UNIVERSITI TEKNIKAL MALAYSIA MELAKA

MILLING MACHINING OF ALUMINIUM ALLOY USING VEGETABLE OIL WITH WASTE FLY ASH ADDITIVES

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

MASTER OF MANUFACTURING ENGINEERING

(INDUSTRIAL ENGINEERING)

2025

Faculty of Industrial and Manufacturing Technology and Engineering

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A master project submitted in partial fulfillment of the requirements for the degree of Master of Manufacturing Engineering (Industrial Engineering)

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2025

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DECLARATION

I declare that this master project entitled "Milling Machining of Aluminium Alloy Using Vegetable Oil with Waste Fly Ash Additives" is the result of my own research except as cited in the references. The master project has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : Gui

Name : BEH YONG GUI

Date : 11/07/2025

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APPROVAL

I hereby declare that I have read this master project and in my opinion this master project is sufficient in terms of scope and quality as a partial fulfillment of Master of Manufacturing Engineering (Industrial Engineering).

Signature : ....

Supervisor Name : PROFESSOR MADYA IR. DR. LIEW PAY JUN

Date : 11/07/2025

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DEDICATION

This research is dedicated to my family, whose unwavering support and love have been my strength throughout this journey. To my parents, for their endless encouragement and sacrifices, your belief in me has been my greatest motivator.

I also dedicate this work to my supervisor, Professor Madya Ir. Dr. Liew Pay Jun, whose guidance, expertise, and mentorship have shaped my research and helped me grow as an academic.

Lastly, I dedicate this thesis to all those who have contributed to my learning, growth, and success, including my course mates, friends, and the faculty members of the Faculty of Industrial & Manufacturing Technology. Thank you for your constant inspiration and support.

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ABSTRACT

This study investigates the incorporation of waste fly ash (FA) as an additive in vegetable oil-based cutting fluids for milling aluminum alloy 6061. Milling aluminum alloys is challenging due to significant heat generation and the need for effective lubrication and cooling. While mineral-based cutting fluids are effective, their environmental impact has driven interest in biodegradable alternatives such as vegetable oils. Waste FA, a byproduct of coal combustion, has potential as a sustainable additive that enhances machining performance. However, the effects of FA additives with different particle sizes and concentrations on milling outcomes remains underexplored. Therefore, this study used the Taguchi method to examine the effects of FA particle sizes (13 µm before ball milling and 1 µm after ball milling) and concentrations (1 wt.% and 2 wt.%) on machining performance. Milling experiments were conducted on aluminum alloy 6061 utilizing a HAAS CNC milling machine, evaluating tool wear, surface roughness, cutting forces, and material removal rate. The findings indicated that the optimal combination for minimizing cutting forces, decreasing tool wear, and enhancing material removal rate was attained with 1 µm FA and a concentration of 2 wt.% (A1B2), yielding the lowest cutting force (47.95 N), minimal tool wear (0.014 mm), and the highest material removal rate (1322.8393 mm^3/min). In contrast, 13 µm particles at 1 wt.% concentration (A2B1) yielded the smoothest surface finish, due to their rolling mechanism, but the smaller 1 µm particles were advantageous for their abrasive properties. In conclusion, the integration of waste FA into vegetable oil-based cutting fluids enhances machining performance and offers an eco-friendly substitute to conventional cutting fluids in industrial applications.

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ABSTRAK

Kajian ini menyiasat penggabungan abu terbang sisa (FA) sebagai bahan tambahan dalam cecair pemotong berasaskan minyak sayuran untuk pengilangan aloi aluminium 6061. Pengilangan aloi aluminium adalah mencabar disebabkan oleh penghasilan haba yang signifikan dan keperluan untuk pelinciran dan penyejukan yang berkesan. Walaupun cecair pemotong berasaskan mineral berkesan, kesan persekitaran yang ditimbulkan telah mendorong minat terhadap alternatif biodegradabel seperti minyak sayuran. FA sisa, produk sampingan pembakaran arang batu, berpotensi sebagai bahan tambahan lestari yang meningkatkan prestasi pemesinan. Walau bagaimanapun, kesan bahan tambahan FA dengan saiz zarah dan kepekatan yang berbeza terhadap hasil pemesinan masih kurang diterokai. Oleh itu, kajian ini menggunakan kaedah Taguchi untuk mengkaji kesan saiz zarah FA (13 µm sebelum penggilingan bola dan 1 µm selepas penggilingan bola) dan kepekatan (1 wt.% dan 2 wt.%) terhadap prestasi pemesinan. Eksperimen pemesinan dijalankan ke atas aloi aluminium 6061 menggunakan mesin pemesinan CNC HAAS, menilai kehausan alat, kekasaran permukaan, daya pemotongan, dan kadar penyingkiran bahan. Hasil kajian menunjukkan bahawa kombinasi optimum untuk meminimumkan daya pemotongan, mengurangkan kehausan alat, dan meningkatkan kadar penyingkiran bahan dicapai dengan FA 1 µm dan kepekatan 2 wt.% (A1B2), yang menghasilkan daya pemotongan terendah (47.95 N), kehausan alat minimum (0.014 mm), dan kadar penyingkiran bahan tertinggi (1322.8393 mm^3/min). Sebaliknya, zarah 13 µm pada kepekatan 1 wt.% (A2B1) menghasilkan permukaan yang paling licin, disebabkan oleh mekanisme gulungan mereka, tetapi zarah 1 µm yang lebih kecil lebih menguntungkan dengan sifat pengasahannya. Kesimpulannya, pengintegrasian FA sisa ke dalam cecair pemotong berasaskan minyak sayuran meningkatkan prestasi pemesinan dan menawarkan alternatif mesra alam kepada cecair pemotong konvensional dalam aplikasi industri.

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ACKNOWLEDGEMENT

First and foremost, I want to sincerely thank Professor Madya Ir. Dr. Liew Pay Jun, my supervisor, for her unwavering support, direction, and insightful advice during this project. Her knowledge and steadfast assistance have been crucial to this project's successful conclusion. Additionally, I would like to express my profound gratitude to UTeM Grant, the financing organization, for their financial assistance, which made this study possible.

For their invaluable assistance and efforts in all laboratory and analytical work, which were essential to the completion of this study, I would especially like to thank the following faculty members: Mr. Mohd Hanafiah Bin Mohd Isa, assistant engineer, CNC laboratory; Mr. Azhar Shah Bin Abu Hassan, assistant engineer, FESEM Laboratory; Mdm. Siti Aisah Binti Khadisah, assistant engineer, metrology laboratory; Mdm. Nor Hidayah Binti Rosly, assistant engineer, tribology laboratory; and all the Faculty of Industrial & Manufacturing Technology & Engineering and Faculty of Mechanical Technology and Engineering.

Finally, I want to sincerely thank my parents for their love, support, and encouragement along this journey. I am also appreciative of my course mates' help and advice, as well as that of all the lecturers and staff at Universiti Teknikal Malaysia Melaka's Faculty of Manufacturing Engineering. We are grateful to everyone who helped make this research a success.

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LIST OF ABBREVIATIONS

FA	-	Fly Ash
BUE	-	Built-Up Edges

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CHAPTER 1

INTRODUCTION

This chapter provided a description of machining of aluminium alloy using vegetable oil with waste fly ash (FA) additives, highlighting the challenges of conventional machining techniques and the possible benefits associated with the use of sustainable cutting fluids. This concern served as the focal issue in the problem statement which required problems associated with the use of mineral-based fluids to be resolved, while the objectives of the study were directed toward testing the performance of vegetable oil cutting fluids with the additive of waste FA particles. The research questions and the hypotheses set the focus of the study toward striving for improvement of machining performance within the framework of ecological balance. The scope of the study was limited to the milling process of aluminium alloys, particularly to the influence which varying additive particle sizes and their concentrations have on machining efficiency. It is anticipated that these results will guide the formulation of better and more eco-friendly cutting fluids for general industrial application.

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1.1 Background of Study

Milling processes are necessary for parts that, due to their complicated geometry, require tight tolerances (Lv et al., 2021). According to Selbmann et al. (2024), aluminium alloys are highly utilised in different sectors like aerospace, automobile, and construction because of their remarkable qualities which include high strength to weight ratio, outstanding corrosion resistance, and good machinability. Cetin & Kabave (2020) stated that these alloys are important in the manufacturing of light structures like car components and aircraft parts. Still, a study by Bork et al., (2014) found out that machining aluminium alloys, especially with mills, presents numerous challenges that negatively impact productivity, tool life, and general quality of the machining process. In addition, Kumar et al. (2023) concluded the discussion by saying that the cutting fluid used in the process influences all these problems, including excessive heating at the cutting interface, excessive wear of the tool, and roughness of the surface.

In 2022, Sonawane and colleagues analysed the function of cutting fluids in milling operations. Sonawane argues that cutting fluids are significant in aiding in cooling the cutting zone, lubricating the cutting zone to reduce friction, and aiding in the removal of chips from the machining surface (Sonawane et al., 2022). Mineral-based cutting fluids have long been preferred because of their superior lubricating properties that resulted in reduced heat generation and tool wear (Subhedar et al., 2021). Notwithstanding, Yadav et al. (2023) noted that these fluids create significant environmental and health hazards. If improperly handled, they can pollute land and water and they are not biodegradable and include toxic chemicals. Furthermore, Roushan et al. (2023) argued that more environmentally friendly alternatives have emerged faster due to a rise in focus on sustainable production methods and the negative impact of these fluids.

Considering the concerns, Ross et al. (2023) claimed that vegetable oils are starting to replace conventional cutting fluids with great interest and attention. Plant-derived oils, unlike mineral oils, are easier to biodegrade, non-harmful to living beings, and pose less risk to the environment. Moreover, because of their inherent polar structure, which may increase tool life and decrease the friction between the cutting tool and the workpiece, Kilincarslan et al. (2021) suggested that these oils possessed great lubricity. Vegetable oils, however, are not without limitations, as noted by Shreeshail et al. (2021). Based on the study by Burton et al. (2014) , vegetable oils tend to have less thermal stability and oxidation resistance when compared to mineral oils and are, therefore, not useful in high-speed machining operations where sufficient heat removal is critical.

Haq et al. (2021) examined the possibility of exceeding these limitations by adding particles into vegetable oils. According to Uysal et al. (2015), nano and micro particles can enhance the functionalities of the cutting fluids by improving lubrication and friction reduction, as well as heat dissipation. Moreover, Liew et al. (2021) discovered that FA, a coal combustion byproduct, is a capable additive particulate made up of tiny particles with interesting properties. Nayak et al. (2022) claimed that FA is primarily silica, alumina, and other oxides, which may improve the thermal conductivity and lubricating efficiency of the base fluid. Moreover, Alterary & Marei (2021) discovered that FA is an environmentally friendly alternative because it converts industrial waste into a valuable component for commercial and industrial applications.

This study investigated the use of vegetable oil mixed with various sizes and concentrations of waste FA as a cutting fluid when milling aluminum alloys. The effects of two distinct particle sizes on cutting forces, tool wear, material removal rate, and surface finish of aluminum alloys were investigated. This research aims to create a more sustainable alternative in the form of a cutting fluid that can replace mineral-based fluids, which have serious environmental consequences when used in the machining of aluminum alloys. Furthermore, the study aims to contribute to the common objective of sustainable manufacturing by substituting mineral oils with renewable bio-based fluids enhanced with industrial wastes such as FA.

1.2 Problem Statement

According to Araujo et al. (2017), milling aluminum alloys is a frequent machining process in many industries since the material has good qualities, such as being strong for its weight and resistant to corrosion. However, this machining method presents difficulties. Shukla et al. (2020) reported that milling aluminum alloys often causes problems such rough surfaces, tools wear, and too much heat generation. The bad surface smoothness and the alloys' high thermal conductivity make things worse, which lowers the efficiency of machining and the overall quality of the product (M. Li et al., 2019).

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Cooling, lubrication, and chip removal are examples of cutting fluid applications that help to minimize challenges and deal with them appropriately. Lawal et al. (2012) claimed, however, that although useful, conventional mineral-based cutting fluids are non-biodegradable and pose serious issues for the environment as well as health.

Furthermore, Roberto et al. (2020) concluded that strict laws cause these fluids to contribute to environmental damage and have huge disposal expenses. As so, sustainable substitutes are in more and more demand.

On the other hand, Yildirim et al. (2023) said that because of their biodegradability, renewability, and improved lubricating qualities, vegetable oils have emerged as a practical substitute. Nevertheless, their poor thermal stability and oxidation sensitivity limit their efficacy under high-speed machining conditions, including those faced during the milling of aluminium alloys (Haseena et al., 2023). Makhesana et al. (2022) proposed that adding additive particles into vegetable oils might be a workable remedy for these restrictions.

Though this is a favourable result, no research has been done on optimising vegetable oil-based cutting fluids using FA additive particles. FA, a byproduct of coal combustion, causes a large wasteland and may pose health and environmental risks. Still, it could be used as an additive to improve cutting fluid performance. Furthermore, the effect of different particle sizes and concentrations on machining performance measures such as cutting forces, tool wear, material removal rate and surface roughness has not been well investigated. This study aims to bridge these gaps by investigating the use of vegetable oil combined with waste FA additive particles as a sustainable cutting fluid for milling aluminium alloys.

1.3 Research Objectives

The objectives of this study are:

i. To investigate the effect of waste fly ash additive of different particle size and concentration on machining responses such as cutting forces, tool wear, surface finish and material removal rate in milling of aluminium alloy.
ii. To analyze the parameters (particle size and concentration) of milling process on aluminium alloy by Taguchi method.

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1.3.1 Relationship Between Problem Statement and Objectives

Table 1.1: Relationship between problem statement and objectives.

Problem Statement	Research Objective	How the Objective Addresses the Problem
i. Aluminium alloy milling generates tremendous heat energy, tool damage, and poor surface quality, which is compounded by the material's high thermal conductivity	To investigate the effect of waste FA additive of different particle size and concentration on machining responses such as cutting forces,	i. The comprehension of the effects of FA additives will yield valuable knowledge regarding the mitigation of thermal energy, the extension of tool

and tendency for adhesion to cutting tools. ii. Conventional mineral-based cutting fluids, although they exhibit efficacy, are characterized by their non-biodegradability and present various environmental and health risks, in addition to incurring substantial disposal expenses because of regulatory requirements.	tool wear, surface finish and material removal rate in milling of aluminium alloy.	longevity, and the enhancement of surface quality throughout the milling process of aluminum alloys. ii. The substitution of mineral-derived fluids with cutting fluids formulated from vegetable oils integrated with waste FA additives effectively addresses sustainability and environmental issues while preserving machining efficacy.
i. Vegetable oils, despite their eco-friendly biodegradability and lubrication characteristics, show inadequate thermal stability and oxidation resistance, which ultimately restricts their effectiveness in high-speed machining methods. ii. There is a lack of scientific study on the analysis of vegetable oil-derived cutting fluids containing waste FA as an	To analyze the parameters (particle size and concentration) of milling process on aluminium alloy by Taguchi method.	i. The analyzation of parameters greatly improves the thermal stability and performance characteristics of vegetable oil-based cutting fluids including FA additives, increasing their applicability in high-speed milling applications. ii. Addressing the current research gap by identifying best parameters ensures the effective use of vegetable oil-derived cutting fluids