ENERGY AND COST INTEGRATION MODEL FOR MULTI-OBJECTIVE OPTIMISATION IN TURNING PROCESS OF STAINLESS STEEL 316

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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ABSTRAK

Daya tahan keluli tahan karat telah menarik minat yang besar kerana kekuatannya yang sederhana, karbon rendah dan rintangan kakisan. Penggunaan minyak sebagai cecair pemotongan adalah unsur-unsur proses pemesinan yang tidak mampan, ia memberi kesan negatif kepada kesan alam sekitar. Oleh itu, pemesinan kering adalah penyelesaian untuk mengurangkan penggunaan tenaga dan kos pemesinan. Dalam kajian ini, ia bertujuan untuk mengoptimumkan model matematik bersepadu untuk tenaga dan kos dalam proses berputar keluli tahan karat 316 (SS316). Ia ditetapkan untuk mengoptimumkan parameter-parameter pemesinan, termasuk penggunaan kuasa, kos pemesinan dan tanggapan pemesinan tradisional kekasaran permukaan dan pakai alat. Keluli tahan karat 316 dipotong dengan jenis alat memotong yang berbeza termasuk karbida yang tidak bersalut. Tiga faktor dikaitkan dengan parameter-parameter pemotongan seperti kelajuan pemotongan, kadar suapan, dan kedalaman pemotongan. Data Analisa varian dan model regresi digunakan menganalisa keputusan. Kaedah pengoptimuman pelbagai objektif digunakan untuk mengoptimumkan parameter pemesinan pada model tenaga dan kos. Sumbangan parameter penting telah ditentukan berdasarkan nilai keinginan kompaun, dan parameter optimum parameter dikenalpasti. Dengan simulasi dalam Pakar Reka Bentuk dan Matlab, masalah pengoptimuman pelbagai tindak balas diselesaikan oleh kaedah permukaan respon (RSM) dan algoritma genetik agihan yang tidak dikuasai (NSGA II) dan integrasi di antara mereka. Keputusan menunjukkan bahawa penggunaan kuasa minimum diperolehi pada nilai laju pemotongan terendah dan pada nilai besar laju suapan dan kedalaman potongan, masing-masing menyumbang 37.43% dan 20.5%. Kekasaran permukaan dikurangkan apabila kadar suapan dan kedalaman potongan berada ditahap terendah mereka, sedangkan laju pemotongan adalah faktor yang paling signifikan pada pakai alat dengan sumbangan sebanyak 39%, diikuti dengan kedalaman potongan pada 14.3%, tetapi tidak mempengaruhi oleh suapan kadar. Keputusan menunjukkan peningkatan dalam penggunaan kuasa di bawah keadaan kering 6.78%, sedangkan kos pemesinan menunjukkan lebih baik dengan 11.89% dan dengan kualiti yang boleh diterima dibandingkan dengan keadaan banjir. Untuk kaedah RSM, nilai keinginan (0.885) dan nilai minimum respon boleh dicapai pada kelajuan pemotongan 110 m / min, kadar suapan 0.192 mm / rev, dan 0.8 mm untuk kedalaman pemotongan. Kombinasi parameter ini menghasilkan penjimatan tenaga sebanyak 9.2% dan mengurangkan kos pemesinan sebanyak 4.6%. Bagi kaedah bersepadu (RSM-NSGA II), nilai objektif optimum adalah 0.57-3.84 kWh dan RM 8.94-9.78 untuk kering dan banjir. Keputusan menunjukkan peningkatan dalam penjimatan tenaga 14.94%, kekasaran permukaan 4.71%, pakai alat 13.98% dan penurunan kos pemesinan sebanyak 4.6%. Tiga kaedah pengesahan telah dijalankan untuk mengesahkan titik optimum. Selain itu, keputusan pengoptimuman generasi kedua menggunakan NSGA II menunjukkan peningkatan lebih daripada 70% berbanding dengan pengoptimuman RSM. Oleh itu, kaedah ini juga berkesan mengurangkan kesan dan kos proses pemesinan dan memelihara alam sekitar, yang mengakibatkan peningkatan keseluruhan pemesinan mampan.

ABSTRACT

The machinability of stainless steel has attracted considerable interest because of its medium strength, low carbon and corrosion resistance. Cutting fluids that are oil-based are unsustainable as the machining process has an environmental impact. Dry machining is a sustainable solution that reduces both energy consumption and machining cost. This study aims to optimize an integrated mathematical model for both energy and cost in the turning process of stainless steel 316 (SS316). It is set out to optimize power consumption, machining cost and the traditional machining responses of surface roughness and tool wear by adjusting machining parameters. Stainless steel 316 was turned with different cutting tool types of uncoated carbide and coated tools. Three factors are associated with cutting parameters, namely cutting speed, feed rate, and depth of cut. Analysis of variance and the regression model was used to analyze the machining parameters and responses. A multi-objective optimization method was employed to optimize machining parameters in terms of energy and cost models. With a simulation in Design Expert and Matlab, the multi-response optimization problems were solved with a response surface methodology (RSM) and non-dominated sorting genetic algorithm (NSGA II), as well as integration between them. Results indicated that the minimum power consumption was obtained at the lowest cutting speed value and at the greatest values of feed rate and depth of cut, which contributed 37.43% and 20.5%, respectively. Surface roughness was minimized when feed rate and depth of cut were at their lowest levels, whereas the cutting speed was the most significant factor on tool wear, with a contribution of 39%, followed by depth of cut at 14.3%, although there was no influence by feed rate. Results also showed an improvement in power consumption under dry conditions, at 6.78%, whereas machining cost was better by 11.89% and there was acceptable quality compared to flood conditions. For the RSM method, the desirability value (0.885) and the minimum value of responses can be achieved at a cutting speed of 110 m/min, feed rate of 0.192 mm/rev, and 0.8 mm for depth of cut. This parameter combination results in an energy saving of 9.2% and reduced machining cost of 4.6%. For the integrated (RSM-NSGA II) method, the optimum objective values are 0.57-3.84 kWh and RM 8.94-9.78 for dry and flood, respectively. The results showed an improvement in energy saving of 14.94%, surface roughness of 4.71%, tool wear of 13.98%, and decreased machining cost of 4.6%. A three-confirmation method was used to validate the optimum point. Moreover, the second-generation results of optimization using NSGA II showed an improvement of more than 70% compared with that of RSM optimization. Therefore, this method also effectively reduces the effects and costs of the machining process and preserves the environment, which results in an overall enhancement of sustainable machining.

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LIST OF SYMBOLS

v_c	Cutting speed (m/min)
Fr	Feed rate (mm/rev)
a_p	Depth of cut (mm)
E_0	Start-Up Energy Consumption
E_{st}	Setup Energy Consumption
Ec	Material Removal Energy Consumption
E_{fp}	Footprint Energy Consumption
E_{air}	Non-Cutting Energy Consumption
E_{col}	Cutting Fluid Energy Consumption
P_{air}	Rotating Spindle Power in Watt
k	Specific Energy Requirement in Cutting (kJ/Cm^3)
V	Removal of Material Rate (Cm^3/S)
t_0	Start-Up Time
t_{st}	Setup Time
t_{air}	Rotating Spindle Without Cut Time
t_t	Tool Change Time
t_c	And Cutting Time
D	Average Workpiece Diameter
l	Length of Cut
x_E	Specific Embodied Energy of Auxiliary Material (kJ/Kg)
ρ_A	Density of Auxiliary Material (Kg/L)
v_A	Consumption Velocity of Auxiliary Material [L/Sec]
C_m	Machining Cost Per Part
C_{tch}	Tool Changing Cost Per Part
C_{tc}	Tool Cost Per Part

LIST OF ABBREVIATIONS

CLFs	Cooling/Lubrication Fluids
MQL	Minimum Quantity Lubrication
CBN	Cubic Boron Nitride
DOE	Design of Experiments
DF	Degree of Freedom
MS	Mean Square
SS	Sum of Square
RSM	Response Surface Methodology
NSGA-II	Non-Dominated Sorting Genetic Algorithm II
TBL	Triple Bottom Line
SEC	Specific Energy Consumption
CCD	Central Composite Design
ANOVA	Analysis of Variance
PW	Power Consumption
SR	Surface Roughness
TW	Tool Wear

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