OPTIMIZATION OF CUTTING PARAMETERS FOR DRILLING CARBON-EPOXY FABRICS LAMINATES WITH DIFFERENT FIBER ORIENTATIONS

BY

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ABSTRACT

The automotive, aerospace, manufacturing and electronics industries have demonstrated an increased demand for critical components made of composite materials due to their unique properties. Machining process especially drilling is usually widely employed in this industry. However, the quality of drilled hole is the main issue since the drilling process usually occurs at the end of the manufacturing process. In this work, a study on cutting parameters such as the speed and feed rate, as well as the laminates configuration were investigated. This research has investigated the parameters that affect the damage mechanism i.e.: peel-up delamination and push-down delamination and the force on the carbon-epoxy laminates during drilling process on the ANILAM CNC machine. Six types of fabrics laminates stacking sequences which are 0°/0°/0°/0°, 45°/45°/45°/45°, 45°/0°/45°/0°, 0°/45°/0°/45°, 0°/0°/45°/45° and 45°/45°/0°/0° have been tested in this research. The force evolutions on each layer have also been studied. This study comprised of identification of optimum parameter and suitable laminates configuration to improve the force, peel-up and push-down delamination. The General factorial was employed to design the number of experiment. Mathematical models were developed for the output responses of peel-up delamination (F_{din}), push-down delamination (F_{dout}) and force (N). A desirability of 98.5% was obtained with the peel-up delamination (F_{din}) value of 1.0479, push-down delamination (F_{dout}) value of 1.00098 and force (N) value of 2.228N. The optimized values were experimentally verified and found to be different 2% to 11% from the predicted values. In the second phase of experimental work, optimum parameters were employed to ensure a clearer view on the force evolution on each layer of the fabrics laminates and its' effects on the damage mechanism.

ملخص البحث

أظهرت السيارات والطيران والصناعات التحويلية وصناعات الالكترونيات وزيادة الطلب على عنصر حاسم المصنوع من المواد المركبة نظرا لخصائصها الفريدة. ويستخدم على نطاق واسع عملية تشكيل الحفر خاصة عادة في هذه الصناعة .ومع ذلك، فإن نوعية حفر حفرة هي القضية الرئيسية منذ عملية الحفر عادة في نهاية عملية التصنيع. في هذا العمل، قد تم التحقيق عن دراسة قطع المعلمة مثل السرعة ومعدل التغذية، فضلا عن تكوين شرائح. وقد حققت هذه البحوث المعلمات التي تؤثر على أي آلية الضرر : قشر متابعة التبطين، ودفع إلى أسفل التبطين والقوة على الايبوكسي الكربون شرائح أثناء الحفر عملية على آلة التصنيع باستخدام الحاسب الآلي ANILAM. ستة أنواع من الأقمشة شرائح وقد تم اختبار التراص متواليات في هذا البحث الذي هو 0°/0°/0°/0° 0°/45°/0°/45°, 45°/0°/45°/0°, 45°/45°/45°/45°, 0°/0°/45°/45° and 45°/45°/0°/0° درجة. والتطورات النفاذ في كل طبقة كما تم دراستها .هذه الدراسة تحديد تتألف من المعلمة الأمثل ومناسبة شرائح التكوين لتحسين القوة، وقشر متابعة والتبطين دفع إلى أسفل. كان يعمل مضروب العام لتصميم عدد من التجربة. تم تطوير نماذج رياضية لاستجابات انتاج ما يصل قشر التبطين (F_{din})، ودفع إلى أسفل التبطين (F_{din})، وقوة(N). م الحصول على استحسان 98.5٪ مع قشر متابعة التبطين (F_{dout}) من قيمة 1.0479، ودفع إلى أسفل التبطين (F_{dout}) من قيمة 1.00098 وقوة (N) من قيمة 2.228N. وتم التحقق تجريبيا القيمة الأمثل وجدت لتكون2٪ إلى11٪ خطأ مع القيمة المتوقعة. في المرحلة الثانية العمل التجريبي، تم توظيف المعلمات الأمثل لديها رؤية واضحة عن تطور التنفيذ في كل طبقة من شرائح الأقمشة وأثرها على آلية ضرر.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion; it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Manufacturing Engineering.

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Md Noor Hj Salleh
Dean,Kulliyah of Engineering

DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Name: Nor Farah Huda Bt Abd Halim

Signature……………………………….. Date……………………

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

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Affirmed by NOR FARAH HUDA BT ABD HALIM

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Signature	Date

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LIST OF ABBREVIATIONS

3D	Three dimensional
ANOVA	Analysis of Variance
FFT	Fast Fourier Transform
GFRP	Glass Fiber Reinforced Plastic
CFRP	Carbon Fiber Reinforce Plastic
SEM	Scanning Electron Microscope
DOE	Design of Experiment
SMC	Sheet Molding Compound
CNC	Computer Numerical Control
HSM	High Speed Machining

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Over the past decades, composite materials such as carbon fibre reinforced plastics (CFRP) and glass fiber reinforced plastics (GFRP) have been widely used in aerospace and automotive industries due to their unique properties such as high mechanical properties and low in weight. Nowadays, their applications are not only limited for automotive and aerospace industries but in electronic industries as well to fabricate printing wired board especially by using the glass fiber reinforced plastics. However, the manufacturing costs of the GFRP and CFRP are to some extent, very high. Thus, the machining operation applied on the composites should be done appropriately to reduce the cost and waste. Machining operations such as conventional drilling, laser beam drilling and water jet drilling have been proposed for a variety of economics and quality reasons but the conventional drilling remains as the most preferred and adopted technique in the industry today. In aviation or automobile industries, drilling is needed due to the large number of holes to be drilled for the final assembly requirement. Drilling problems can account to expensive production waste because many drilling operations are usually among the final stages in manufacturing operation unless the drilling operations are performed properly. However, poor drilling practices can reduce the properties of the CFRP and the machining of composite materials are more complicated than machining the metals. Several problems can take place due to poor drilling practises and techniques such as delamination, inter laminar cracking, fiber/matrix debonding and thermal damage. As a result, such problems that occur in the drilling area can reduce the strength of the composites. Therefore, less delamination area during drilling composite materials needs to be achieved and predicted.

1.2 PROBLEM STATEMENT AND ITS SIGNIFICANCE

Drilling of composite has become a major problem to the industry when it comes to the surface finish on the composite. The quality of the hole plays a vital role in drilling. Obtaining the desired hole dimensions, roundness, and surface finish along the length of the hole are significant to the industry.

As mentioned by Abrão, Faria, et al. (2007) , the primary drawbacks are related to surface delamination, fiber/resin pullout and inadequate surface roughness of the hall wall. Among the defects caused by drilling, delamination appears to be the most critical one. The delamination will occur at both the entrance and exit of the composites laminates. The peel-up delamination and push-down delamination are the most common damage investigated by many researchers. The delamination occurrence will reduce the strength of the composite laminates and decrease the hole quality by the drilling operation.

Up until today, most researchers are unable to obtain a satisfactory outcome in drilling composite materials. Most researchers have investigated on the unidirectional laminates or mat/ short fiber composite laminates, where there are a few researches that investigated on the effect of fabric orientation while drilling composite laminates. This research involves the analysis of the surface finish and the forced exerted on the laminates with different laminates configurations and the variation of machining parameters.

This study identified the optimal cutting parameter for composites such as the force, speed and diameter of the tool depending on the fabric direction. Different fabric orientations incorporated with spindle speed and feed rate have been tested in this research to obtain the optimum results on delamination and force. In this study, the laminates configurations were the major element for finding optimal surface quality.

The results collated from this study may be useful in improving the composites surface finish after undergoing the drilling process. This study provides the descriptive knowledge on the optimum cutting parameters of the composites and the prediction of delamination area due to drilling at different fabric directions. It is believed that it can contribute as a guide to machines with good surface quality that are widely used in engineering application.

1.3 RESEARCH OBJECTIVES

The objective of this research is to identify the optimum cutting parameter and fabric direction for cutting the carbon-epoxy fabric laminates. The specific objectives of this research are as follows:

i. To fabricate the composites plate with different fabric fiber stacking sequences i.e.; 0°/0°/0°/0° ,45°/45°/45°/45° ,0°/45°/0°/45° ,45°/0°/45°/0° ,0°/0°/45°/45°,45°/45°/0°/0°.
ii. To establish effects of fiber fabrics stacking sequences during drilling operations.
iii. To investigate the effect of machining parameter (cutting speed and feed rate) and effect of fabric orientation on force and delamination factors**.**

iv. To determine the optimal cutting parameters e.g.; cutting speed, feed rate, depth of cut, drill diameter on carbon-epoxy laminates with different fabric direction and to investigate the damage mechanism on the laminates.

1.4 RESEARCH METHODOLOGY

In this study, the research begins with the review of other works. Figure 1.1 illustrates the research methodology involved in this research. In order to achieve the aim of the research, the materials and cutting tools employed in this research are first selected. The work material used in this research is carbon-epoxy laminates with different fabrics orientation. The carbon-epoxy laminates were fabricated by hand lay-up and have been compressed by the compression molding machine by 7-8 psi pressure for 24 hours.

Six types of laminates stacking sequences were tested in this investigation. In order to design the number of experiment, the Design Expert software was used. General factorial has been selected as the design of experiment since it can fit with the parameters involved in this research. Cutting experiments were conducted on the ANILAM CNC machine. A force measurement device, the dynamometer was attached on the working table to record the force history during the drilling process. The damaged areas were captured by the digital microscope and analyzed by using the software included. Drilling operations were conducted with 4mm High Speed Steel drill bits.

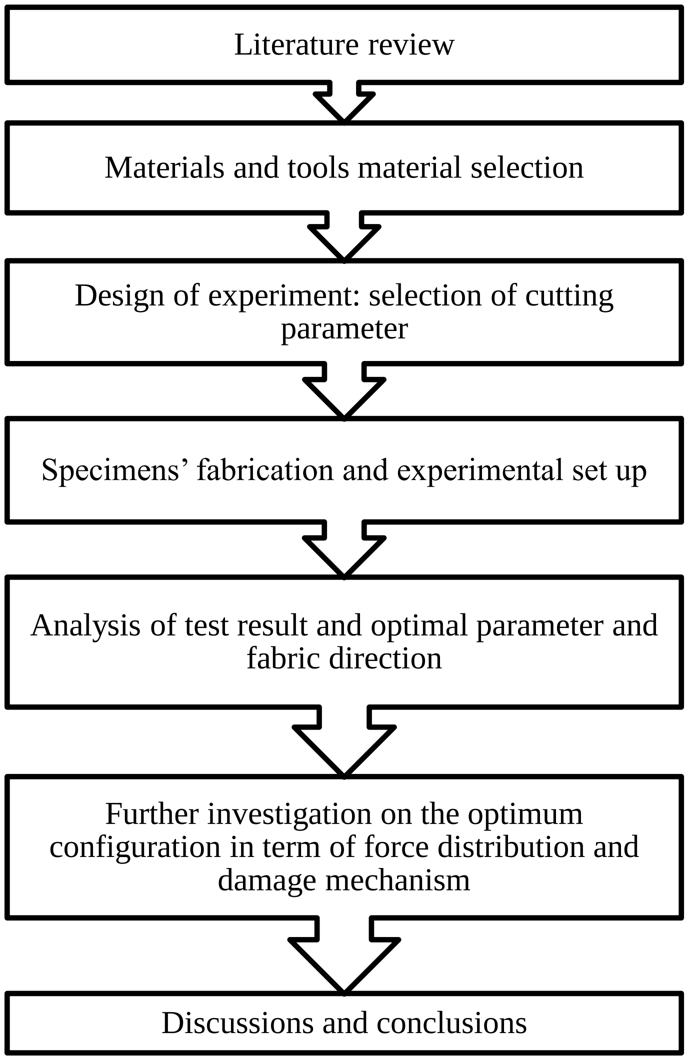

Figure 1.1: Research methodology

1.5 RESEARCH SCOPE

In this study, the scopes of the research are defined as follows:

i. The carbon-epoxy composite plates were employed in this research whereas in real application the composites are actually in various shapes.

ii. The composites laminates fabrication is fabricated manually by mixing the carbon fabric and matrix as a resin under compression loading with various fabrics laminates configurations. In the aerospace application, the Prepeg method is employed where a cycle of temperature is involved in the material fabrication.

iii. High Speed Steel (HSS) twist drill with 4 mm diameter has been employed in this study

iv. Delamination factors i.e. peel-up and push-down delamination and force that exerted on the composites laminate are the dependent variable that have been investigated in this study.

1.6 THESIS ORGANIZATION

The first chapter of this thesis introduced the general knowledge on drilling fiber-reinforced plastics. It presents the problem statement and its significance, research objectives, research methodology and research scope. The rest of the thesis is organized as follows:

Chapter 2 explains more details on the literature review of the machining of the composites materials, specifically on the drilling of carbon reinforced plastics. The characteristic of the composite materials such as the type of carbon-reinforced plastics used and the machining aspects such as the machining parameters, types of tool implemented in the drilling process and the quality of the composites after machining are also elaborated in this chapter. Moreover, the hole quality such as the delamination and the thrust force and torque briefly explained in this chapter.

Chapter 3 highlights on the methodology applied in conducting this research starting from the literature review until the second phase of experimentation.

Chapter 4 clarifies on the design of experiment (DOE), experimental setup and material preparation. It presents the DOE used to generate the number of experiment.

Chapter 5 contains the results obtained from the drilling process. The force and delamination factors have been analyzed using the Analysis of Variance (ANOVA) that is included in the DOE. The optimum parameter design was discussed based on the test result analysis. Further investigation is carried out based on the optimum parameter and fabric configuration in terms of the force evolution during drilling process to understand the damage mechanism.

Chapter 6 concludes the overall results and recommends the optimum parameter for the machining operation.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

In recent years, the utilization of composites materials in comparison with metallic materials has increased significantly. Composites material are widely used in the aerospace industry due to its unique properties and characteristics such as low in weight, high mechanical properties, good corrosive resistance compared to metal and many others. Nowadays, composite materials are not only limited to the aerospace industry but they are also largely utilized in manufacturing, construction, automotive and electronic industry.

In general, composite materials are made up by two or more materials. When they are mixed and combined together by proper and appropriate way, the different characteristics and behavior of the different materials can result to final properties such as mechanical properties that cannot be found in other materials. Polymeric composites such as carbon fiber reinforced plastic (CFRP) and glass fiber reinforced plastic (GFRP) are commonly employed in the aerospace and automotive industries. Polymeric matrix is thermoset and thermoplastics are commonly used. Resin that goes into the thermoset groups have better mechanical properties even though they have higher cost. The most commonly used fabrics in fiber reinforced composites are carbon, fiber and Aramid fabrics especially for making tribo-components that encounter harsh operating conditions such as high stresses, speeds and temperatures.

The drilling process is usually employed in machining composite materials. The final process which is the assembly of part requires for the composite parts to be drilled. Joining part by part requires holes to be made. Part rejection at the final process will increase the cost of manufacturing and material processing. Above all, it is really important in the selection of machining parameters such as feed rate, spindle speed and cutting speed, tool materials and geometry, and types of composite materials to be used.

2.2 CHARACTERISTICS AND APPLICATIONS OF COMPOSITE

2.2.1 CFRP and GFRP Composite Laminates

Composite materials are basically divided into three categories which are polymeric composites, metallic composites and ceramics composites. Basically, carbon fiber reinforced plastic and glass fiber reinforced plastics lay under the polymeric composites (PMC) groups. In this PMC, the matrix is made by the thermoset or a thermoplastics polymeric resin. The most commonly used types of reinforcement are glass, carbon and Aramidic fiber while for resins, they are polyester and epoxy. Polyester has good mechanical characteristics where they are easy to handle and polymerized at room temperature. However, the epoxy resin has better mechanical properties compared to polyester although they are highly costly. Table 2.1 shows the properties of matrices commonly used from the polymeric composite materials.

Basically, there are several arrangements of reinforcement such as mat, roving, woven fabrics and pre-peg. Fibers are arranged in a random manner on a plane and are compressed lightly in mat arrangement. The mat arrangements are usually used to create quasi-isotropic composites with moderate mechanical properties. For roving, long fibers are wound around the bobbins. It can be used as continuous composites or cut into short fibers. Figure 2.1 indicates the different reinforcement arrangement in composites.