Faculty of Manufacturing Engineering

MULTI OBJECTIVE PERFORMANCE OPTIMIZATION OF HYBRID ROTARY ULTRASONIC ASSISTED END MILLING FOR MACHINING HARDENED STEEL MATERIAL

Azlan Bin Ramli

Doctor of Philosophy

2020

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AZLAN BIN RAMLI

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

Faculty of Manufacturing Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2020

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DECLARATION

I declare that this thesis entitled “Multi Objective Performance Optimization of Hybrid Rotary Ultrasonic Assisted End Milling for Machining Hardened Steel Material” 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 : Azlan Bin Ramli

Date : ……

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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 : Associate Professor Dr. Raja Izamshah Bin Raja Abdullah

Date : ……..…

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DEDICATION

I dedicated this thesis to my beloved family.

Ramli Bin Muda

Esah Binti Mahmud

Linawati Binti Razak @ Ali

Nurul Fadhlina Binti Azlan

Nurul Zahirah Farhanah Binti Azlan

Nurul Najihah Farhanah Binti Azlan

Nurul Anisah Amni Binti Azlan

Faris Iskandar Bin Azlan

Nurul Auni Nabihah Binti Azlan

and

Associate Professor Dr. Raja Izamshah Bin Raja Abdullah

and

Ir. Dr. Muhamad Arfauz Bin A Rahman

and

to all my friends

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ABSTRACT

Hardened D2 tool steel is widely used in the mold and die industry especially for injection molding tools, cold forming tools and precision engineering parts. Most of the applications require an excellent surface finish as it will reflect on the end product appearance. However, the high strength of these materials (>50 HRC) results in rough machined surface when using the conventional machining process, hence, special machining technique is required to maintain the part quality. In current industry practice, the machining tolerances are generally achieved by subsequent manual finishing process such as, polishing and grinding in order to realize both the required geometry and surface finish. Notably, the aforementioned manufacturing techniques for mould and die fabrication tend to decrease productivity and create uncertainty over the component accuracy. Hence, this thesis proposed a significant advancement on improving the mould fabrication process using a hybrid machining technique such as, combining two established machining processes into a new combined set-up known as Rotary Ultrasonic Assisted End Milling (RUAEM) whereby the advantages of each discrete process could be exploited synergistically. A total of 162 experimental runs based on statistical Response Surface Methodology matrix were executed comprising different level of machining parameter namely cutting speed, feed rate, depth of cut, frequency of vibration, amplitude vibration and alumina oxide slurry concentration towards surface roughness, cutting force and material removal rate. The investigation proceeded until a set of optimal machining parameter and satisfactory validation index were achieved. Based on the recommended optimized model, the best achievable surface roughness (Ra), resultant force (FR) and material removal rate (MRR) values was 0.12 µm, 4.98 N and 161.58 mg/min respectively. The results yielded that RUAEM process was able to improve 97% of the surface roughness, 92% of cutting force magnitude and 26% of material removal rate in comparison to the conventional machining processes within the same cutting conditions. For the multiple response optimization result, the combination of 111.45 rpm, 5.75 mm/min feed rate, 27.05 µm depth of cut, 20.91 kHz vibration frequency, 3 µm amplitude and 13.26% abrasive concentration yielded the highest desirability index of 0.87. Lastly, a good agreement value between the prediction and experimental validate the new proposed parameter optimization.

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ABSTRAK

Keluli tahan karat, D2 digunakan meluas dalam industri acuan dan die terutama untuk alat pengacuan suntikan, alat membentuk dingin dan peralatan kejuruteraan ketepatan. Kebanyakan aplikasi memerlukan kemasan permukaan yang sangat baik kerana ia mencerminkan penampilan produk akhir. Walau bagaimanapun, pemesinan secara konvensional untuk bahan kekuatan tinggi (> 50 HRC) menghasilkan permukaan pemesinan yang kasar, maka teknik pemesinan khas diperlukan untuk mengekalkan kualiti pemesinan. Dalam amalan industri semasa, toleransi pemesinan dicapai melalui proses pemesinan akhir secara manual iaitu proses pengisaran dan pengggilapan berterusan untuk menghasilkan geometri dan kemasan permukaan yang diperlukan. Teknik pembuatan fabrikasi acuan dan die berpotensi untuk mengurangkan produktiviti dan mewujudkan ketidakpastian terhadap ketepatan komponen. Tesis ini mencadangkan teknik pemesinan terkini dalam proses fabrikasi acuan dengan menggunakan teknik pemesinan hibrid iaitu gabungan dua proses pemesinan ke dalam satu gabungan yang dikenali sebagai Pengisaran Akhir Berputar Berbantu Ultrasonik (RUAEM). Sebanyak 162 eksperimen telah dijalankan berdasarkan kaedah statistik Matrik Tindakbalas Permukaan yang berbeza parameter pemesinan iaitu kelajuan pemotongan, kelajuan suapan, kedalaman pemotongan, frekuensi getaran, getaran amplitude dan kecairan kepekatan alumina oksida terhadap kekasaran permukaan, daya pemotongan dan kadar penyingkiran bahan. Kajian diteruskan sehingga mencapai pemesinan yang optimum dan indeks pengesahan yang memuaskan. Berdasarkan model yang dioptimumkan, kekasaran permukaan yang dicapai (Ra), kekuatan pemangkin (FR) dan nilai penyingkiran bahan (MRR) adalah 0.12 μm, 4.98 N dan 161.58 mg/min masing-masing. Hasil kajian menunjukkan RUAEM mampu meningkatkan 97% kekasaran permukaan, 92% magnitud daya pemotongan dan 26% kadar penyingkiran bahan berbanding pemesinan konvensional dalam keadaan pemotongan yang sama. Keputusan Pengoptimuman Tindakbalas Pelbagai menunjukkan bahawa kombinasi 111.45 rpm, kadar suapan minuman 5.75 mm, kedalaman 27.05 μm, 20.91 kHz frekuensi getaran, 3 μm amplitude dan 13.26% kepekatan cairan menghasilkan indeks keinginan tertinggi 0.87. Nilai persetujuan yang baik di antara ramalan dan pengesahan melalui eksperimen telah menghasilkan pengoptimuman parameter yang baru.

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ACKNOWLEDGEMENTS

Almighty Allah and peace be upon the beloved Prophet Muhammad s.a.w. Alhamdulillah. Thanks to Allah S.W.T for giving encouragement, strength, patience in completing this research and thesis writing. First and foremost, I would like thanks to my mother, my wife, daughters, sons, and my family for their constant prayer. Also, I sincerely thanks to my supervisor, Associate Professor Dr. Raja Izamshah Bin Raja Abdullah for his essential supervision, guidance, advice, encouragement and support. Also, the gratitude goes to Ir. Dr. Muhamad Arfauz Bin A Rahman as my co-supervisor for his time and support in giving advice and guidance towards the completion of this research and thesis. Not to forget, thanks to Mr. Hanafiah, Mr. Taufiq, Mr. Mazlan, Mr. Azhar, Mr. Hairul Hisham, Mr. Helmi and all the assistant engineer from Faculty of Manufacturing Engineering for their assistance and efforts in all the lab and analysis works. Lastly, thanks to Kementerian Pendidikan Tinggi for their financial support through the HLP scholarship.

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