OPTIMIZATION OF DRILL GEOMETRY AND PENETRATION ANGLE FOR HIGH QUALITY DRILLING OF CFRP/AL HYBRID COMPOSITE

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Industrial and Manufacturing Technology and Engineering

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FATIMATUZZAHRAH BINTI MOHAMED ARIF

A thesis submitted
in fulfillment of the requirements for the degree of
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2024

DECLARATION

I declare that this thesis entitled “Optimization of Drill Geometry and Penetration Angle for High Quality Drilling of CFRP/Al Hybrid Composite“ is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :.....

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Date : 29-10-2024

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Manufacturing Engineering.

Signature :.....

Supervisor Name : Dr Mohd Sanusi Bin Abdul Aziz

Date : 29 - 10 - 2024

DEDICATION

To my beloved husband and my dearest son

To my supportive parents and family

Thank you for giving me moral support, cooperation, encouragement, and understandings.

I have the courage and drive to overcome obstacles and follow my ambitions because of

their love and faith in me. Without their efforts and unceasing support,

this achievement would not have been possible.

I want to thank me for, for never quitting.

ABSTRACT

In recent years, composite materials have become alternative materials in various industries due to their mechanical properties, where they are lightweight and corrosion resistant. Among these, hybrid composites that combine Carbon Fiber Reinforced Plastic (CFRP) and Aluminum (Al) have attracted a lot of attention because of its performance in the aerospace industry. CFRP/Al features with multiple plies of material stacked together in reinforced laminate form, with varying properties throughout the structure, making it ideal for aerospace, automotive, and sports equipment manufacturing. However, the anisotropic nature of these hybrid composites presents unique challenges during the drilling process which often results in hole defects such as delamination, poor surface roughness and burr formation. This research aims to investigate the optimized drill bit design for drilling at various angles to improve hole quality and minimize defects, while increasing the application of CFRP/Al composites. In this study, a matrix planning was employed using the Taguchi method to screen significant factors. From five parameters, including machining parameters, tool geometry features, and drilling angle conditions, three key parameters (point angle, helix angle, and drilling penetration angle) were selected for optimization using Response Surface Methodology (RSM). Through statistical analysis, the remaining parameters were fixed at optimal levels to produce the best hole quality. Two DOEs for entry and exit holes are conducted separately for a comprehensive understanding of the drilling process. In RSM, mathematical regression models and 3D response surface plot have successfully been analyzed to describe the relationships between the key parameters and hole quality. Optimization results indicated that drill geometry with a 124° point angle, 20° helix angle, and a 6° penetration angle is optimal parameter for drilling CFRP/Al. A custom drill bit was developed and validated through experimental work, which showed less than 10% error compared to the predicted values, confirming its accuracy and validity. The customized drill bit design, combined with the optimal penetration angle, demonstrates significant potential for enhancing hole quality and reducing defects in CFRP/Al composites, thereby improving the reliability and cost-efficiency of manufacturing processes within the aerospace industry.

PENGOPTIMUMAN GEOMETRI GERUDI DAN SUDUT PENEMBUSAN UNTUK PENGGERUDIAN BERKUALITI TINGGI BAGI KOMPOSIT HIBRID CFRP/AL

ABSTRAK

Dalam beberapa tahun kebelakangan ini, bahan komposit telah menjadi bahan alternatif yang menonjol dalam pelbagai industri kerana sifat mekanikalnya yang luar biasa, di mana ia ringan dan tahan kakisan. Antaranya, komposit hibrid yang menggabungkan Carbon Fiber Reinforced Plastic (CFRP) dan Aluminium (Al) telah menarik perhatian ramai kerana prestasinya dalam industri aeroangkasa. Ciri CFRP/Al dengan pelbagai lapisan bahan yang disusun bersama dalam bentuk lamina bertetulang, dengan sifat yang berbeza-beza di seluruh struktur, menjadikannya sesuai untuk pembuatan peralatan aeroangkasa, automotif dan sukan. Walau bagaimanapun, sifat anisotropik komposit hibrid ini memberikan cabaran unik semasa proses penggerudian yang sering mengakibatkan kecacatan lubang seperti penembusan, kekasaran permukaan yang lemah dan pembentukan burr. Kajian ini menyiasat pengaruh geometri bit gerudi dan sudut penembusan ke atas kualiti lubang dalam penggerudian komposit hibrid CFRP/Al. Penyelidikan ini bertujuan untuk menyiasat reka bentuk mata gerudi yang dioptimumkan untuk penggerudian pada pelbagai sudut untuk meningkatkan kualiti lubang dan meminimumkan kecacatan, sambil meningkatkan penggunaan komposit CFRP/Al. Daripada lima parameter, termasuk parameter pemesinan, ciri geometri alat dan keadaan sudut penggerudian, tiga parameter utama (sudut titik, sudut heliks dan sudut penembusan penggerudian) telah dipilih untuk pengoptimuman menggunakan Metodologi Permukaan Respons (RSM). Melalui analisis statistik, parameter selebihnya telah ditetapkan pada tahap optimum untuk menghasilkan kualiti lubang terbaik. Dua DOE untuk lubang masuk dan keluar dijalankan secara berasingan untuk pemahaman menyeluruh tentang proses penggerudian. Dalam RSM, model regresi matematik dan plot permukaan tindak balas 3D telah berjaya dianalisis untuk menerangkan hubungan antara parameter utama dan kualiti lubang. Keputusan pengoptimuman menunjukkan bahawa geometri gerudi dengan sudut titik 124°, sudut heliks 20° dan sudut penembusan 6° ialah parameter optimum untuk penggerudian CFRP/Al. Mata gerudi khas telah dibangunkan dan disahkan melalui kerja eksperimen, yang menunjukkan ralat kurang daripada 10% berbanding dengan nilai yang diramalkan, mengesahkan ketepatan dan kesahihannya. Rekabentuk mata gerudi khas, bersama dengan sudut penembusan optimum, menunjukkan potensi yang signifikan dalam meningkatkan kualiti lubang dan mengurangkan kecacatan pada komposit CFRP/Al, sekali gus meningkatkan kebolehpercayaan dan kecekapan kos proses pembuatan dalam industri aeroangkasa.

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LIST OF ABBREVIATIONS

CFRP	-	Carbon Fibre Reinforced Polymer
CFRP/Al	-	Carbon Fibre Reinforced Polymer/Alminum
CNC	-	Computer Numerical Control
ANOVA	-	Analysis of Variance
RSM	-	Response Surface Methodology
DOE	-	Design of Experiment
ISO	-	American Standard Test Method
S/N	-	Signal-to-Noise Ratio
SEM	-	Scanning Electron Microscopy
EDS	-	Energy-Dispersive Spectroscopy
WC	-	Tungsten Carbide
Co	-	Cobalt
Fe	-	Iron
C	-	Carbon
O	-	Oxygen
Al	-	Aluminium
F	-	Fluorine
SMSS	-	Sequential Model Sum of Squares

BBD	-	Box-Behnken Design
FEA	-	Finite Element Analysis
HV		Vicker Hardness

LIST OF SYMBOLS

mm	-	Millimetre
mm/min		Millimetre per minute
mm/rev		Millimetre per revolution
rpm		Revolution per minute
^{o}		Degree (Angle)
F_d		Delamination Factor
A_{del}	-	Maximum Delaminated Area
A_o	-	Actual Hole Diameter
%	-	Percentage
μm	-	Micrometre
N	-	Newton
A	-	Area of Circle
$\pi r2$		pi times the radius squared
F_x		force at x-direction
F_y		force at y-direction
F_z		force at z-direction
Ø		Diameter

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Proceeding Paper

1. Fatimatuzzahrah Arif, R. Balakrishnan, Mohd Sanusi, Mohd Hadzley, R. Izamshah, N. Ab Wahab, 2022. Finite Element Analysis on Influence of Drill Bit Geometry on Hole Accuracy in Drilling HCFRP. *Proceedings of International Innovative Research and Industrial Dialogue 2022 (iIRID'22),* pp. 81 – 82. (Published)

Extended Abstract

1. Fatimatuzzahrah Arif, Lingges A/L Kumaran, Mohd Sanusi, 2023. Optimization of Machining Parameter in Drilling Carbon Fiber Reinforced Plastic (CFRP), *Colloquium On Manufacturing and Industrial Engineering 2023 (MIE2023)*. (Extended Abstract – Accepted in MIE 2023).

CHAPTER 1

INTRODUCTION

This chapter provides an overview of the study's background, focusing on the influence of hybrid composite materials in the current industry. It includes a problem statement that highlights the industry's challenges, which prompted this experimental investigation. Therefore, this section will also present the research objectives, scope of study, significance of study and the thesis arrangement of the report.

1.1 Background of Study

Nowadays, composite materials such as Carbon Fibre Reinforced Plastic (CFRP) are widely used in machining industries such as, automotive, aerospace, marine industry, medical devices, and robotics. This demand is driven by CFRP's mechanical properties, which is much lighter than traditional metals like steel and aluminum (Xu and El Mansori, 2016). Therefore, its low density contributes to its high specific strength and is advantageous in industries where reducing weight is essential for performance and efficiency. Figure 1.1 shows that more than 50% of composites are used to make airframes in aerospace industry. In addition, hybrid CFRP is also frequently used in the machining industry. Therefore, my research focuses on CFRP/Al hybrid composite materials and their impact on high-quality assembly and drilling processes.

A hybrid type of CFRP/AL which consists of carbon fibre reinforcements with a secondary reinforcement that improves the fracture toughness and tensile elastic modulus is

still new in the machining field. The application of hybrid composites in the aerospace industry has increased due the combination of various matrix materials such as epoxy or carbon fibers offer a high strength-to-weight ratio. Therefore, it is ideal for aerospace applications where weight reduction is important for fuel efficiency and flight performance. According to Redouane Zitoune *et al.* (2012) and Wang *et al.* (2021), carbon fiber reinforced plastic/polymer (CFRP) and aluminum alloy (Al) is the best material in aircraft structures for weight reduction.

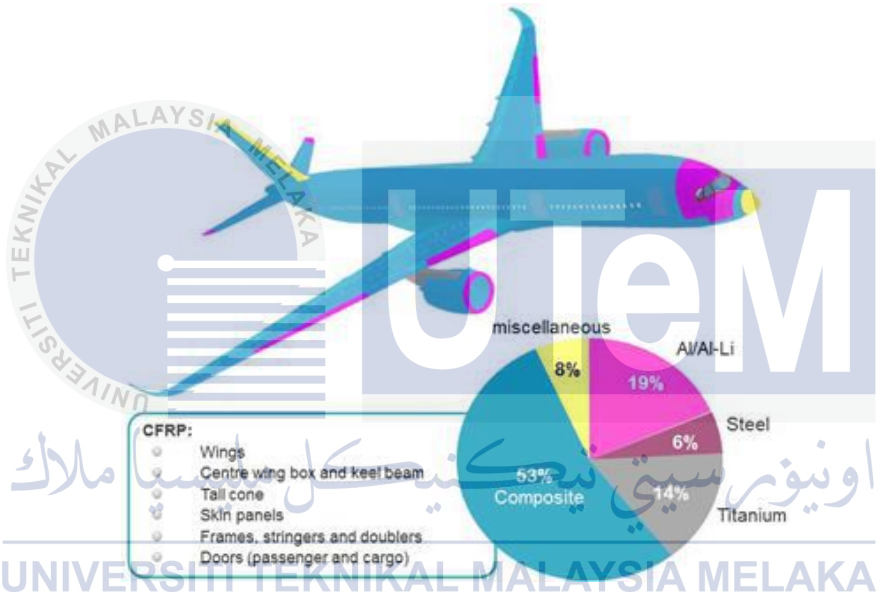

Figure 1.1: CFRP in Aircraft (Bachmann *et al*., 2017)

Drilling on CFRP/AL material is a crucial assembly step in aircraft manufacturing. However, the anisotropic properties of CFRP/AL create major problem during the drilling process that been reportedly causes 60% of defective parts. Jia *et al*. (2016) mentioned that in drilling CFRP/Al, CFRP is a hard-to-cut material, where there is interaction on the composite material that causes defects during machining process. Decades ago, a lot of research was done on drilling CFRP/AL composites. Most of these studies are only focused on drill bit design and drill bit geometry, but there is no research that highlights the issue of