DISSERTATION

MODELLING AND OPTIMISATION OF MILLING PROCESS ON THIN-WALLED TI64 UNDER CARBON DIOXIDE CRYOGENIC USING RESPONSE SURFACE METHODOLOGY AND GENETIC ALGORITHM

ARIE YUDHA BUDIMAN
NIM. 03013681924006

ENGINEERING SCIENCE PROGRAM STUDY
DOCTORAL PROGRAM
FACULTY OF ENGINEERING
S R I W I J A Y A U N I V E R S I T Y
2025

DISSERTATION

MODELLING AND OPTIMISATION OF MILLING PROCESS ON THIN-WALLED TI64 UNDER CARBON DIOXIDE CRYOGENIC USING RESPONSE SURFACE METHODOLOGY AND GENETIC ALGORITHM

Submitted to fulfill the requirements for the Doctor of Engineering Degree in the field of Mechanical Engineering

ARIE YUDHA BUDIMAN
NIM. 03013681924006

ENGINEERING SCIENCE PROGRAM STUDY
DOCTORAL PROGRAM
FACULTY OF ENGINEERING
S R I W I J A Y A   U N I V E R S I T Y
2025

ENDORSEMENT PAGE

MODELLING AND OPTIMISATION OF MILLING PROCESS ON THIN-WALLED TI64 UNDER CARBON DIOXIDE CRYOGENIC USING RESPONSE SURFACE METHODOLOGY AND GENETIC ALGORITHM

DISSERTATION

Submitted to fulfill the requirements for the Doctor of Engineering Degree
In the field of Mechanical Engineering

By

ARIE YUDHA BUDIMAN
NIM. 03013681924006

Has been approved
On July 30th, 2025

Supervisor	**Co-Supervisor**
Prof. Dipl-Ing. Ir. Amrifan Saladin Mohruni, Ph.D	**Prof. Dr. Safian Sharif**
NIP. 196409111999031001	**I/C No. 610621-04-5235**

Approved by,

Faculty of Engineering	**Coordinator Study Program**
Dean,	
Dr. Ir. Bhakti Yudho Suprapto, S.T., M.T., IPM.	**Prof. Dr. Ir. Nukman, M.T.**
NIP. 197502112003121002	**NIP. 195903211987031001**

PAGE OF APPROVAL

The Dissertation entitled "**Modelling and Optimisation of Milling Process on Thin-Walled Ti64 under Carbon Dioxide Cryogenic using Response Surface Methodology and Genetic Algorithm**" was defended in front of the Doctoral Promotion Examination Team, Engineering Science Study Program, Doctoral Program, Faculty of Engineering, Sriwijaya University on July 30, 2025.

Palembang, July 30th, 2025

Chairman of Examiner Team:

1. Ir. Irsyadi Yani, S,T., M.Eng., Ph.D., IPM. ( )
   NIP. 197112251997021001

Examiner Team Members:

1. Ir. Fatahul Arifin, S.T., M.Eng.Sc., Ph.D ( )
   NIP. 197201011988021004

2. Dr. Muhammad Yanis, S.T., M.T. ( )
   NIP. 197002281994121001

3. Dr. Ir. Diah Kusuma Pratiwi, M.T ( )
   NIP. 196307191990032001

Approved by,

Faculty of Engineering	**Coordinator Study Program**
Dean,	
Dr. Ir. Bhakti Yudho Suprapto, S.T., M.T., IPM.	**Prof. Dr. Ir. Nukman, M.T.**
NIP. 197502112003121002	**NIP. 195903211987031001**

PLAGIARISM STATEMENT

I, the undersigned:

Name	: Arie Yudha Budiman
NIM	: 03013681924006
Study Program	: Doctoral Program in Engineering Science
Faculty	: Faculty of Engineering
University	: Sriwijaya University
Address	: Jl. Mayor Salim Batubara No. 71 RT/RW 01/01, Kel. 20 Ilir D.II, Kec. Kemuning, Palembang City, South Sumatra

I hereby declare that my dissertation entitled “Modelling and Optimisation of Milling Process on Thin-Walled Ti64 under Carbon Dioxide Cryogenic using Response Surface Methodology and Genetic Algorithm” is free from fabrication, falsification, plagiarism, unauthorized authorship, conflicts of interest, and multiple submissions, as stipulated in the Regulation of the Minister of Education, Culture, Research, and Technology of the Republic of Indonesia Number 39 of 2021.

Should any inconsistency with the above be found, I am willing to accept academic sanctions from Universitas Sriwijaya under the prevailing regulations.

This statement is made truthfully and sincerely.

Palembang, July 30th, 2025
Sincerely,

METERAI TEMPEL
79D61AMX381920239

Arie Yudha Budiman
NIM. 03013681924006

PREFACE

Alhamdulillah, all praise be to Allah SWT for His blessings, guidance, and mercy that have enabled the completion of this dissertation entitled ***"Modelling and Optimisation of Milling Process on Thin-Walled Ti64 under Carbon Dioxide Cryogenic using Response Surface Methodology and Genetic Algorithm."***

The dissertation report is a prerequisite for achieving a Doctoral degree in the Engineering Science Study Program at the Faculty of Engineering, Sriwijaya University. This research was conducted to address the machining challenges of aerospace-grade titanium alloys by integrating an environmentally sustainable cooling approach, CO_2 cryogenic cooling, with advanced optimisation techniques. Surface Methodology (RSM) was employed to develop predictive models, while the Genetic Algorithm (GA) was implemented to determine the optimal cutting conditions. The findings of this study are anticipated to offer significant contributions to both academia and industry in promoting sustainable machining practices for high-performance aerospace materials.

The completion of this report was delayed due to the COVID-19 pandemic. Nevertheless, with the unwavering support of my family, the valuable advice of my friends, and the guidance of my supervisor and co-supervisor, I was able to restore my enthusiasm and confidence, which ultimately enabled me to bring this work to completion.

I acknowledge that the process of writing this dissertation has involved various individuals and institutions who have contributed directly and indirectly to its completion. On this occasion, I would like to express my deepest thanks and highest appreciation to all those who have contributed:

1. Dr. Ir. Bhakti Yudho Suprapto, S.T., M.T., IPM, as Dean of the Engineering Faculty.
2. Prof. Dr. Ir. Nukman, M.T., as Coordinator of the Study Program.
3. I would like to express my deepest gratitude to Prof. Dipl.-Ing. Ir. Amrifan Saladin Mohruni, Ph.D., my supervisor, and Prof. Ts. Dr. Safian Sharif, my co-supervisor, for their invaluable guidance, constructive feedback, and continuous encouragement throughout this research.

4. I would like to convey my sincere gratitude to Ir. Irsyadi Yani, S.T., M.Eng., Ph.D., IPM, as Chairman of the Examiner Team, for his valuable insights, constructive feedback, and guidance during the examination process. My appreciation also goes to the Examiner Team Members: Ir. Fatahul Arifin, S.T., M.Eng.Sc., Ph.D., Dr. Muhammad Yanis, S.T., M.T., and Dr. Ir. Diah Kusuma Pratiwi, M.T., for their thorough evaluation, critical comments, and meaningful suggestions that have significantly contributed to the improvement and refinement of this dissertation.
5. I am deeply grateful to my beloved wife, Vivi Kusumawardhani, for her unwavering love, patience, and understanding throughout this research. Her constant encouragement, sacrifices, and support, both emotionally and practically, have been an invaluable source of strength, enabling me to persevere through challenges and complete this dissertation.
6. I would like to express my deepest gratitude to my father, Almarhum Darmi Asril Agoes, and my grandmother Almh Zubaidah, whose values, prayers, and life lessons have been a lasting source of inspiration and strength throughout my life. My heartfelt thanks also go to my beloved mother Rita Astuti for her endless love, prayers, and unwavering support during my academic journey. I am equally grateful to my brothers and sister, Arvan Zulhandi, Rinaldi Triasaputra, and Yulivia Ramadonna for their constant encouragement and understanding, as well as to all my nieces and nephews, whose joy and affection have been a source of motivation and comfort during the challenging times of this research.
7. All parties that I cannot mention individually have helped me from the beginning of the research until the completion of this dissertation.

Palembang, 30 August 2025

The Author

SUMMARY

This dissertation presents an in-depth investigation into the cryogenic machining performance of thin-walled Ti6Al4V (Ti64) alloy using carbon dioxide (CO_2) as a sustainable cooling medium. The research aims to improve surface quality while minimizing environmental impact by replacing conventional cutting fluids with cryogenic CO_2. Both uncoated and AlCrN-coated carbide end mills were used to assess the influence of key machining parameters including cutting speed (V_c), feed rate (f_z), radial depth of cut (a_r), and axial depth of cut (a_x) on surface roughness (Ra). A Central Composite Design (CCD) with 30 experimental runs was implemented, and surface roughness was measured at multiple axial depths on each workpiece. The optimization and modeling were carried out using Response Surface Methodology (RSM) and Genetic Algorithm (GA), with the aim of predicting optimal cutting conditions and minimizing Ra. For uncoated tools, the RSM model predicted a minimum surface roughness of 0.158 µm, while GA slightly improved it to 0.1568 µm after 64 generations. In contrast, coated tools significantly enhanced machining performance, producing a minimum Ra of 0.132 µm through RSM and further reduced to 0.12725 µm by GA within 96 generations, representing an 18.8% improvement over uncoated tools. The feed rate was found to be the most influential factor in both tool conditions, while cutting speed also contributed positively to surface quality. Although RSM models yielded higher predictive accuracy based on lower Mean Square Error (MSE), GA consistently produced lower Ra values, demonstrating superior global optimization capabilities. The application of AlCrN coating also helped suppress tool wear and thermal degradation, contributing to smoother surface finishes and greater process stability. Overall, the combination of CO_2 cryogenic cooling, advanced tool coating, and hybrid optimization techniques (RSM-GA) proves to be highly effective for the precision machining of thin-walled Ti64 alloy. This approach not only enhances surface integrity and tool life but also supports the broader goal of sustainable manufacturing by reducing dependence on traditional oil-based coolants. The findings offer valuable insights for machining difficult-to-cut aerospace materials and provide a foundation for integrating green technologies into high-performance manufacturing systems. This research contributes to the evolving field of intelligent, eco-friendly machining and sets the stage for further exploration of cryogenic processes in advanced material applications.

Keywords: Titanium Alloy, Thin-Walled, Surface Roughness, Cryogenic, RSM, GA

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Page

CHAPTER 1
INTRODUCTION

1.1 Overview

This study investigates the machining performance of thin-walled Ti64 alloy under carbon dioxide-based cryogenic cooling. Both coated and uncoated cutting tools are considered in the experimental setup. To analyze the influence of key machining variables on surface quality and process efficiency, Response Surface Methodology (RSM) and Genetic Algorithm (GA) are employed in combination, serving both as modelling frameworks and optimisation techniques to determine the most effective parameter settings..

1.2 Background of the Problems

The manufacturing industry continually seeks to improve productivity while maintaining high product quality. One of the primary challenges in metal cutting processes is the generation of excessive heat at the tool and workpiece interface. This thermal buildup can negatively affect dimensional accuracy, accelerate tool wear, and degrade surface finish. Although conventional cutting fluids are widely used to manage this heat, their effectiveness diminishes at elevated cutting speeds, particularly because they struggle to reach the critical contact zone (Dhar, et al., 2006). Moreover, traditional oil-based coolants pose environmental and health risks. Their disposal can lead to soil and water contamination, and their use increases operational costs due to the need for complex storage, circulation, and filtration systems. Consequently, there is a growing demand for more sustainable and efficient cooling methods in machining operations.(Dilip Jerold and Pradeep Kumar, 2011).

Cryogenic cooling has emerged as a viable alternative. Utilizing extremely low-temperature substances such as liquid nitrogen or carbon dioxide, this approach efficiently removes heat from the cutting zone (Tazehkandi, et al., 2015). Carbon dioxide at -78.5°C and liquid nitrogen at -196°C can significantly enhance tool life and surface quality by maintaining lower temperatures during the cutting process (MacHai and Biermann, 2011; Pusavec, et al., 2014)

With increased global emphasis on environmentally friendly manufacturing, green machining practices are becoming more prevalent. Cutting fluids can contribute up to 20% of total production costs, making their reduction economically attractive. While complete elimination of cutting fluids is not yet feasible, cryogenic methods offer a path toward cleaner machining without compromising performance. (Maruda, et al., 2016; Fernández, et al., 2014).

Though cryogenic machining has historical roots Reitz first reported the use of CO_2 in 1919 it has seen renewed interest due to advancements in delivery systems and a greater focus on sustainability (Jawahir, et al., 2016). Compared to conventional coolants, cryogenic cooling offers superior thermal control, lower ecological impact, and potential cost reductions (Dilip Jerold and Pradeep Kumar, 2012). Numerous studies confirm that liquid nitrogen effectively reduces tool wear when machining materials like AISI 4140, while CO_2 has demonstrated excellent performance in facilitating chip removal. Surface quality remains a key indicator of machining success, with attributes such as residual stress and roughness serving as critical benchmarks. These are influenced by factors including machining technique, tool type, and process parameters. (Kaynak and Gharibi, 2018).

Surface quality plays a vital role in assessing the durability and performance of machined components throughout their service life (Kenda, et al., 2011; Ulutan and Ozel, 2011). It is commonly evaluated using parameters such as surface roughness and residual stress, which offer insights into the functional performance of a machined surface (Pusavec, et al., 2011; Umbrello, et al., 2012). Several factors can influence surface quality, including the selected cutting process, the type and condition of machine tools, the cutting parameters applied, and the specific machining environment. These elements must be carefully controlled to ensure optimal surface integrity and product reliability (Benardos and Vosniakos, 2003).

To systematically improve machining processes, researchers have moved away from empirical approaches toward data-driven modelling and optimisation. RSM provides a structured method for developing mathematical models that describe the interactions among process variables. GA, in turn, is well-suited for exploring large solution spaces to identify optimal parameter combinations. (Mokhtari Homami, et al., 2014; Pereira and Delijaicov, 2019). Statistical modelling and computational techniques estimate the machining process's surface integrity variables using a cryogenic cooling system (Jawahir, et al., 2016). Instead of relying solely on trial-and-error experimentation, machining processes can be optimized through mathematical modelling. Statistical and computational tools like RSM and GA are useful in predicting outcomes and guiding decision-making. These methods are especially relevant when machining advanced materials like titanium alloys, which are commonly used in aerospace applications.

1.3 Statement of The Problems

Thin-walled components are widely used in aerospace, energy, and precision engineering due to their high strength to weight ratio and structural flexibility. Typically fabricated through additive manufacturing, these parts require high-precision finishing processes to meet functional requirements. However, machining thin-walled structures made of titanium alloys presents challenges such as deformation, poor surface finish, and rapid tool wear. (Isaev, et al., 2016). The selection of appropriate cutting tools and cooling strategies becomes crucial in addressing these issues. Both coated and uncoated tools behave differently under cryogenic conditions, influencing the machining response. Therefore, it is essential to establish predictive models and optimize machining parameters to improve overall process reliability. This study employs RSM and GA not only to model the machining performance but also to achieve multi-parameter optimisation.

1.4 Objectives of The Study

This study aims to:

1. Develop predictive models using RSM to evaluate the effects of machining parameters on CO_2-based cryogenic machining of thin-walled Ti64 alloy, utilizing both coated and uncoated cutting tools..
2. Apply RSM and GA to identify the optimal combination of process parameters for improved machining outcomes.
3. Validate the accuracy of the predictive models through experimental trials, using mean square error (MSE) as the performance metric.

1.5 Significance of The Study

This study contributes to the field of sustainable manufacturing by examining the role of CO_2-based cryogenic cooling in machining thin-walled Ti64 alloy. The findings demonstrate the potential of cryogenic systems to enhance surface finish, extend tool life, and reduce reliance on conventional lubricants. Furthermore, the combined use of RSM and GA provides a structured and effective approach to process optimisation, aligning with current trends in smart and green manufacturing.

1.6 Scopes of The Study

The scope of this study encompasses the application of CO_2 cryogenic cooling in machining aerospace-grade Ti-64 alloy. The research focuses on evaluating the influence of cutting speed (V_c), feed rate (f_z), radial depth of cut (a_r), and axial depth of cut (a_x) on surface roughness (Ra). Both RSM and GA are used to construct predictive models and determine the optimal settings for these parameters. Limitations include the exclusion of other performance indicators such as cutting forces or temperature distributions, which may be addressed in future studies.

REFERENCES

Arrazola, P.J., Özel, T., Umbrello, D., Davies, M., and Jawahir, I.S., 2013. Recent Advances in Modelling of Metal Machining Processes. *CIRP Annals - Manufacturing Technology*, 62(2), pp.695–718.

Benardos, P.G. and Vosniakos, G.C., 2003. Predicting Surface Roughness in Machining: A Review. *International Journal of Machine Tools and Manufacture*, 43(8), pp.833–844.

Bhaumik, M., Maity, K., and Mohapatra, K.D., 2016. Determination of Material Removal Rate and Radial Overcut in Electro Discharge Machining of AISI 304 Using Dimensional Analysis. *Applied Mechanics and Materials*, 852, pp.160–165.

Budiman, A.Y., Mohruni, A.S., Sharif, S., Firdaus, A., Nugraha, B.S., 2021. The influence of machining parameters using cryogenic cooling system. AIP Conference Proceedings, 2338 (November). https://doi.org/10.1063/5.0070884

Buranský, I., Bračík, M., and Simna, V., 2018. Influence of End Mill Helix Angle on Surface Quality of Aluminium Thin-Walled Parts. *Research Papers Faculty of Materials Science and Technology Slovak University of Technology*, 26(42), pp.177–188.

Burhanudin, Margono, Suryono, E., Atmoko, N.T., and Zainuddin, Z.-., 2022. The Effect of Finishing Allowance and Milling Methode on Surface Roughness in the Finishing Process of Al5052 and Al7075. *Key Engineering Materials*, 935, pp.63–71.

Chang, C.-S., 2005. Prediction of Cutting Forces in Milling Stainless Steels Using Chamfered Main Cutting Edge Tool. *Journal of Mechanics*, 21(3), pp.145–155.

Cui, C., Hu, B.M., Zhao, L., and Liu, S., 2011. Titanium Alloy Production

Technology, Market Prospects and Industry Development. *Materials and Design*, 32(3), pp.1684–1691. Available at: http://dx.doi.org/10.1016/j.matdes.2010.09.011.

Daniyan, I., Tlhabadira, I., Phokobye, S., Siviwe, M., and Mpofu, K., 2019. Modelling and Optimisation of the Cutting Forces During Ti6al4v Milling Process Using the Response Surface Methodology and Dynamometer. *Mm Science Journal*, 2019(04), pp.3353–3363.

Davoodi, B. and Tazehkandi, A.H., 2016. Cutting Forces and Surface Roughness in Wet Machining of Inconel Alloy 738 with Coated Carbide Tool. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, 230(2), pp.215–226.

Deris, A.M., Zain, A.M., Sallehuddin, R., and Sharif, S., 2019. Modelling and Optimisation of Electric Discharge Machining Performances Using Harmony Search Algorithm. *Elektrika- Journal of Electrical Engineering*, 18(3–2), pp.56–61.

Dhar, N.R., Islam, M.W., Islam, S., and Mithu, M.A.H., 2006. The Influence of Minimum Quantity of Lubrication (MQL) on Cutting Temperature, Chip and Dimensional Accuracy in Turning AISI-1040 Steel. *Journal of Materials Processing Technology*, 171(1), pp.93–99.

Dilip Jerold, B. and Pradeep Kumar, M., 2012. Experimental Comparison of Carbon-Dioxide and Liquid Nitrogen Cryogenic Coolants in Turning of AISI 1045 Steel. *Cryogenics*, 52(10), pp.569–574. Available at: http://dx.doi.org/10.1016/j.cryogenics.2012.07.009.

Dilip Jerold, B. and Pradeep Kumar, M., 2011. Experimental Investigation of Turning AISI 1045 Steel Using Cryogenic Carbon Dioxide as the Cutting Fluid. *Journal of Manufacturing Processes*, 13(2), pp.113–119.

Ding, T., 2013. An Experimental Study of Cutting Forces in Ball-End Milling of AISI H13. *Advanced Materials Research*, 690–693, pp.2403–2407.

Dotcheva, M., 2008. A Generation of More Efficient CNC Tool Paths Using

Simulation Modelling. *International Journal of Simulation Modelling*, 7(3), pp.135–145.

Du, M., Cheng, Z., Zhang, Y., and Wang, S., 2018. Multiobjective Optimisation of Tool Geometric Parameters Using Genetic Algorithm. *Complexity*, 2018(1).

El-Hofy, H., 2005. *Advanced Machining Processes - Nontraditional and Hybrid Machining Processes*, McGraw-Hill.

Fernández, D., García Navas, V., Sandá, A., and Bengoetxea, I., 2014. Comparison of Machining Inconel 718 with Conventional and Sustainable Coolant. *MM Science Journal*, (December 2014), pp.506–510.

Ha, S., Zahari, T., and Tmys, T.Y., 2012. Minimum Quantity Lubrication (MQL) Using Ranque - Hilsch Vortex Tube (RHVT) for Sustainable Machining. *Applied Mechanics and Materials*, 217–219(2012), pp.2012–2015.

Hao, Y.L., Li, S.J., and Yang, R., 2016. Biomedical Titanium Alloys and Their Additive Manufacturing. *Rare Metals*, 35(9), pp.661–671.

Hasçelik, A. and Aslantaş, K., 2023. Examination of Deformation in Thin-Walled Structures Processed by Micro-Milling Method. *Journal of Materials and Mechatronics A*, 4(1), pp.134–146.

Huang, R., Riddle, M., Graziano, D., Warren, J., Das, S., Nimbalkar, S., Cresko, J., and Masanet, E., 2016. Energy and Emissions Saving Potential of Additive Manufacturing: The Case of Lightweight Aircraft Components. *Journal of Cleaner Production*, 135, pp.1559–1570. Available at: http://dx.doi.org/10.1016/j.jclepro.2015.04.109.

Isaev, A., Grechishnikov, V., Pivkin, P., Mihail, K., Ilyuhin, Y., and Vorotnikov, A., 2016. Machining of Thin-Walled Parts Produced by Additive Manufacturing Technologies. *Procedia CIRP*, 41, pp.1023–1026. Available at: http://dx.doi.org/10.1016/j.procir.2015.08.088.

Jawahir, I.S., Attia, H., Biermann, D., Duflou, J., Klocke, F., Meyer, D., Newman, S.T., Pusavec, F., Putz, M., Rech, J., Schulze, V., and Umbrello, D., 2016. Cryogenic Manufacturing Processes. *CIRP Annals - Manufacturing Technology*, 65(2), pp.713–736. Available at: http://dx.doi.org/10.1016/j.cirp.2016.06.007.

Jiao, F., Yao, C., Li, Z., and Qi, F., 2018. Research on Milling Force in Ultrasonic Assisted End Milling of Titanium Alloy Thin-Walled Parts. *Key Engineering Materials*, 764, pp.252–260.

Kang, Y.G., Wang, Z.Q., Lou, W.M., and Jiang, C., 2006. Study of the Classification of Cutting Forces and the Build of Accurate Milling Force Model in End Milling. *Materials Science Forum*, 532–533, pp.636–639.

Kaynak, Y., 2014. Evaluation of Machining Performance in Cryogenic Machining of Inconel 718 and Comparison with Dry and MQL Machining. *International Journal of Advanced Manufacturing Technology*, 72(5–8), pp.919–933.

Kaynak, Y. and Gharibi, A., 2018. Progressive Tool Wear in Cryogenic Machining: The Effect of Liquid Nitrogen and Carbon Dioxide. *Journal of Manufacturing and Materials Processing*, 2(2), p.31.

Kaynak, Y., Lu, T., and Jawahir, I.S., 2014. An Cryogenic Machining-Induced Surface Integrity : A Review and Comparison with Dry, MQL, and Flood-Cooled Machining. *Machining Science and Technology: An International Journal*, 18(2), pp.37–41.

Kenda, J., Pusavec, F., and Kopac, J., 2011. Analysis of Residual Stresses in Sustainable Cryogenic Machining of Nickel Based Alloy - Inconel 718. *Journal of Manufacturing Science and Engineering, Transactions of the ASME*, 133(4), pp.1–7.

Khan, A.M., Jamil, M., Ul Haq, A., Hussain, S., Meng, L., and He, N., 2019. Sustainable Machining. Modelling and Optimisation of Temperature and Surface Roughness in the Milling of AISI D2 Steel. *Industrial Lubrication and Tribology*, 71(2), pp.267–277.

Khan, T., Broderick, M., Sajid, S.A., Secker, J., and Taylor, C.B., 2020.

Examination of Deformation in Thin-Walled Structures Processed by Micro-Milling Method. *Proceedings of the Institution of Mechanical Engineers Part B Journal of Engineering Manufacture*, 235(10), pp.1644–1654.

Kishawy, H.A., Hegab, H., and Saad, E., 2018. Design for Sustainable Manufacturing: Approach, Implementation, and Assessment. *Sustainability (Switzerland)*, 10(10), pp.1–15.

K N, M., Hosamani, B., Nagaraju, Kemminje, V., Raju, V.R., Nagahanumaiah, 2024. An investigation into the surface integrity and cutting force characteristics in titanium alloy end milling using soluble oil and MQL as coolants. Results in Surfaces and Interfaces, 17 (November): 100341. https://doi.org/10.1016/j.rsurfi.2024.100341

Kuram, E., Ozcelik, B., and Demirbas, E., 2013. Environmentally Friendly Machining: Vegetable Based Cutting Fluids. *Manufacturing Processes and Systems, J. Paulo Davim (Es.). Springer, Berlin Heidelberg,*, pp.23–48.

Lalwani, D.I., Mehta, N.K., and Jain, P.K., 2008. Experimental Investigations of Cutting Parameters Influence on Cutting Forces and Surface Roughness in Finish Hard Turning of MDN250 Steel. *Journal of Materials Processing Technology*, 206(1–3), pp.167–179.

Liang, Q., Zhang, D., Coppola, G., Mao, J., Sun, W., Wang, Y., and Ge, Y., 2016. Design and Analysis of a Sensor System for Cutting Force Measurement in Machining Processes. *Sensors*, 16(1), p.70.

MacHai, C. and Biermann, D., 2011. Machining of β-Titanium-Alloy Ti-10V-2Fe-3Al under Cryogenic Conditions: Cooling with Carbon Dioxide Snow. *Journal of Materials Processing Technology*, 211(6), pp.1175–1183. Available at: http://dx.doi.org/10.1016/j.jmatprotec.2011.01.022.

Mahboubkhah, M., Movahhedy, M.R., and Feizi, A.J., 2021. Three Dimensional Prediction of Stability Lobes in End Milling of Thin-Walled Structures Based on Tool and Workpiece Dimensions. *Scientia Iranica*, 0(0), p.0.

Maruda, R.W., Krolczyk, G.M., Nieslony, P., Wojciechowski, S., Michalski, M., and Legutko, S., 2016. The Influence of the Cooling Conditions on the Cutting Tool Wear and the Chip Formation Mechanism. *Journal of Manufacturing Processes*, 24, pp.107–115. Available at: http://dx.doi.org/10.1016/j.jmapro.2016.08.006.

Mohruni, A.S., Yanis, M., Sharif, S., Yani, I., Yuliwati, E., Ismail, A.F., and Shayfull, Z., 2017. A Comparison RSM and ANN Surface Roughness Models in Thin-Wall Machining of Ti6Al4V Using Vegetable Oils under MQL-Condition. *AIP Conference Proceedings*, 1885.

Mokhtari Homami, R., Fadaei Tehrani, A., Mirzadeh, H., Movahedi, B., and Azimifar, F., 2014. Optimisation of Turning Process Using Artificial Intelligence Technology. *International Journal of Advanced Manufacturing Technology*, 70(5–8), pp.1205–1217.

Morgan, M.N., Barczak, L., and Batako, A., 2012. Temperatures in Fine Grinding with Minimum Quantity Lubrication (MQL). *International Journal of Advanced Manufacturing Technology*, 60(9–12), pp.951–958.

Myers, R.H., Montgomery, D.C., and Anderson-Cook, C.M., 2016. *Response Surface Methodology - Process and Product Optimisation using Designed Experiments* Fourth., John Wiley & Sons, Inc., Hoboken, New Jersey.\

Nur, R., Muas, M., Apollo, Risal, S., 2019. Effect of Current and Wire Speed on Surface Roughness in the manufacturing of Straight Gear using Wire-cut EDM Process. IOP Conference Series: Materials Science and Engineering, 619 (1). https://doi.org/10.1088/1757-899X/619/1/012002

Oke, S.R., Ogunwande, G.S., Onifade, M., Aikulola, E.O., Adewale, E.D., Olawale, O.E., Ayodele, B.E., Mwema, F.M., Obiko, J., and Bodunrin, M.O., 2020. An Overview of Conventional and Non-Conventional Techniques for Machining of Titanium Alloys. *Manufacturing Review*, 7, p.34.

Patil, R.A. and Gombi, S.L., 2018. Experimental Study of Cutting Force on a Cutting Tool During Machining Using Inverse Problem Analysis. *Journal* *of the Brazilian Society of Mechanical Sciences and Engineering*, 40(10).

Paul, S., 2019. Chatter Mitigation in Milling Process Using Discrete Time Sliding Mode Control With Type 2-Fuzzy Logic System. *Applied Sciences*, 9(20), p.4380.

Pereira, O., Rodríguez, A., Barreiro, J., Fernández-Abia, A.I., and de Lacalle, L.N.L., 2017. Nozzle Design for Combined Use of MQL and Cryogenic Gas in Machining. *International Journal of Precision Engineering and Manufacturing - Green Technology*, 4(1), pp.87–95.

Pereira, W.H. and Delijaicov, S., 2019. Surface Integrity of INCONEL 718 Turned under Cryogenic Conditions at High Cutting Speeds. *International Journal of Advanced Manufacturing Technology*, pp.2163–2177.

Piórkowski, P., 2024. Investigation of Cutting Tool Wear in the Milling Process of the Inconel 718 Alloy. *Advances in Science and Technology – Research Journal*, 18(2), pp.26–35.

Pusavec, F., Hamdi, H., Kopac, J., and Jawahir, I.S., 2011. Surface Integrity in Cryogenic Machining of Nickel Based Alloy - Inconel 718. *Journal of Materials Processing Technology*, 211(4), pp.773–783. Available at: http://dx.doi.org/10.1016/j.jmatprotec.2010.12.013.

Pusavec, F., Deshpande, A., Yang, S., M’Saoubi, R., Kopac, J., Dillon, O.W., and Jawahir, I.S., 2014. Sustainable Machining of High Temperature Nickel Alloy - Inconel 718: Part 1 - Predictive Performance Models. *Journal of Cleaner Production*, 81, pp.255–269. Available at: http://dx.doi.org/10.1016/j.jclepro.2014.06.040.

Rafaqat, M., Mufti, N.A., Saleem, M.Q., Ahmed, N., Rehman, A.U., and Ali, M., 2023. Machining of Triangular Holes in D2 Steel by the Use of Non-Conventional Electrodes in Die-Sinking Electric Discharge Machining. *Materials*, 16(10), p.3865.

Rahman, M., Senthil Kumar, A., and Manzoor-Ul-Salem, 2001. Evaluation of Minimal Quantities of Lubricant in End Milling. *International Journal of*

Advanced Manufacturing Technology, 18(4), pp.235–241.

Ramana, M., Vishnu, A., Rao, G., and Rao, D., 2012. Investigations, Optimisation of Process Parameters and Mathematical Modelling in Turning of Titanium Alloy. *Journal of Engineering (IOSRJEN)*, 2(1), pp.86–101.

Rao, R.V. and Kalyankar, V.D., 2014. Optimisation of Modern Machining Processes Using Advanced Optimisation Techniques: A Review. *The International Journal of Advanced Manufacturing Technology*, pp.1159–1188.

Rizal, M., Ghani, J.A., Nuawi, M.Z., and Haron, C.H.C., 2015. Development and Testing of an Integrated Rotating Dynamometer on Tool Holder for Milling Process. *Mechanical Systems and Signal Processing*, 52–53, pp.559–576.

Salem, A., 2023. Experimental Investigation of the Derivative Cutting When Machining AISI 1045 With Micro-Textured Cutting Tools. *Metals*, 13(9), p.1587.

Shnfir, M., Olufayo, O.A., Jomaa, W., and Songmené, V., 2019. Machinability Study of Hardened 1045 Steel When Milling With Ceramic Cutting Inserts. *Materials*, 12(23), p.3974.

Shokrani, a., Dhokia, V., Muñoz-Escalona, P., and Newman, S.T., 2013. State-of-the-Art Cryogenic Machining and Processing. *International Journal of Computer Integrated Manufacturing*, 26(November), pp.616–648. Available at: http://www.tandfonline.com/doi/abs/10.1080/0951192X.2012.749531.

Singh, P., Pungotra, H., and Kalsi, N.S., 2017. On the Characteristics of Titanium Alloys for the Aircraft Applications. *Materials Today: Proceedings*, 4(8), pp.8971–8982. Available at: https://doi.org/10.1016/j.matpr.2017.07.249.

Del Sol, I., Rivero, A., de Lacalle, L.N.L., and Gamez, A.J., 2019. Thin-Wall

Machining of Light Alloys: A Review of Models and Industrial Approaches. *Materials*, 12(12).

Stephenson, D.A. and Agapiou, J.S., 2016. *Metal Cutting Theory and Practice* Third Edit., New York: CRC Pres-Taylor & Francis Group.

Stribick, S., 2023. Temperature and Wear Analysis of Adhesively Bonded and Soldered Cutting Tools for Woodcutting. *Journal of Manufacturing and Materials Processing*, 7(6), p.223.

Tagiuri, Z.A.M., Dao, T.-M., Samuel, A.M., and Songmené, V., 2022. Numerical Prediction of the Performance of Chamfered and Sharp Cutting Tools During Orthogonal Cutting of AISI 1045 Steel. *Processes*, 10(11), p.2171.

Tang, Jiajia, Deng, C., Chen, X., and Zhai, H., 2023. Analysis and Optimisation of Milling Deformations of TC4 Alloy Thin-Walled Parts Based on Finite Element Simulations. *Machines*, 11(6), p.628.

Tang, Yuyang, Zhang, J., Hu, W., Liu, H., and Zhao, W., 2023. Prediction of Surface Location Error Considering the Varying Dynamics of Thin-Walled Parts During Five-Axis Flank Milling. *Processes*, 11(1), p.242.

Tazehkandi, A.H., Shabgard, M., and Pilehvarian, F., 2015. Application of Liquid Nitrogen and Spray Mode of Biodegradable Vegetable Cutting Fluid with Compressed Air in Order to Reduce Cutting Fluid Consumption in Turning Inconel 740. *Journal of Cleaner Production*, 108, pp.90–103. Available at: http://dx.doi.org/10.1016/j.jclepro.2015.07.045.

Tseng, T.L. (Bill), Konada, U., and Kwon, Y. (James), 2016. A Novel Approach to Predict Surface Roughness in Machining Operations Using Fuzzy Set Theory. *Journal of Computational Design and Engineering*, 3(1), pp.1–13.

Ulutan, D. and Ozel, T., 2011. Machining Induced Surface Integrity in Titanium and Nickel Alloys: A Review. *International Journal of Machine Tools and Manufacture*, 51(3), pp.250–280. Available at: http://dx.doi.org/10.1016/j.ijmachtools.2010.11.003.

Umbrello, D., Micari, F., and Jawahir, I.S., 2012. The Effects of Cryogenic Cooling on Surface Integrity in Hard Machining: A Comparison with Dry Machining. *CIRP Annals - Manufacturing Technology*, 61(1), pp.103–106. Available at: http://dx.doi.org/10.1016/j.cirp.2012.03.052.

Vates, U.K., Aggarwal, A., and Jamwal, A., 2017. Effect of Electrical and Non-Electrical Parameters on the Performance Measures of Electro-Discharge Machining: A Review. *International Journal of Trend in Scientific Research and Development*, Volume-1(Issue-6), pp.925–936.

Wang, C., Ghani, S.A.C., Cheng, K., and Rakowski, R.T., 2012. Adaptive Smart Machining Based on Using Constant Cutting Force and a Smart Cutting Tool. *Proceedings of the Institution of Mechanical Engineers Part B Journal of Engineering Manufacture*, 227(2), pp.249–253.

Wang, K., Wang, L., Zheng, K., Zhang, H., Politis, D.J., Liu, G., and Yuan, S., 2020. High-Efficiency Forming Processes for Complex Thin-Walled Titanium Alloys Components: State-of-the-Art and Perspectives. *International Journal of Extreme Manufacturing*, 2(3), p.32001.

Wang, Y., Yan, F.G., Wang, P., Yue, C.X., and Liu, X.L., 2007. Finite Element Analysis of Precision Hard Cutting Using Different Cutting Edge Preparation. *Applied Mechanics and Materials*, 10–12, pp.353–358.

Warsi, S.S., Zahid, T., Elahi, H., Liaqait, R.A., Bibi, S., Gillani, F., and Ghafoor, U., 2021. Sustainability-Based Analysis of Conventional to High-Speed Machining of Al 6061-T6 Alloy. *Applied Sciences*, 11(19), p.9032.

Wu, J., Lin, H., Wu, Y., Zhou, C., Zou, Zhongfei, Zhan, G., Zhou, T., Du, F., Tian, P., Zou, Zichuan, and Xiu-hua, Z., 2021. Enhancing Wear Resistance and Cutting Performance of a Long-Life Micro-Groove Tool in Turning AISI 201. *Coatings*, 11(12), p.1515.

Yan, X., Li, Yunfei, Li, H., Li, Yujie, and Pang, X., 2022. Output-Only Time-Varying Modal Parameter Identification Method Based on the TARMAX Model for the Milling of a Thin-Walled Workpiece. *Micromachines*, 13(10), p.1581.

Yildiz, Y. and Nalbant, M., 2008. A Review of Cryogenic Cooling in Machining Processes. , 48, pp.947–964.

Zain, A.M., Haron, H., Qasem, S.N., and Sharif, S., 2012. Regression and ANN Models for Estimating Minimum Value of Machining Performance. *Applied Mathematical Modelling*, 36(4), pp.1477–1492.

Zhang, C., Zhou, G., Xu, Q., Wei, Z., Chong, H., and Wang, Z., 2022. A Digital Twin Defined Autonomous Milling Process Towards the Online Optimal Control of Milling Deformation for Thin-Walled Parts. *The International Journal of Advanced Manufacturing Technology*, 124(7–8), pp.2847–2861.

Zhang, N., Yang, F., Jiang, F., Zhang, Y., and Liu, G., 2019. Investigation of Tribological Performance of Micro-Groove Textured Cemented Carbide Surfaces. *Surface Engineering*, 36(11), pp.1190–1199.

Zhang, Z., Luo, M., Wu, B., and Zhang, D., 2020. Dynamic Modelling and Stability Prediction in Milling Process of Thin-Walled Workpiece With Multiple Structural Modes. *Proceedings of the Institution of Mechanical Engineers Part B Journal of Engineering Manufacture*, 235(14), pp.2205–2218.

Zhou, X., Zhang, C., Xu, M., Wu, B., and Zhang, D., 2023. Prediction of Chatter Stability in Bull-Nose End Milling of Thin-Walled Cylindrical Parts Using Layered Cutting Force Coefficients. *Applied Sciences*, 13(11), p.6737.

Zhu, L., Yang, Z., and Li, Z., 2019. Investigation of Mechanics and Machinability of Titanium Alloy Thin-Walled Parts by CBN Grinding Head. *International Journal of Advanced Manufacturing Technology*, 100(9–12), pp.2537–2555.

Zou, Z., Lin, H., Jiang, H., Yuan, S., and Ren, Z., 2021. Influence of Microgroove Structure on Cutting Performance and Chip Morphology During the Turning of Superalloy Inconel 718. *Materials*, 14(15), p.4142.