



Faculty of Manufacturing Engineering

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

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Doctor of Philosophy

2023

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ELECTRICAL DISCHARGE TURNING FOR TI-6AL-4V MATERIAL**

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



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2023

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 diperolehi 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 ($10\ \mu\text{m}$) 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.

ACKNOWLEDGEMENTS

In the name of Allah, the Most Gracious and the Most Merciful.

Alhamdulillah, all praises to Allah the Almighty for His blessing in completing this thesis. Special appreciation goes to my supervisor, Associate Professor Dr. Raja Izamshah bin Raja Abdullah for his supervision and constant support. His invaluable help especially in giving constructive comments and suggestions throughout the experimental and thesis works have contributed to the success of this research. I wish to extend my gratitude to my co-supervisor Associate Professor Dr. Mohd Shahir bin Kasim for his inspirational guidance, help and great supervision. Working with them was indeed a wonderful and learning experience, which I thoroughly enjoyed.

I would like to express my appreciation to the Dean, Faculty of Manufacturing Engineering, Professor Ir. Dr. Hambali bin Arep@Ariff and also to the Deputy Dean, Associate Professor Ir. Ts. Dr. Mohd Shukor Salleh for their support and help towards my postgraduate affairs.

I am thankful to all the assistant laboratory engineer and office staffs at centre of advanced manufacturing (AMC) and Faculty of Manufacturing Engineering in supporting and sharing their skills, opinions, and guidance in handling the equipment throughout the study particularly to Mr. Hanafiah in aiding the fabrication, experimental setup and troubleshoot, Mr. Taufiq in helping to prepare the machines, Madam Aisyah for helping in measurement and Mr. Azhar for assisting in identifying the SEM micrograph.

A big thanks to the Centre of Graduate Studies of Universiti Teknikal Malaysia Melaka for providing Zamalah Scheme sponsorship throughout my study and Faculty of Manufacturing for providing experimental facilities used in this project.

My deepest gratitude goes to my beloved parents; Mohd Zakaria bin Aziz and Fauziah binti Jaafar and to my siblings Siti Norhani, Mohd Redzwan and Siti Nurazlinda for their endless love, prayers, and encouragement. They are always closest to my joys and sorrows and always there for me. I am also grateful for the support and guidance received from my colleagues. Thank you to all my friends in UTeM for sharing this journey with me.

Finally, my heartfelt thanks to my biggest supporter, my caring and loving wife; Arbaeyah who had encouraged me when times get rough. It was a great comfort and relief that you willingly took care of our household activities and nurture our precious daughter; Aisha Al Humaira while I completed the research, and I am very much appreciate all your sacrifices.

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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 ₃ N 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



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