber Reinforced Polymer (CFRP) , application, machining and its challenges in machining (problem statement) are described. The research objectives and scope of the research are also explained in this chapter and Gantt chart for the research is shown in appendix A.

In Chapter 2, principle, knowledge and function of CFRP material on machining especially in drilling conventional drilling and ultrasonic is explained. The work of previous research on CFRP performance in machining are also reviewed. Furthermore, the gaps of study between present and previous researches are identified. This chapter also describes the significance of statistical method which can be used to find the optimal drilling parameters for CFRP machining.

Chapter 3 presents the methodology of this research which includes type of specimen, equipment, drilling tool and experimental setup. The fabrication process for drilling tool and experimental design used in this research are also explained. The experimental design presented in this chapter includes the detail of statistical method and data analysis method used for optimizing the drilling parameter feature in CFRP machining.

Chapter 4 presents about experiment test results and analysis. In this chapter, specimens will be tested and all the required data will be collected and analysed. The result will be analysed and discussed focusing on the optimization of the milling parameters and then discussion about the interaction between the parameters and the results from performance observations for each drilling CFRP.

Chapter Five concludes the work done in this project, it emphasizes on the importance of studies and the recommendations of the future working is also presented in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The study on optimization of drilling for GFRP materials are based on several manufacturing knowledge such as theories and methods of material removal. In this chapter, topics that are related to analyse the optimization of drilling feature are reviewed. They include mechanical and chemical properties of GFRP, potential application of GFRP as automotive, sports gear areas and in airship production, mechanism of tool drilling geometry in machining operation, measurement of drilling performance demonstrated by previous researchers and several statistical methods which has potential to be used for optimization process on variables that being studied. The purpose of reviewing these topics is to provide a theoretical base for the remainder of this thesis.

2.2 Composite Material:

Composite is a combination of two or more material having individual chemical, mechanical and physical properties. After combining this material, the property of the particular material change and a better single material is obtained, as a composite. Now this composite have many advantages of being used in fields like shipping, aerospace, and aircraft industries. A composite has enough specific stiffness, high specific strength (Guner F. S., Yagci Y.et.al.2006), less thermal expansion coefficient, high moisture absorption ability with time (Mohanty et al.2001), and a real ability for corrosion protection. Composite materials are fully different from conventional materials. In conventional material, machining is easy in comparison with polymer composite. The machining of composites is performed under consideration of some behavior as it depends on physical and mechanical properties of fiber of the composite. And also the properties depend on the amount of fiber, quality of fiber, type of fiber and chemical composition of fiber (Kaw A. K. et. al 2010). The fibrous material is the most advanced composite, made by resin matrix. It's laminated in a sequence of particular direction hence get enough material stiffness and better strength. Composite stiffness and strength also depends on the orientation of fibers. The value of orientation is determined by applying proper load on fiber filament. Carbon composite material has little orientation value as compared to glass composite material.

The composites consist of two primary phases: matrix and reinforcement

i. Matrix: Matrix is the first phase in composition present in large amount and is continuous. In structure composite, matrix possess individual property and enhances the overall property of the product.

ii. Reinforcement: It is more strong, more stiff and harder than the first phase that is the matrix. Reinforcement changes the physical properties like thermal resistance, wear resistance, and thermal conductivity. In this phase machining operation such as extrusion, rolling, forging and drilling, etc. can be performed. Carbon fiber, silicon fiber or glass fiber is monofilament fiber that is used in continuous reinforcement. When both phase meet its make other physical identification (Ahamed A. R., Asokanand et al.2010).

2.3 Classifications of composite materials:

Many property of composite materials have been classified in two phases that as described below

2.3.1 According to arrangement and nature of reinforcement

i. Reinforced composites

ii. Laminated composite

iii. Particulate reinforced composite

iv. Hybrid composite

i. Reinforced Composite: When a length of the reinforcement is higher than cross-sectional dimension, this type of composite is known as the Reinforced composite. In a single layer composite, length of reinforcement may be long or short as it depends on the size of the reinforce (Albuquerque et al.2000).

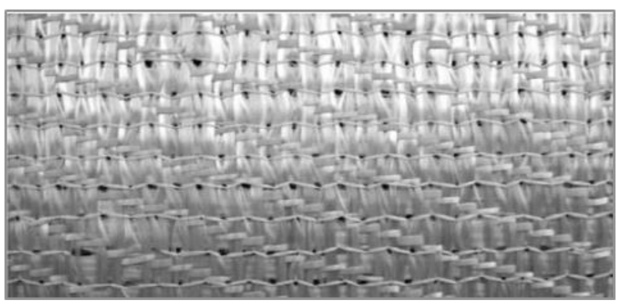

Figure 2.1: Reinforced Composite

Orientation of long reinforced fiber composite is in one way or one direction, this type of fiber is known as the continuous fiber reinforced composite and the length of fiber is neither too short nor too long, this type of composite is known as discontinuous fiber reinforcement composite.

ii. Laminated Composite: The layer of fibrous is arranged in a particular way or particular direction, by bonding some unusual condition that increase the engineering property of tensile strength by 33% and tensile modulus by 75% (Rashed H. M. et al.2006) of the composite. For better bonding of fibrous, three layers are arranged in alternative way between reinforcement and polymer matrix. Combining individual layer results in increment of the property of high modulus (Guner F. S., Yagci Y.et.al.2006), high strength and corrosion resistance. An example of laminated composite is paper and plywood is shown in figure 2.2

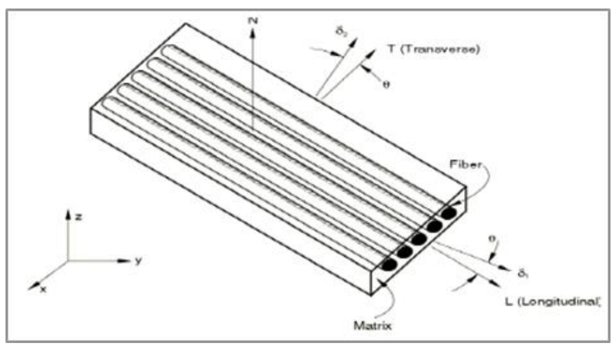

Figure 2.2 : Laminated Composite

iii. Particulate Reinforced Composite: Reinforcement used equally in all the available directions resulted in making Particulate reinforced composite. This phenomenon is resulted improved stiffness but at the same time it also effects the strength of particulate composite. Advantages of particulate composites are high wear resistance, high thermal performance of composite, low coefficient of friction and very small shrinkage in the composite in compared to others.

iv. .Hybrid Composite: In single matrix fillers are used to increase the mechanical property. When two or more types of fillers are used, the composite is said to be hybrid composite. This type of composite is efficient in improving the properties due to hybridization. Hybrid composite is more economical when compared to others. Most standard hybrid composites are carbon fiber, glass fiber and polymeric resin in the matrix. The property of single phase composite is lower than the hybrid fiber composite.

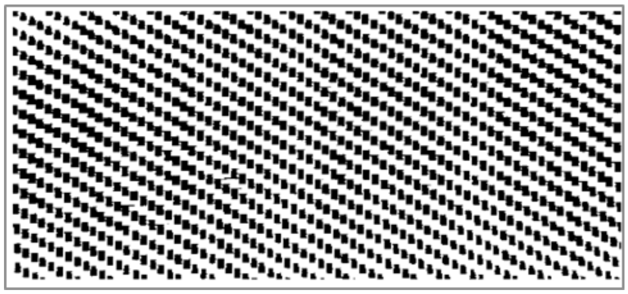

Figure 2.3 : Hybrid Composite

2.3.1 According to Types of Matrix Material

i. Polymer Matrix Composite (PMC)

ii. Metal Matrix Composite (MMC)

iii. Ceramic Matrix Composite (CMC)

i. Polymer Matrix Composite (PMC): Polymer matrix composite are most useful in the field of structural components due to their unique properties. The use of reinforced polymer in matrix improves the strength and stiffness. Polymer matrix composite doesn't need high temperature and high pressure in the processing phase. Manufacturing of polymer matrix composite is simple in comparison to Metal Matrix Composite (MMC) and Ceramic Matrix Composite (CMC) which makes it viable in structure field. Particles reinforced polymer (PRP) and Fiber reinforced polymer are the type of polymer matrix composite.

ii. Metal Matrix Composite (MMC): In this composite metal is used in the form of matrix hence this composite is called metal matrix composite. It has greater properties (Mehrabian R. G. R.et.al.1974) elevated in the range of temperature, thermal expansion coefficient low, high specific modulus and high strength of composite as compared to monolithic. Metal matrix composite is used in many industry like in thermal plant turbines, boilers, combustion chambers, nozzles of rocket, heat exchanger and in structure fields and others.

Figure 2.4 : Metal Matrix Composite

iii. Ceramic Matrix Composite (CMC): In matrix phase, ceramic materials are used to make the composites. The primary aim in manufacturing ceramic composite is, it has improved strength and stiffness along with the toughness of the material. It is able to performs in very high-temperature condition, even in stressed placed. It’s also used in construction field.

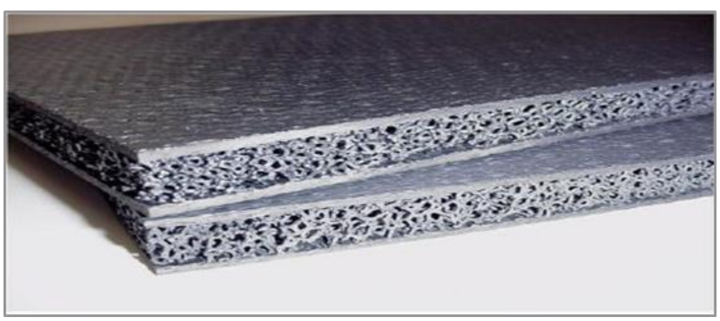

Figure 2.5: Ceramic Matrix Composite