UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Manufacturing Engineering

MACHINING PARAMETERS AND TOOL GEOMETRY OPTIMIZATION FOR TRIMMING COMPOSITE LAMINATES USING RESPONSE SURFACE METHODOLOGY

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A thesis submitted
in fulfillment of the requirements for the degree of Doctor of Philosophy in Manufacturing Engineering

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DECLARATION

I declare that this thesis entitled "Machining Parameters and Tool Geometry Optimization for Trimming Composite Laminates using Response Surface Methodology" 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 : 15 / 05 / 2021 ……………………………..……

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 Doctor of Philosophy in Manufacturing Engineering.

Signature : ………………………………………………………………

Supervisor Name : Associate Professor Dr. Raja Izamshah Bin Raja Abdullah

Date : 20 / 05 / 2021

DEDICATION

To my beloved parents,

family and all my supportive friends.

ABSTRACT

In recent years, carbon fiber-reinforced polymer (CFRP) materials have gained tremendous attention from industries, especially in the aerospace industry due to their properties such as high strength-to-weight ratio and high corrosion resistance. In general, composite materials are usually manufactured in a near-net shape. Hence, secondary processes such as trimming, drilling and countersinking are usually applied to obtain the final desired dimension. Composite behavior such as its inhomogeneity, anisotropy, and interaction with the cutting tool becomes challenging for the manufacturers. Matrix cracking, un-cut fibers, fibers pull-out, and burned matrices are the typical problems or damages that arise during the machining process which may contribute to the rejection of parts. Moreover, the abrasive nature of the reinforcement fibers of the composite materials induces rapid wear rate to the cutting tool during machining which finally impacted the overall manufacturing cost. Therefore, this present study aims to determine an optimum tool geometry for a router tool-type (the number of teeth and the helix angles) and the optimized machining parameters in minimizing workpiece damages during the trimming of CFRP material. The trimming performances evaluated include the trimmed surface roughness in the longitudinal and transverse direction as well as the cutting force. Surface roughness evaluation was done by utilizing the portable surface roughness while cutting force was measured using the piezoelectric-dynamometer. Besides, further qualitative observation on the trimmed surface quality, and the effect on the tool wear, were performed using an optical microscope and a 3-Dimensional (3D) surface topography imager. The design of experiment (DOE-Taguchi and Response Surface Method-RSM) is the primary method deployed in the overall research's milestones. Through the statistical analysis, the machining parameters (cutting speed, V_c, and feed per tooth, f_z) resulted in a more significant effect on the surface roughness and the cutting force value than the selected tool geometry. On the other hand, considering only the tool geometry, the most predominant factor that affected the trimmed surface quality was the number of teeth on the left side, followed by the helix angle and the number of teeth on the right side. The relationship for each mentioned response, namely, the surface roughness (in the longitudinal and transverse direction) and the cutting force associated with the tool geometry, was successfully established using statistical model analysis. The optimum tool geometry (the combination of the number of teeth on the left and the right side respectively; 12, 8 and the helix angle; 24°) and the machining parameters (the cutting speed, V_c 118.47 m/min and the feed per tooth, f_z 0.05 mm/rev) were chosen based on the highest desirability score. The new optimum router tool geometry was fabricated and a validation experimental work was performed which finally confirmed its validity by obtaining the relative error between the predicted and the experimented data less than 10%. Ultimately, the main aim of the present study which was to determine an optimum tool geometry for a router tool-type geometry that can accommodate the trimming results, namely minimum surface roughness (the longitudinal and transverse direction), the cutting force and the tool wear has been successfully achieved.

PENGOPTIMUMAN PARAMETER PEMESINAN DAN GEOMETRI PERKAKAS UNTUK PEMOTONGAN KOMPOSIT BERLAPIS MENGGUNAKAN METODOLOGI PERMUKAAN SAMBUTAN

ABSTRAK

Kebelakangan ini, bahan polimer yang diperkuat dengan serat karbon (CFRP) mendapat perhatian luar biasa oleh industri, terutamanya industri aeroangkasa disebabkan oleh sifat bahannya seperti nisbah kekuatan kepada berat yang tinggi dan ketahanan kakisan. Secara amnya, bahan komposit diperbuat kepada rupabentuk yang hampir. Oleh itu, proses sekunder seperti pemotongan, penggerudian dan pembenaman biasanya digunakan untuk mendapatkan dimensi akhir yang diinginkan. Tingkah laku komposit seperti ketidaksamaan, anisotropi dan interaksi dengan perkakas menjadikan tugas yang mencabar bagi pengeluar. Keretakan matriks, serat yang tidak dipotong, serat yang ditarik keluar dan matriks terbakar merupakan antara permasalahan umum atau kerosakan yang berlaku semasa proses pemesinan yang boleh menyebabkan penolakan bahan tersebut. Selain itu, sifat serat tetulang yang kasar pada bahan komposit tersebut mampu mempercepatkan kadar kehausan kepada perkakas semasa proses pemesinan seterusnya mengakibatkan peningkatan kos. Oleh itu, kajian ini bertujuan untuk menentukan geometri perkakas yang optimum (jumlah gigi dan sudut heliks) serta parameter pemesinan yang optimum dalam meminimakan kerosakan benda kerja semasa pemotongan bahan CFRP. Analisa pemesinan yang dinilai merangkumi kekasaran permukaan pada arah menegak dan melintang serta daya pemotongan. Penilaian kekasaran permukaan dilakukan dengan menggunakan kekasaran permukaan mudah alih sementara daya pemotong diukur dengan menggunakan piezoelectric-dynamometer. Selain itu, analisa kualitatif lebih lanjut mengenai kualiti permukaan serta kehausan kepada perkakas dilakukan dengan menggunakan mikroskop optik dan pencitraan topografi permukaan 3-Dimensi (3D). Reka bentuk eksperimen (DOE-Taguchi dan Response Surface Method-RSM) adalah kaedah utama yang digunakan dalam pencapaian keseluruhan penyelidikan. Merujuk kepada analisis statistik, parameter pemesinan (kelajuan pemotongan, V_c, dan suapan per gigi, f_z) menunjukkan kesan yang lebih ketara pada kekasaran permukaan dan nilai daya pemotongan daripada geometri perkakas yang dipilih. Sebaliknya, faktor yang paling ketara mempengaruhi kualiti permukaan yang dipotong adalah bilangan gigi di sebelah kiri diikuti dengan sudut heliks dan jumlah gigi di sebelah kanan. Hubungan untuk setiap tindak balas, iaitu kekasaran permukaan pada kedua-dua arah dan daya pemotongan yang berkaitan dengan geometri perkakas, dihubungkait dengan menggunakan analisis model statistik. Geometri perkakas optimum (gabungan bilangan gigi kiri dan kanan masing-masing; 12, 8 dan sudut heliks; 24°) dan parameter pemesinan (kelajuan pemotongan, V_c 118.47 m/min dan suapan per gigi, f_z 0.05 mm/rev) dipilih berdasarkan skor keinginan tertinggi. Perkakas dengan geometri optimum tadi kemudiaannya difabrikasi dan divalidasi dengan eksperimen yang akhirnya ditentu-sahkan dengan ralat relatif diantara data yang diramal dan yang sebenar adalah kurang daripada 10%. Kesimpulannya, objektif utama kajian ini iaitu menentukan geometri perkakas yang optimum dalam meminimakan kekasaran permukaan, daya pemotongan dan kehausan perkakas telah dapat dicapai dengan jayanya.

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ANOVA	-	analysis of variance
AWJ	-	abrasive water jet machining
CA	-	chilled air
CBN	-	cubic boron nitride
CFRP	-	carbon fiber reinforced plastic composite
CMC	-	ceramic matrix composite
CNC	-	computer numerical control
CTE	-	coefficient of thermal expansion
CVD	-	chemical vapor deposition
DLC	-	diamond liked carbon
EHM	-	equivalent homogenous material
FEA	-	finite element analysis
FRP	-	fiber reinforced polymer composite
GFRP	-	glass fiber reinforced plastic composite
HAZ	-	heat affected zone
HLU	-	hand lay-up
HSM	-	high speed machining
HSS	-	high speed steel
HV	-	hardness Vickers
IR	-	infra-red

ISO - international standard organization

LPI - liquid phase impregnation

MD - multi-directional

MIS - manufacturing instruction sheet

MMC - metal matrix composite

MQL - minimum quantity lubrication

MS - mean square

MSDS - material safety data sheet

MSE - mean square of error

N - Noise

NDT - non-destructive test

PCD - polycrystalline diamond

PCR - percentage of contribution

PEEK - polyetheretherketone

PMC - polymer matrix composite

PVD - physical vapor deposition

RMS - root mean square

SEM - scanning electron microscopy

SS - sum of square

SST - sum of square total

UAM - ultrasonic assisted machining

UD - unidirectional

UHM - ultra-high modulus

WC - tungsten carbide

LIST OF PUBLICATIONS

Indexed Journal with Impact Factor

1. **Sundi, S.A.**, Izamshah, R., Kasim, M.S., 2020. Effect of Machining Parameters on Surface Roughness in Edge Trimming of Carbon Fiber Reinforced Plastics (CFRP). *Tribology Online*, 15 (2), pp. 53-59. (Scopus indexed, Q2, IF = 0.38 (2019)

2. **Sundi, S.A.**, Izamshah, R., Kasim, M.S., S.Ding and M.F Jaafar, 2020. Statistical Analysis on the Effect of Machining Conditions towards Surface Finish during Edge rimming of Carbon Fiber Reinforced Plastics (CFRP). *International Journal of Nanoelectronics and Materials (IJNEAM)*, 13 (Special Issue), pp. 199-210. (Scopus indexed, Q3, IF = 0.22 (2019)

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2. **Sundi, S.A**., Izamshah, R., Kasim, M.S., Amin, A.T.M. and Kumaran, T., 2019. Influence of Router Tool Geometry on Surface Finish in Edge Trimming of Multi-Directional CFRP Material. *IOP Conference Series: Materials Science and*