Faculty of Industrial and Manufacturing Technology and Engineering

MODELING AND OPTIMIZATION OF THE END MILLING PROCESS FOR ALUMINIUM ALLOY (AA6041) USING RESPONSE SURFACE METHOD

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A thesis submitted
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DECLARATION

I declare that this thesis entitled “Modeling and Optimization of the End Milling Process for Aluminium Alloy (AA6041) using Response Surface Method” 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 : Agus Sudianto

Date : 21 October 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 Doctor of Philosophy.

Signature : ……

Supervisor Name : Prof. Dr. Zamberi Jamaludin

Date : 21 October 2024

DEDICATION

This thesis is dedicated to

my parents and my in-law parents, who always wait for the completion of my study session, my beloved wife and children, who are never silent, never stop for themselves giving full support in every way, stand by me when things look bleak and they huge hopes my thesis will be finished soon without any flaws.

ABSTRACT

End milling process is among the most widely used method in machining of components for industrial needs and purposes. Manufacturers are faced with greater demands for precision, quality, and efficiency of production process. This has raised the needs for establishing optimal machining process measured by the quality of the dependent responses such as the surface finishing quality, cutting temperature, and the generated cutting force. This thesis presented work on end milling process parameters modelling and optimization that considered the cutting speed, feed rate, depth of cut, width of cut and number of flute of high precision machining type tool on a 3-axes Computer Numerical Control (CNC) machining centre. The specific material of concerned was aluminium alloy AA6041 which made up the connecting rod of an automotive engine component. The screening phase applied the Minitab statistical tool using the Taguchi method with regression analysis for the surface roughness response that identified cutting speed, feed rate and depth of cut for final consideration of optimal end milling process parameters based on a coefficient p-value of less than 0.05. In the second phase, optimization and modelling were performed using Design Expert software with Response Surface Method (RSM). Results of the three optimal response values were analysed in ANOVA using the analysis of variance based on quadratic model with randomized Box-Behnken method that generated three regression equations whereby one optimization test and three validation tests were performed. Results were compared with Function Block and Python Program. The ANOVA analyses have identified optimal cutting speed, feed rate, and depth of cut at 155 m/min, 708.256 mm/min, 0.306 mm respectively. The predicted responses in the forms of surface roughness value (R_a), cutting temperature (T_c), and cutting force (F_c) were measured using Mitutoyo surface roughness tester, infrared thermometer sensor MLX90614 and a Kistler dynamometer respectively. The optimized cutting parameters produced predictive errors of 1.16%, 0.11%, and 8.12% while the validation machining process produced predicted error values of 4.168%, 0.819% and 11.171% for surface roughness, cutting temperature, and cutting force respectively. These findings will contribute toward improvements in machining efficiency of metal-based manufacturing process industries. In future, further analysis on impacts of other cutting parameter such as cutting tool geometry can be included and analysed using finite element method embedded with artificial intelligent elements.

PEMODELAN DAN PENGOPTIMUMAN PROSES PENGISARAN AKHIR ALOI ALUMINIUM (AA6041) MENGGUNAKAN KAEDAH PERMUKAAN TINDAK BALAS

ABSTRAK

Proses pengisar hujung adalah salah satu kaedah pemesinan yang biasa digunakan bagi pembuatan komponen untuk keperluan dan tujuan industri. Pengeluar berhadapan dengan permintaan yang semakin tinggi terhadap ketepatan, kualiti, dan kecekapan proses pengeluaran. Ini telah membangkitkan keperluan untuk mewujudkan proses pemesinan optimum yang diukur dengan kualiti tindakbalas proses seperti kualiti kemasan permukaan, suhu pemotongan dan daya pemotongan yang dihasilkan. Tesis ini membentangkan hasil kerja berkaitan pengoptimum dan pemodelan parameter proses pengisar hujung seperti kelajuan pemotongan, kadar suapan, lebar potongan dan bilangan seruling alat pemesinan berketepatan tinggi menggunakan mesin kawalan berangka (CNC) 3-paksi. Bahan khusus yang terlibat adalah aloi aluminium (AA6041)yang membentuk rod penyambung komponen enjin automotif. Fasa saringan awal menggunakan perisian statistik Minitab dengan kaedah Taguchi analisa regresi untuk tindak balas kekasaran permukaan yang mengenal pasti kelajuan pemotongan, kadar suapan dan kedalaman pemotongan sebagai pertimbangan akhir parameter proses pemesinan pengisar hujung yang optimum berdasarkan nilai p pekali yang kurang dari 0.05. Pada fasa kedua, pengoptimum dan pemodelan dilaksanakan menggunakan perisian Design Expert dengan kaedah permukaan tindak balas (RSM). Keputusan bagi tiga nilai tindak balas optimum melalui analisa varians ANOVA berdasarkan model kuadratik kaedah Box-Behnken rawak telah menghasilkan tiga persamaan regresi di mana satu ujian pengoptimum dan tiga ujian validasi telah dilakukan. Keputusan telah dibandingkan dengan Blok Fungsi dan Pengaturcaraan Python. Analisa ANOVA telah mengenalpasti nilai optimum kelajuan pemotongan, kadar suapan, dan kedalaman pemotongan pada 155m/min, 708.256 mm/min, dan 0.306mm. Tindakbalas yang diramalkan untuk nilai kekasaran permukaan (R_a), suhu pemotongan (T_c), dan daya pemotongan (F_c) telah diukur menggunakan penguji kekasaran permukaan Mitutoyo, termometer inframerah MLX90614 dan dinamometer Kistler. Parameter pemotongan optimum tersebut menghasilkan ralat ramalan masing-masing sebanyak 1.16%, 0.11%, dan 8.12% manakala proses pemesinan pengesahan menghasilkan ralat ramalan masing-masing sebanyak 4.168%, 0.819%, dan 11.171% untuk kekasaran permukaan, suhu pemotongan dan daya pemotongan. Penemuan kajian ini akan menyumbang kepada industri proses pembuatan berteraskan logam dengan meningkatkan tahap kecekapan proses pemesinan. Adalah dicadangkan untuk dilaksanakan analisa lanjutan mengenai kesan parameter pemotongan lain seperti geometri alat pemotong dan analisa menggunakan kaedah unsur terhingga yang teradun dengan unsur kepintaran buatan.

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R_a	Roughness value
R_p	Maximum profile pick height
R_v	Maximum profile valley depth
l	Sampling length
T_c	Cutting temperature
F_c	Cutting force
V_c	Cutting speed
V_f	Feed rate
D_{oc}	Depth of cut
f	Feed per tooth
W_{oc}	Width of cut
Z	Flute
D	Diameter of end mill
n	Spindle speed
π	Pi, 3.14
Q	Metal removal rate
A	Cutting cross section
a_p	Cut depth
L	Total feed length

S_m	Sum of square due to mean
V_e	Mean square
T	Sum of data
P_{pi}	Percentage of each parameter
SS_{pi}	Sum of square
SS_T	Total sum of square
SS_E	Error of square
A_i	Average roughness
n_{Ai}	Number of parameter level
N	Number of test
x_i	Roughness value representation
Y	Desired function
F	Response function
Δ	Estimation error