Faculty of Manufacturing Engineering

THE EFFECT ON USAGE OF QUARRY DUST SUSPENSION AS COOLANT IN DRILLING OF TITANIUM ALLOY

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Master of Science in Manufacturing Engineering

2022

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A thesis submitted
in fulfilment of the requirements for the degree of Master of Science in Manufacturing Engineering

Faculty of Manufacturing Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2022

DECLARATION

I declare that this thesis entitled "The Effect on Usage of Quarry Dust Suspension as Coolant in Drilling of Titanium Alloy" 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 : Maisarah binti Kursus @ Othman

Date : 5 July 2022

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 Master of Science in Manufacturing Engineering.

Signature	:	…….
Supervisor Name	:	Professor Madya Dr. Liew Pay Jun
Date	:	7 July 2022

DEDICATION

To my beloved mother and father

Adore siblings and husband

Respectable supervisors and lecturers

Loving colleagues and friends

ABSTRACT

In the aerospace field, titanium alloys are extensively used for the airframe and engine parts to improve aircraft fuel consumption. Drilling through these parts in a single-shot process to produce high quality holes is challenging. During drilling, high temperatures are generated owing to the friction between the cutting tool and workpiece. This phenomenon causes in rapid tool wear and the deterioration of the machined/drilled surface. With increased tool wear, the cutting tool loses its sharpness, leading to burr formation at the exit of the drilled hole. To reduce the temperature produced in the cutting zone, different types of cooling techniques during drilling have been used by researchers. However, limited studies have been found by utilizing the quarry dust suspension as coolant in the drilling process. Therefore, the main objective of this study is to investigate the effect of different concentrations of quarry dust suspension as coolant in drilling of titanium alloy. Before drilling, the thermophysical properties of quarry dust suspension, namely, thermal conductivity and viscosity, were investigated experimentally. The effects of different concentrations of quarry dust on surface roughness, thrust force, and burr formation were evaluated, and their machining performances were compared with those obtained using aluminium oxide suspension. Before the experiments, both suspensions were prepared by dispersing quarry dust and aluminium oxide particles into deionised water at various concentrations ranging from 0 wt% to 0.10 wt%. Results indicated that thermal conductivity and viscosity improved with increased concentration of quarry dust suspension. When 0.06 wt% quarry dust suspension was used, there were improvement by 51.1% and 0.5% on thermal conductivity and viscosity, respectively compared to deionized water. The lowest thrust force and surface roughness as well as the best hole quality also can be obtained by using 0.06 wt% of quarry dust suspension. Besides that, thrust force and surface roughness showed an improvement by 8.31% and 18.29%, respectively, compared with those of aluminium oxide suspension at the same concentration. The burr height formed at the drilled holes using 0.06 wt% of quarry dust was also lower than that formed with aluminium oxide suspension at the same concentration. These results demonstrated the capability of quarry dust suspension as coolant, which could be beneficial to the machining industries.

KESAN PENGGUNAAN AMPAIAN DEBU KUARI SEBAGAI PENYEJUK UNTUK PROSES GERUDI PADA ALOI TITANIUM

ABSTRAK

Dalam bidang angkasa, aloi titanium telah digunakan secara meluas dalam pembuatan bingkai kapal angkasa dan bahagian enjin untuk menambahbaik penggunaan bahan bakar kapal angkasa. Penggerudian di bahagian tersebut bagi mendapatkan kualiti lubang yang tinggi adalah amat mencabar. Semasa penggerudian, suhu tinggi akan berlaku akibat daripada geseran yang berlaku antara alat pemotong dan bahan. Fenomena ini mengakibatkan penumpulan alat potongan berlaku dengan pantas dan kemerosotan permukaan bahan yang telah digerudi. Dengan berlakunya penumpulan alat potongan, ketajaman alat potongan menghilang dan menyebabkan berlakunya pembentukan berduri di bahagian keluar lubang yang telah digerudi. Untuk merendahkan suhu yang terjadi di kawasan pemotongan, beberapa jenis teknik penyejukan semasa penggerudian telah digunakan oleh penyelidik sebelum ini. Namun begitu, penyelidikan yang telah dijumpai dalam penggunaan cecair debu kuari sebagai cecair penyejuk dalam proses penggerudian aloi titanium adalah sangat terhad. Oleh itu, objektif utama di dalam penyelidikan ini adalah untuk mengenalpasti kesan menggunakan pelbagai jenis kepekatan cecair debu kuari sebagai cecair penyejuk semasa penggerudian aloi titanium. Sebelum penggerudian, sifat termofizik cecair debu kuari iaitu kondaktivi haba dan kadar kelikatan cecair telah didapatkan melalui eksperimen. Kesan menggunakan cecair debu kuari dengan pelbagai kepekatan terhadap kekasaran permukaan, daya tujahan, dan pembentukan duri telah dinilai dan prestasi pemesinan telah dibandingkan dengan data yang didapati melalui cecair aluminium oksida. Sebelum bermula eksperimen, kedua-dua cecair telah disediakan dengan penguraian zarah debu kuari dan aluminium oksida ke dalam air nyah-ion di pelbagai jenis kepekatan bermula daripada 0 wt% sehingga 0.10 wt%. Keputusan menunjukkan bahawa kadar kondaktiviti haba dan kadar kelikatan meningkat seiring dengen meningkatnya kepekatan cecair debu kuari. Semasa 0.06wt% cecair debu kuari digunakan, terdapat peningkatan sebanyak 51.1% dan 0.5% pada kadar kondaktiviti haba dan kelikatan secara seiring berbanding menggunakan air nyah-ion. Kadar terendah daya tujahan dan kekasaran permukaan serta kualiti lubang terbaik dapat ditemui dengan menggunakan 0.06wt% cecair debu kuari. Selain itu, daya tujahan dan kekasaran permukaan, masing-masing menjadi lebih baik sebanyak 8.31% dan 18.29% berbanding menggunakan cecair aluminium oksida dengan kepekatan yang sama. Pembentukan berduri di lohong dengan menggunakan 0.06 wt% cecair debu kuari juga menjadi lebih rendah berbanding dengan menggunakan cecair aluminum oksida dengan kepekatan yang sama. Keputusan ini menunjukkan kebolehan cecair debu kuari sebagai cecair penyejuk di mana ianya dapat memberikan banyak manfaat terhadap industri pemotongan.

ACKNOWLEDGMENTS

In the name of Allah, the Most Gracious and the Most Merciful. Alhamdulillah, I praise and thank Allah SWT for His greatness and for giving me the strength and courage to complete this thesis.

I wish to express my sincere gratitude to my respected supervisor, Professor Madya Dr. Liew Pay Jun for the kindness, unwavering patience and great mentoring that was given to me to complete the project. Also, Dr. Chang Siang Yee, my co-supervisor that always helps me to understand everything regarding to this project every single time and teach me how to become a great researcher.

Finally, I would like to give special thanks to all my friend especially Marina binti Mohamad, all technician and every single person who gave me much cooperation and motivation physically and mentally in completing this report as well as expressing my apology that I could not mention personally each one of you.

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LIST OF ABBREVIATION

ASTM	-	American Society for Testing and Materials
SEM	-	Scanning Electron Microscope
ISO	-	International Organisation for Standardisation
HR	-	Rockwell Hardness
XRF	-	X-ray Fluorescence
XRD	-	X-ray Diffraction

LIST OF SYMBOLS

µ	-	Micro
cm	-	Centimetre
m	-	Metre
min	-	Minute
mm	-	Millimitre
µm	-	Micro Meter
mm/min	-	Millimetre per Minute
RPM	-	Revolutions per Minute
m/s	-	Mitre per Second
m/min	-	Mitre per Minute
%	-	Percentage
mL	-	Millilitre
g	-	Gram
^{o}C	-	Degree Celsius
n	-	Nano
wt%	-	Weight Percentage

LIST OF PUBLICATIONS

Journal Articles

Liew, P. J., Maisarah, K. O., Juoi, J. M., & Wang, J. (2019). Milling of Titanium Alloy Using Hexagonal Boron Nitride (Hbn) Nanofluid as A Coolant. Journal of Advanced Manufacturing Technology (JAMT), vol. 13(3), pp. 61-71 (Scopus)

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AWARDS AND SCHOLARSHIPS

Awards:

2019

Silver Medal – Eco-Friendly Coolant with Recycled Quarry Dust Suspension for Machining, Karnival Inovasi UTeM-EX 2109, Universiti Teknikal Malaysia Melaka (UTeM), Melaka, 9-10 October 2019.

Copyright – Intellectual Poperty Corporation of Malaysia (MyIPO). Title: Eco EDM Dielectric Fluid for Coating Purpose And Eco-Friendly Coolant with Recycled Quarry Dust Suspension for Machining Purpose (LY2020004900).

CHAPTER 1

INTRODUCTION

This research emphasised drilling by using different concentrations of quarry dust suspension. This chapter also includes the problem statement, objective and scope, significance of the study, and thesis organisation.

1.1 Research Background

In the aerospace field, titanium alloy is extensively used for the airframe and engine parts to improve aircraft fuel consumption. High strength, lightweight, and good corrosion resistance are the common characteristics of titanium alloy that lead to its high demand and usage in the industry (Vasanth et al., 2016). Considering the increasing demand for titanium alloy, ensuring that the product finishing is always high quality is important. Unfortunately, despite the advantages of titanium alloy, cutting this material is challenging because of its high strength. In machining, as the cutting tool makes contact with the workpiece, the friction starts to produce heat and leads to increased temperature in the cutting zone. High temperature has negative impacts such as tool wear and poor surface finish on the machining process. Thus, the heat generated in the cutting zone is important to reduce during the machining of titanium alloy; otherwise, the product is bound to have poor surface roughness (Ogedengbe et al., 2019).

Drilling through a critical part such as engine in a single-shot process to produce high-quality holes with acceptable tolerance is a primary challenge. During drilling, high temperatures are generated owing to the friction between the drill bit and workpiece, causing

rapid tool wear and poor drilled surface (Rahim and Sasahara, 2011). Therefore, cutting fluid is one of the most vital roles in the machining process to increase lubrication between cutting tool and workpiece and reduce cutting temperature (Mir and Wani, 2018).

Recently, the use of particles suspension in machining operations has become a new research focus. Various types of particles have been used in previous studies such as aluminum oxide (Al_2O_3), molybdenum disulphate (MoS_2), silicon dioxide (SiO_2), graphite and others. Quarry dust is one of the by-products of concrete aggregates during rock crushing. According to Ramesh et al. (2014), quarry dust contains a high composition of silicon dioxide (SiO_2) followed by Al_2O_3. Sharma et al. (2015) showed that SiO_2 and Al_2O_3 suspension have excellent properties, and they significantly reduce the cutting force, cutting temperature, tool wear, and surface roughness during machining. SiO_2 in mineral oil act as a combination of rolling and sliding bearings at the tool–chip interface. They, in turn, reduce the coefficient of friction and significantly improve the machining performance (Sayuti et al., 2014; Sharma et al., 2017).

Therefore, quarry dust which is high in SiO_2 and Al_2O_3 content can be a great economical alternative to the expensive conventional ceramic particles in fluid suspension. However, up to now, very limited studies have been found on the use of quarry dust suspension as cutting fluid in machining process. Thus, in the present study, the quarry dust suspension was used as cutting fluid in the drilling process of titanium alloy. Before the experiment, the properties of the quarry dust suspension such as viscosity and thermal conductivity were investigated. The effects of different concentrations of quarry dust on the surface roughness, thrust force, and burr formation were evaluated. A comparison of machining performances by using quarry dust suspension and aluminium oxide suspension was also carried out.

1.2 Problem Statement

Titanium alloy is extensively used in the aerospace industries because of its excellent properties such as high strength-to-weight ratio, high temperature strength, and exceptional corrosion resistance. However, owing to their high chemical reactivity and poor thermal conductivity, one of the key challenges in machining titanium components is the preparation of high quality holes driven by demands from the aerospace industry (Yi et al., 2017) .

During drilling, high temperatures are generated owing to the friction between the cutting tool and workpiece that lead to tool wear (Dehghan et al., 2018). Given the poor thermal conductivity of titanium alloy, the heat generated does not dissipate easily and tends to concentrate at the cutting edge, thereby causing the edge temperature to reach 1000 °C easily. This phenomenon then results in rapid tool wear and the deterioration of the machined/drilled surface. With increased tool wear, the cutting tool loses its sharpness, leading to burr formation at the exit of the drilled hole (Perçin et al., 2016). Although cutting fluids are extensively used to dissipate the heat in machining, they threaten the ecology and the health of workers. Conventional cutting fluid can harm the environment through the rapid growth of bacteria and pathogens (Teti et al., 2021). Hence, eco-friendly and user-friendly alternatives to conventional cutting fluids need to be identified. Recently, fluid suspensions have attracted huge interest owing to their great enhanced thermal properties. These suspensions contain metallic and nonmetallic microparticles/nanoparticles that disperse in liquid.

Quarry dust, which is one of the by-products of the crushing process during quarrying activities, is eliciting increased attention in various applications in the construction industry, such as road construction and building-material manufacture. However, very limited studies on the use of quarry dust suspension as cutting fluid for drilling process have been conducted. In the present study, quarry dust suspension was used as a cutting fluid in the drilling process

of titanium alloy, and the effect of different concentrations of quarry dust on machining performance was investigated. It is expected that by using the quarry dust suspension, the machining characteristics such as surface roughness, burr formation and cutting force could be reduced. As the quarry dust suspension is categorised as a hybrid particle suspension, it may perform better than aluminium oxide suspension, which is mono particle in the suspension.

1.3 Research Objective

The objectives of this research are as follows:

1. To characterize the properties (thermal conductivity and viscosity) of different concentrations of quarry dust suspension,
2. To investigate the effect of different concentrations of quarry dust and aluminium oxide suspension on the machining performances of titanium alloy.

1.4 Scope of Research

This research focused on the different concentrations of quarry dust suspension in titanium alloy drilling. To prepare the suspension, deionised water (DI) was used as a base fluid. The concentration of 0.0 wt% (deionised water) served as a control sample. The concentration of quarry dust and aluminium oxide in the suspension were varied at 0.02 wt%, 0.04 wt%, 0.06 wt%, 0.08 wt%, and 0.10 wt% , and results from both suspension were compared. The properties of the suspension, namely, viscosity and thermal conductivity, were investigated, and the physical and chemical characteristic were not included in the current study. During drilling, cobalt drill bit was used as cutting tool, and drilling parameters such as cutting speed, feed rate, and depth of cut were held constant during experiments. The effects of coolants on the surface roughness of titanium alloy, thrust force,

and burr formation during drilling of titanium alloy were collected and analysed.

1.5 Significance of Study

The significance of this research is to promote the inclusion of the waste quarry dust in DI water as a coolant to replace the conventional cutting fluid. Due to the high composition of SiO_2 followed by Al_2O_3 in quarry dust, the use of quarry dust suspension has a high potential to improve the machining performance of titanium alloy. It may help to improve the surface finish and lower the tool wear and burr formation on the drilled hole. The obtained results could be beneficial to the machining industries.

1.6 Thesis Organisation

This thesis is organised into five chapters. In Chapter 1, the introduction and background of the research are explained and clarified. The main problem of drilling titanium alloy in the industry and the potential of quarry dust powder are described. The objectives and scope are also found in Chapter 1. The literature review is presented in Chapter 2. In this chapter, important information and literature with regard to this topic, collected from books and other related journals, are summarised and organised. The procedure, apparatus, and materials used in the experiments are then described in Chapter 3. Next, collected data and discussion of results are presented in Chapter 4. In this section, results are compared and analysed. Lastly, Chapter 5 concludes and summarises the data analysis, results, and achievement of the objectives.

CHAPTER 2

LITERATURE REVIEW

This chapter presents the literature review of this dissertation. Related information of previous studies is extracted as references and discussed based on their research about titanium alloy, drilling, cooling fluid, and coolant properties.

2.1 Titanium Alloy (Ti-6AL-4V)

Titanium alloy (Ti-6Al-4V) is commonly known as a hard-to-cut material (Yi et al., 2017). Nevertheless, the use of titanium alloy is rising because of its good properties, such as excellent corrosion resistance, light weight, good resistance to creep and fatigue, and high specific strength (Ogedengbe et al., 2019). However, titanium alloys are hard to be machined owing to their poor thermal conductivity and high chemical reactivity that lead to rapid temperature rise at the cutting zone. This phenomenon can lead to premature tool life and poor surface finish. Table 2.1 and 2.2 show the chemical composition and physical properties of titanium alloy, respectively

Table 2.1: Chemical composition of titanium alloy (Xu et al., 2020)

Element	Composition (wt.%)
Titanium (Ti)	Base
Aluminum (Al)	5.50-6.75
Vanadium (V)	3.50-4.50
Iron (Fe)	<0.30
Oxygen (O)	<0.20
Carbon (C)	<0.08
Nitrogen (N)	<0.05
Hydrogen (H)	<0.015