Faculty of Manufacturing Engineering

PARAMETERS OPTIMIZATION OF MICRO DRILLING PROCESS FOR CFRP USING TWO FLUTE SOLID CARBIDE DRILL BIT

Nur Syuhada Binti Md Nasir

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PARAMETERS OPTIMIZATION OF MICRO DRILLING PROCESS FOR CFRP USING TWO FLUTE SOLID CARBIDE DRILL BIT

NUR SYUHADA BINTI MD NASIR

A thesis submitted
in fulfilment of the requirements for the degree of Master of Science
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DECLARATION

I declare that this thesis entitled "Parameters Optimization of Micro Drilling Process for CFRP Using Two Flute Solid Carbide Drill Bit" 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	:	……………………………………….
Name	:	NUR SYUHADA BINTI MD NASIR
Date	:	……………………………………….

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 reward of Master of Science in Manufacturing Engineering.

Signature : ……………………………………………...

Supervisor Name : TS. DR. NORFARIZA BINTI AB WAHAB

Date : ……………………………………………...

DEDICATION

To my beloved husband

Mohamad Afiq Amiruddin Bin Parnon

To my awesome babies

Mohamad Ariq Rayhan Bin Mohamad Afiq Amiruddin

Nur Airis Raysha Binti Mohamad Afiq Amiruddin

To my supportive parents and parents in law

Md Nasir Bin Nordin & Norizan Binti Da

Parnon Bin Saikon & Rubiah Binti Wakiman

And my supportive family.

ABSTRACT

Today, composites material is an alternative to the metal components in the airliner bodies and structures because of its lightweight material characteristic which can contribute to reducing aircraft fuel consumption. Carbon Fibre Reinforced Polymer (CFRP) has multiple plies of material that is piled together in reinforced laminates component form with different material properties throughout the structure. Micro hole on CFRP panel is required for acoustic panel of an aircraft engine. However, drilling process for CFRP material is typically challenging due to high structural stiffness of the composite, low thermal conductivity of polymer and thermally stable of its carbon fiber. Poor resin areas between adjacent laminated plies are prone to drilling-induced damage such as delamination that compromises the material structural integrity. Delamination always related to thrust force during machining process. It can lead to lower hole accuracy of the drill hole entry and exit. Therefore, the optimum parameter for drilling process such as machine spindle speed and feed rate are essential to improve the quality of the hole as well as increase the tool life span. In order to understand the behaviour of CFRP material during machining process, tribological study using Ball-on-disk (BOD) tester was conducted to evaluate properties of CFRP material towards frictional force and wear rate. As the applied load increase, the average frictional force also increased. The result contributed to the selection of the optimum range of parameter for the micro drilling process. The thrust force during machining and hole accuracy at hole entry and exit are investigated by using variable spindle speed and feed from 8,000 to 12,000 rpm and 0.001 to 0.015 mm/rev, respectively. Hence, from the Taguchi L9 (3^2) experiment the feed rate of 0.001 mm/rev was eliminated to proceed for the optimization stage due to its' insignificant impact on the investigated variable. Based on one-way ANOVA results from Taguchi L9 (3^2) experiments, the significant parameter for thrust force was cutting feed rate with p-value = 0.004, while hole accuracy was analysed by S/N ratio, in which feed rate achieved 1st rank and spindle speed at the 2nd rank for the significant factor. The optimisation and validation of micro-drilling parameters with respect to the thrust force and hole accuracy in machining of CFRP material were subsequently investigated. The experiments were systematically carried out by 2-Level Factorial experiment. The mathematical models for thrust force, 1st hole entry accuracy, 20th hole entry accuracy, 1st hole exit accuracy and 20th hole exit accuracy were developed in this stage. In addition, analysis of variance (ANOVA) was also carried out to check the significance of the models. Three validation experiments are conducted to determine the error percentage of thrust force and hole accuracy. Based on the results, the error was less than 10% for hole accuracy measurements while for thrust force an error of 17.70% was recorded. However, since the desired response for thrust force was to "minimize", hence the value can be acceptable. The optimum conditions for minimum thrust force and high hole accuracy were found to be at spindle speed of 10,762 rpm and feed rate of 0.01 mm/rev.

PENGOPTIMUMAN PARAMETER DALAM PROSES PENGGERUDIAN MIKRO UNTUK CFRP MENGGUNAKAN MATA GERUDI DUA FLUT KARBIDA PEPEJAL

ABSTRAK

Hari ini, bahan komposit adalah alternatif kepada komponen logam pada badan dan struktur kapal terbang kerana sifat bahan yang ringan dapat menyumbang kepada pengurangan penggunaan bahan bakar pesawat. Polimer Diperkuat Gentian Karbon (CFRP) mempunyai beberapa lapisan bahan yang disusun bersama dalam bentuk komponen laminasi bertetulang dengan sifat bahan yang berbeza di seluruh struktur. Lubang mikro pada panel CFRP diperlukan untuk panel akustik enjin pesawat. Walau bagaimanapun, proses penggerudian mikro pada bahan CFRP biasanya mencabar kerana kekukuhan struktur komposit yang tinggi, polimer yang berkonduksi haba rendah dan karbonnya yang berhaba stabil. Kawasan yang kurang resin antara lapisan dalam laminasi terdedah kepada kerosakan seperti delaminasi yang menjejaskan keutuhan struktur bahan. Delaminasi selalu dikaitkan dengan daya tujah semasa proses penggerudian. Ianya boleh menyebabkan ketepatan lubang yang rendah pada lubang masuk dan keluar. Oleh itu, parameter yang optimal untuk proses penggerudian seperti kelajuan gelendong mesin dan kadar suapan sangat penting untuk meningkatkan kualiti lubang serta meningkatkan jangka hayat alat. Untuk memahami sifat bahan CFRP semasa proses penggerudian, kajian tribologi menggunakan alat Bola-pada-cakera (BOD) dilakukan untuk menilai sifat bahan CFRP terhadap daya geseran dan kadar haus. Apabila beban yang dikenakan meningkat, purata daya geseran juga meningkat. Hasil kajian menyumbang dalam pemilihan julat parameter yang optimal untuk proses penggerudian mikro. Daya tujah semasa penggerudian mikro dan ketepatan lubang masuk dan keluar disiasat dengan menggunakan pemboleh ubah kelajuan gelendong mesin dan suapan pada 8,000 hingga 12,000 rpm dan 0.001 hingga 0.015 mm/putaran. Oleh itu, dari eksperimen Taguchi L9 (32) suapan 0.001 mm/putaran dihapuskan daripada tahap pengoptimuman kerana ianya memberi kesan yang tidak bermakna pada pemboleh ubah yang diselidiki. Berdasarkan hasil ANOVA sehala dari eksperimen Taguchi L9 (32), parameter yang bermakna untuk daya tujah adalah suapan pemotongan dengan nilai $p = 0.004$, sementara ketepatan lubang dianalisis dengan nisbah S/N, di mana untuk penilaian faktor yang bermakna suapan mencapai tempat pertama dan kelajuan gelendong pada kedudukan ke-2. Pengoptimuman dan pengesahan parameter penggerudian mikro berkenaan dengan daya tuju dan ketepatan lubang dalam pemesinan bahan CFRP kemudiannya disiasat. Eksperimen dijalankan secara sistematik dengan kaedah eksperimen Faktorial Dua Peringkat. Model matematik untuk daya tujah, ketepatan lubang masuk pertama, ketepatan lubang masuk ke-20, ketepatan lubang keluar pertama dan ketepatan lubang keluar ke-20 telah dikembangkan pada tahap ini. Selain itu, analisis varians (ANOVA) juga dilakukan untuk memeriksa kepentingan model. Tiga eksperimen pengesahan dijalankan untuk menentukan peratusan ralat daya tujah dan ketepatan lubang. Berdasarkan keputusannya, peratusan ralat kurang daripada 10% untuk pengukuran ketepatan lubang sementara untuk daya tujah peratusan ralat sebanyak 17.70% dicatatkan. Namun, kerana tindak balas yang diinginkan untuk daya tujah adalah untuk "meminimakan", maka nilainya dapat diterima. Keadaan optimal untuk daya tujah yang minimum dan ketepatan lubang yang tinggi didapati pada kelajuan gelendong 10,762 rpm dan suapan 0.01 mm/putaran.

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LIST OF ABBREVIATIONS

AE	-	Acoustic emissions
ANOVA	-	Analysis of variance
ASTM	-	American standard test method
BOD	-	Ball-on-disk
CER	-	Cutting edge radius
CFRP	-	Carbon fibre reinforced polymer
COF	-	Coefficient of friction
CP-T	-	Cutting process tribometer
DF	-	Delamination factor
DOE	-	Design of experiment
FE	-	Finite element
FRP	-	Fibre reinforced polymer
FTIR	-	Fourier transformed infrared
GA	-	Genetic algorithm
HSS	-	High speed steel
min	-	Minutes
mm	-	Millimetre
MRR	-	Material removal rate
PCD	-	Pitch circle diameter
PKAC-E	-	Palm kernel activated carbon-epoxy
rpm	-	Revolution per minutes

RSM	-	Response surface methodology
SEM	-	Scanning electron microscope
SN	-	Signal to noise
Std	-	Standard
TFL	-	Transfer film layers
TiAlN	-	Titanium aluminium nitride
TiN	-	Titanium nitride
TWR	-	Tool wear rate
VB	-	Tool wear
WC	-	Woven CFRP

LIST OF SYMBOLS

%	-	Percentage
°	-	Degree of angle
°C	-	Degree Celsius
µ	-	micron
A	-	area of circle
a	-	wear track thickness
b	-	measured specimen width in mm
C_f	-	Uncut fiber level criterion
C_i	-	Circularity error
C_y	-	Cylindricity error
d	-	depth of the specimen
E_x	-	Effect of X
F	-	Contact force
f	-	feed rate
F	-	friction force
F^{sbs}	-	short beam strength
F_a	-	Axial force
F_d	-	Delamination level criterion
F_x	-	force at x-direction
F_y	-	force at y-direction
F_z	-	force at z-direction

GPa	-	Giga Pascal
H	-	Hardness of material
h	-	height
h	-	measured specimen thickness in mm
K	-	Archard's wear coefficient
k	-	kilo
K	-	specific wear rate
kg	-	kilogram
L	-	Cutting length
L	-	sliding distance
L	-	support span
L_c	-	Contact length
N	-	applied load
N	-	Newton
Ø	-	diameter
P	-	load at a given point on the load deflection curve
P_m	-	maximum load observed during the test
r	-	radius of circle
r	-	radius of the ball bearing
R	-	radius of the wear track
R^2	-	Coefficient of determination
Ra	-	Surface roughness
T_g	-	Glass transition temperature
v	-	spindle speed
V_{loss}	-	volume loss

W	-	applied load
W	-	Volumetric wear of the material
y_{x-}	-	Average response of X at low level
y_{x+}	-	Average response of X at high level
Π	-	pi = 3.142
σ_f	-	stress in the outer fibers at midpoint in MPa

LIST OF PUBLICATIONS

Journal

1. **Nur Syuhada Nasir**, Norfariza Ab Wahab, Badri Bin Sofian, Raja Izamshah, Hiroyuki Sasahara, 2021. Experimental Investigations Towards Hole Accuracy in Micro-drilling of Carbon Fibre Reinforced Polymer Material. *Manufacturing Technology*, ISSN: 1213-2489. (Scopus) (Published)
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4. N. Ab Wahab, Syafiq Abd Latiff, H. Sasahara, R. Izamshah and **N. Syuhada Nasir**, 2020. The Behaviour of CFRP Material in Micro Drilling Process Towards Thrust Force. *International Journal of Mechanical and Production Engineering Research and Development*, ISSN: 2249-8001, Volume 10, No. 3, pp. 10195–10204. (Scopus) (Published)