MACHINABILITY STUDY OF UNCOATED AND COATED CARBIDE TOOLS WHEN DRILLING CFRP/METAL STACKS

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Dedicated to:

My beloved parents,

Norizan Esa, Mahamad Hakimi Ibrahim

My wife and daughter,

Nur Hazwani Mohamad, Fatimah

My dedicated lecturers,

My endless spirits

and all my friends.

This is for you.

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ABSTRACT

Carbon fiber reinforced plastic (CFRP) composite is often used in combination with other materials, requiring it to be machined during fabrication of a structure. In the aerospace industry, CFRPs are often stacked together with metals to provide stronger and better performance of aircraft structural components with the advantage of weight reduction and increasing mechanical strength. Drilling which is the most common machining process of CFRP is complex and often results in delamination of the composites. This study presents the findings of an experimental investigation in drilling of CFRP plate stacked on top of Aluminum 2024 plate. Uncoated carbide and TiAlN coated carbide tool were used to perform the drilling of the CFRP/aluminum stack at cutting speeds of 70, 85, 100 mm/min with constant feed rate of 0.1 mm/rev using dry drilling. The responses that were analyzed include thrust force, torque, hole quality, CFRP surface delamination, and tool wear. Experimental results showed that the application of various cutting speeds have no significant effect on all the responses analyzed when drilling CFRP/aluminum stacks for both tools. In terms of hole quality and CFRP surface delamination, the uncoated tool displayed better results compared to coated tool at cutting speeds of 85 and 100m/min. This is due to the sharp cutting edge of the uncoated tool that enabled efficient cutting in producing holes. Experimental results also showed that coated tool performed better than uncoated tool producing lower thrust force and torque, lower surface roughness, and lower tool wear rate.

ABSTRAK

Komposit karbon bertetulang gentian plastik (CFRP) lazimnya digabungkan dengan bahan lain yang memerlukan ia dimesin ketika fabrikasi sebuah struktur. Di dalam industri aeroangkasa, CFRP lazimnya disusun berlapis bersama-sama logam untuk memberi kekuatan dan prestasi yang lebih baik bagi komponen struktur pesawat dengan pengurangan berat dan menambah kekuatan mekanikal. Penggerudian CFRP adalah proses pemesinan yang sukar di mana lekangan komposit seringkali berlaku. Kajian ini menunjukkan penemuan ujikaji ketika menggerudi kepingan CFRP yang disusun berlapis di atas kepingan Aluminum 2024. Mata alat karbida tidak bersalut dan karbida bersalut TiAlN digunakan untuk menggerudi kepingan CFRP/aluminum pada halaju pemotongan pelbagai iaitu 70, 85, dan 100 m/min serta kadar uluran tetap pada 0.1 mm/pusingan dalam keadaan kering. Sambutan yang dianalisa adalah daya tujah, daya kilas, kualiti lubang, lekangan permukaan CFRP, dan kehausan mata alat. Keputusan ujikaji menunjukkan bahawa penggunaan halaju pemotongan yang pelbagai tidak memberi kesan yang ketara terhadap semua sambutan yang dianalisa ketika menggerudi lapisan kepingan CFRP/aluminium bagi kedua-dua mata alat. Dari segikualitilekangan; iaitu masing-masingdndisebabkancekap Keputusan ujikaji juga menunjukkan prestasi mata alat bersalut lebih baik daripada mata alat tidak bersalut dengan menghasilkan daya tujah dan daya kilas yang rendah, kekasaran permukaan yang rendah, serta kadar kehausan mata alat yang perlahan.

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LIST OF SYMBOLS AND ABBREVIATIONS

FRP	Fiber Reinforced Plastic
CFRP	Carbon Fiber Reinforced Plastic
BUE	Built Up Edge
HSS	High Speed Steel
TiAlN	Titanium Aluminum Nitride
Wc	Tungsten
2p	Drill Point Angle
Fz	Drilling thrust force
Mz	Drilling torque
L	Lead length of the helix
γ	Chisel edge angle
VBB	Average width of flank wear
VBBmax.	Maximum width of flank wear
f	Feed rate
D	Diameter
Ra	Arithmetical mean surface roughness
S	Spindle rotational speed
Cs	Cutting speed

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CHAPTER 1

INTRODUCTION

1.1 Background

Machining is widely used in the manufacturing industries to produce accurate and precise components. A material is considered machinable when it can be machined with relative ease while producing the desired range of surface finish. The characteristics of a good machinability materials are when less power is consumed in a short machining time, good surface finish and can be produced without causing the cutting tool to wear in a short period of usage. It is difficult to determine the machinability of a material since it involved many criteria such as workpiece material, type of cutting tool used, the cutting parameters, and also machine tool. Among all the machining processes, drilling is known to be most used machining process which is usually done at the end of manufacturing stage [1].

Carbon fiber reinforced plastic is (CFRP) a unique material that is highly used in industries such as aerospace, automotive, marine, electronics, medical, and others. This is due to the unique characteristics of CFRP especially in the materials structure that provides high performance properties such as high strength-to-weight and stiffness-to-weight ratios [2]. Since the mechanical properties of CFRP is superior and having different structure than the majority of conventional material, a different approach is needed in order to obtain the best results when drilling CFRP. The uniqueness of CFRP structure is based on its fiber orientation, fiber and matrix properties, and relative volume of the fiber and matrix [2]. In the CFRP drilling process, the tool encounters different layer of fiber materials and matrix thus causing the tool to experience a variety of cutting mechanisms.

Aluminum or aluminum alloys play a significant role in the world of manufacturing, especially in the aerospace industry. Aluminum alloy 2024 is chosen in this research as they are widely used as structural applications of aircrafts around the world [3]. This highly abundant material is favored due to its properties such as high durability, high strength, and light weight that are highly suitable for aircrafts. These advantages are utilised in aircraft structural applications such as fuselage, wing tension members, shear webs and ribs and in vital places that require stiffness, outstanding fatigue resistance and good strength-to-weight ratio. There are also substantial applications of aluminum alloy 2024 in commercial and military aircrafts. These include fuselage skins, wing skins, and engine parts that usually experience high temperatures.

Combining the advantages of CFRPs high strength-to-weight ratio with aluminium in the structural applications of aerospace, a hybrid multi-layer material is produced. This combination allows the properties structural component of an aircraft to be heightened to a new level. CFRP is usually selected as a substitute for aluminium in an aircraft, whereby it provides considerable weight reduction to an aircraft while maintaining its strength comparable to metals [4]. For instance, the new Boeing 787 Dreamliner and Airbus A350 utilised the benefits of CFRP as aircraft parts as it comprises more than 60% of the weight of the aircraft when empty [5]. When composites and metals are joined together in a manufacturing line, the processing time and productivity can be improved. However, in a drilling process, different materials have different machining characteristics. Both materials have different set of machining parameter settings as they are of different properties. The stacking of CFRP with aluminium means that a tight control of drilling procedure must be followed to avoid errors such as hole diameter tolerances and hole location. A number of studies in drilling multi-layer materials such as CFRP stacked on top of metals are available; however, they are still limited as compared to studies that focused on drilling on a single material only. Thus, various characteristics can be explored in drilling multi-layer materials. Through the findings of this study, it is expected that a further apprehension of the machinability and the effect of coating performance and drilling parameters in drilling stack of CFRP/Aluminium 2024.

1.2 Problem Statement

Drilling a stack of different materials such as CFRP and aluminum plates posesses great challenges to manufacturing industries. Both materials behave distinctly during drilling process due to the fact that CFRP has low thermal conductivity and highly abrasive properties. The abrasiveness nature of CFRP, would accelerate tool wear and shorten tool life. Meanwhile aluminum is a ductile material which cause built up edge (BUE) on the cutting tool during machining. The formation of BUE is caused by the adhesion of aluminum to the cutting tool. This BUE is responsible for accelerating the tool wear leading to premature tool failure, low quality of hole, poor surface roughness, and high deviation of hole diameter.

Suitable cutting tool selection must be done in order to allow good finishing for both materials. In addition, cutting conditions must comply with tool and workpiece as the response differently towards cutting parameters. The general cutting parameter recommended for drilling CFRP is to employ relatively high speed combined with low feed rate [6]. This cutting parameter is most likely selected to minimize or avoid drilling-induced delamination. As such for aluminum alloys, there is a contrasting effect between drilling at high and low speed [7]. Selection of suitable cutting parameters to create holes with good quality when drilling aluminum alloy is not easy because of the ductility and the tendency of this material to cause BUE to the cutting tool thus causing undesireable continuous chips and poor hole quality [7]. BUE usually occurs frequently at low cutting speed thus one of the solution to reduce or avoid BUE is to apply higher cutting speed. However, increasing the cutting speed, increases the drilling temperature. Aluminum alloy is much more ductile, harder, and having more density than CFRP, thus cutting tools that is suitable to drill aluminum is also suitable for drilling CFRP/aluminum stack.

Fiber-reinforced materials possess better mechanical properties and its strength-to-weight ratio is highly advantageous compared to most metal alloys. These advantages lie in the material structure of fiber-reinforced materials. Due to the material structure of CFRP, as compared to metal alloys [2]. The different behaviour of CFRP during drilling process causes defects that are dissimilar compared to drilling of metal. The process is used to produce holes in the composite's body before joining with other materials. In drilling process, it is highly desirable to avoid defects. The defects that were commonly found in CFRP drilling are matrix cracking, fiber pullout, fiber fracture, fiber debonding, delamination, fuzzing and spalling. Among the common defects induced by drilling process, delamination is the most undesirable and most frequently occurs [3,4,5,7-12].

Delamination is of interest when drilling CFRP since it may result in reduction of material strength and fracture toughness [10] and the fact that 60% of part rejections during final assembly in aircraft industry consist of delamination rejects due to drilling [11]. There are various factors in the process parameters that are directly related to the defects in drilling CFRP. For example, the most common factors identified were the cutting tool type, cutting tool material, point angle, and helix angle of the cutting tool, cutting speed, feed rate, and thrust force [3,4,5,7-12]. These factors in turn can be related to the progress of the tool wear which is used to determine the appropriate tool life of a drilling tool.

1.3 Objectives

The main objective of this research study is to investigate the machinability of CFRP/Aluminum 2024 stack during drilling process. The specific objectives of this study are as follows:

i. To evaluate the machining performance of uncoated and TiAlN coated carbide tools when drilling of CFRP/Aluminum 2024 stack.
ii. To study the effect of cutting speed on thrust force, torque, hole size, delamination, surface roughness, and tool wear.

1.4 Scope of Study

This study focuses on the drilling of CFRP/Aluminum 2024 stack using carbide drill bits, which are uncoated carbide, and TiAlN coated carbide. The cutting conditions include variation in cutting speed of 70. 80, and 100 m/min and constant feed rate of 0.1 mm/rev. The workpiece, CFRP plate was supplied by CTRM Malaysia. All experimental and analysis works are conducted at the Production Laboratory, FKM, UTM using a CNC machining centre various measuring equipments.

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