Faculty of Manufacturing Engineering

PERFORMANCE EVALUATION OF ULTRASONIC ASSISTED WIRE ELECTRICAL DISCHARGE TURNING FOR TI-6AL-4V MATERIAL

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DEDICATION

I would like to dedicate this thesis to my parents, who have been my emotional anchors through my entire life. They gave the little they had to ensure I would have the opportunity of an education. Their efforts and struggles have allowed me to successfully complete this research journey.

ABSTRACT

Recently, the machining of precise cylindrical forms on hard and difficult-to-cut materials by spark erosion has gained popularity. However, the performance of this process always reflects the drawbacks in terms of distortion in gap equilibrium due to sensitivity of rotating workpieces in which the surface finish of the machined parts and the material removal rate (MRR) are not satisfying even when advanced computing and statistical optimisation methods have been used to obtain the best machining conditions. Solving the conflict of MRR and surface roughness is challenging because no single combination of parameters can provide the best machining performance. Therefore, the main objective of this research is to evaluate the performance of ultrasonic assisted in wire electrical discharge turning (WEDT) for Ti-6Al-4V on MRR and surface roughness. The ultrasonic attachment accessories are fabricated and retrofitted into the existing WEDT. The collected data for parametric study is analysed by analysis of variance (ANOVA). For the evaluation of surface roughness, five machining paths are evaluated on the basis of conventional turning operations, such as straight-turning and cone angle. The machined surface conditions are characterised by elemental analysis and surface morphology in post-evaluation measurement. Results showed that, the integration of ultrasonic vibration to WEDT revealed positive effects, where the average of MRR and surface roughness are improved by 2.9% and 13.4%, respectively, even though the proposed ultrasonic parameters have not been optimised yet. The electrode wire debris generated during machining, which can resolidify to the machined surface, is able to be reduced with the integration of ultrasonic vibration to WEDT machining when using low ultrasonic amplitude (10 µm). After performing with multi-objective parameter optimization with the goal of maximising the MRR and minimising the surface roughness using genetic algorithm method, there is a 5.2% improvement for the MRR and 11.6%–27.9% improvement for surface roughness compared to conventional WEDT. In conclusion, this study successfully applied the ultrasonic vibration to rotating workpieces, proved the capability in machining and enhanced both MRR and surface roughness.

PENILAIAN PRESTASI LARIK WAYAR NYAHCAS ELEKTRIK TERBANTU ULTRASONIK UNTUK BAHAN TI-6AL-4V

ABSTRAK

Kebelakangan ini, pemesinan jitu merujuk kepada bentuk silinder pada bahan keras dan sukar dipotong menggunakan proses hakisan percikan api telah mendapat sambutan menggalakkan. Namun, proses ini mempunyai kelemahan iaitu gangguan keseimbangan pada celah percikan yang berpunca daripada bendakerja yang berputar dimana hasil kekemasan permukaan dan hasil kadar penyingkiran bahan tidak memuaskan walaupun kaedah pengkomputeran lanjutan dan pengoptimuman statistik telah digunakan untuk mendapatkan keadaan pemesinan yang terbaik. Menyelesaikan konflik di antara kadar penyingkiran bahan dan kekasaran permukaan amat mencabar kerana tiada satu kombinasi parameter yang mampu memberikan prestasi pemesinan yang terbaik. Oleh itu, objektif utama penyelidikan ini adalah untuk menilai prestasi pemesinan larik wayar nyahcas elektrik terbantu ultrasonik untuk bahan Ti-6Al-4V pada aspek hasil kadar penyingkiran bahan dan hasil kekasaran permukaan. Ultrasonik aksesori telah dihasilkan dan dinaik taraf pada proses pemesinan larik wayar nyahcas elektrik. Data yang dikumpulkan untuk kajian parametrik dianalisa menggunakan teknik analisis varians. Bagi penilaian kekasaran permukaan pula, lima jenis pemesinan dinilai berasaskan operasi pemesinan larik konvensional iaitu meliputi larik lurus dan kon. Keadaan permukaan pemesinan dinilai menggunakan kaedah analisis elemen dan morfologi sebagai penilaian pasca pengukuran. Hasil kajian yang positif telah diperoleh iaitu purata kadar penyingkiran bahan telah bertambah baik sebanyak 2.9% dan kekasaran permukaan telah bertambah baik sebanyak 13.4% walaupun parameter ultrasonik yang digunakan masih belum dalam keadaan yang optimum. Selain itu, pengurangan pada serpihan wayar elektrod yang berkemampuan untuk terendap semula pada permukaan bendakerja semasa pemesinan dapat dicapai dengan menggunakan nilai parameter terendah (10 µm) bagi ultrasonik amplitud. Dengan menyempurnakan pengoptimuman parameter berbilang objektif dibantu kaedah algoritma genetik pada aspek hasil maksima bagi kadar penyingkiran bahan dan minima pada kekasaran permukaan, hasil kajian telah berjaya membuktikan kadar penyingkiran bahan telah bertambah baik sebanyak 5.2% dan kekemasan permukaan telah bertambah baik sebanyak 11.6%–27.9% berbanding pemesinan larik konvensional wayar nyahcas elektrik. Kesimpulannya, kajian ini telah berjaya mengaplikasikan getaran ultrasonik pada bahan kerja berputar dan membuktikan keupayaannya dalam pemesinan di samping meningkatkan hasil pada kadar penyingkiran bahan dan kekemasan permukaan.

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LIST OF SYMBOLS

σ	-	(Sigma) units for stress calculation
μ	-	(Micro) metric unit denoting a factor of 10^{-6} or represent small
α	-	(Alpha) coded-unit distance for axial points in central composite design
δ	-	Deflection
df	-	Degrees of Freedom
k	-	number of factors in design
R^2	-	Index of determination
n	-	number of observations in sample
P	-	Probability Value
V	-	(volt) unit for electric potential difference
D	-	Diameter
T	-	Thickness
ID	-	Inside Diameter
OD	-	Outside Diameter
Pa	-	(pascal) unit of pressure/stress
Ω	-	(Ohm) unit of electrical resistance
LA	-	Machine power supply low
MP	-	Machine power supply medium
HP	-	Machine power supply high
L, l	-	Length
Ra	-	Arithmetic average surface roughness

LIST OF ABBREVIATIONS

AC	-	Alternating Current
AISI	-	American Iron and Steel Institute
ANOVA	-	Analysis of Variance
C.V.	-	Coefficient of Variation
CAD	-	Computer-Aided Design
CAM	-	Computer-Aided Manufacturing
CCD	-	Central Composite Design
CNC	-	Computer Numerical Control
DC	-	Direct Current
EDM	-	Electrical Discharge Machining
EDT	-	Electrical Discharge Turning
EDX	-	Energy Dispersive X-ray
GA	-	Genetic Algorithm
H	-	Hydrogen
ICSP	-	In Circuit Serial Programming
IDE	-	Integrated Development Environment
IFM	-	Infinite Focus Microscope
ISO	-	International Standardization Organization
LCD	-	Liquid-Crystal Display
LED	-	Light-Emitting Diode
M	-	Metric
MRR	-	Material Removal Rate
O	-	Oxygen
PIC	-	Programmable Interface Controllers
PWM	-	Pulse Width Modulation

RSM	-	Response Surface Methodology
SEM	-	Scanning Electron Microscopy
Si_3N_4	-	Silicon Nitride
Ti6Al4V	-	Titanium Alloy Grade 5
USB	-	Universal Serial Bus
VG	-	Voltage Gap
W	-	Watt
WEDG	-	Wire Electrical Discharge Grinding
WEDM	-	Wire Electrical Discharge Machining
WEDT	-	Wire Electrical Discharge Turning

LIST OF PUBLICATIONS

Journals:

1. Zakaria, M.A.M., Izamshah, R., Halim, M., Kasim, M.S., Zamri, R., Yob M.S., Aziz M.S.A., and Abdullah, R.S.A., 2022. Prediction of Material Removal Rate in Wire Electrical Discharge Turning using Artificial Neural Networks and Adaptive Neuro-Fuzzy Models, *International Journal of Nanoelectronics and Materials*, 15, pp. 101-112.

2. Zakaria, M.A.M., Izamshah, R., Kasim, M.S., Hafiz, M.S.A., and Ramli, A., 2021. Effect of Wire Electrical Discharge Turning Parameters on Surface Roughness of Titanium Alloy. *Journal of Applied Science and Engineering*, 25(2), pp. 267–274.

3. Zakaria, M.A.M., Izamshah, R., Kasim, M.S., Hafiz, M.S.A., and Putra W.T., 2020. An Ultrasonic Assistance in Wire Spark Erosion Machining for Fabricating Cylindrical Shapes Components: A Review. *ARPN Journal of Engineering and Applied Sciences,* 15(21), pp. 2486–2491.

4. Izamshah, R., Akmal, M., Ibrahim, M.H., Kasim, M.S., Ding, S., Nawi, M.H., and Noorazizi, M.S., 2020. Development of Ultrasonic Pulsation Wire Electrical Discharge Turning Device for Micro/Nano Medical Part Manufacturing. *International Journal of Nanoelectronics & Materials*, 13, pp. 363-378.

5. Izamshah, R., Akmal, M., and Kasim, M.S., 2019. Improvement of the Wire Compensation Configuration Model for Improving Part Accuracy in Cylindrical Wire Electrical Discharge Turning. *International Journal of Manufacturing Technology and Management*, 33(6), pp. 428-445.

6. Zakaria, M.A.M., Abdullah, R.I.R., Kasim, M.S., and Ibrahim, M.H., 2019. Enhancing the Productivity of Wire Electrical Discharge Machining Toward Sustainable Production by Using Artificial Neural Network Modelling. *EMITTER International Journal of Engineering Technology*, 7(1), pp. 261–274.

Proceedings:

1. Akmal, M., Izamshah, R., and Kasim, M.S., 2018. Cutting Capabilities for Macro-Micro Cylindrical Shapes Component by Wire Electrical Discharge Turning (WEDT). In: *Proceedings of Innovative Research and Industrial Dialogue'18*, 1(1), p. 178. *(IRID18)*, Melaka, Malaysia, 18 July 2018. Universiti Teknikal Malaysia Melaka.