UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Manufacturing Engineering

EFFECT OF ELECTRODEPOSITION CURRENT DENSITY AND QUARRY DUST CONTENT ON THE CHARACTERISTICS AND TRIBOLOGICAL PROPERTIES OF Ni-RECYCLED QUARRY DUST COMPOSITE COATINGS

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Master of Science in Manufacturing Engineering (Industrial Engineering)

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

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DECLARATION

I declare that this thesis entitled "Effect of Electrodeposition Current Density and Quarry Dust Content on the Characteristics and Tribological Properties of Ni- Recycled Quarry Dust Composite Coatings" 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 : ....

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Date : 26/9/2022

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 (Industrial Engineering).

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DEDICATION

To my beloved son, Muhammad Aqil Yusuf bin Abdullah Asyraf.

ABSTRACT

The study experimentally investigated the effect of various current density and quarry dust content on the surface properties and tribological properties of electrodeposited nickel quarry dust composite coatings on High Speed Steel (HSS) substrate. HSS is widely used as a high speed cutting tool due to their excellent red hardness and good wear resistance. Quarry dust is used in this study as a reinforcement because of its high silica and alumina content, which helps to improve the coating's properties. In order to get finer size of quarry dust particles, quarry dust has undergo ball milling process before electrodeposition process. Various current density with range from 2 A/dm^2 to 8 A/dm^2 and various quarry dust content with range between 15 g/L to 60 g/L were used in this study as the different range of current density and quarry dust content have different outcome. The composite coatings was characterized using Scanning Electron Microscope (SEM) and X- Ray Diffraction (XRD). The influence of current density and quarry dust content was investigated using hardness test and wear test. As the current density and quarry dust content increases, the hardness of the substrate will increases too. The highest hardness value is obtained when current density is at 6 A/dm^2 and quarry dust content is 45 g//L. It is same as for the result of wear test as the wear track length is smaller and the wear occur on the surface. With an increase in current density and quarry dust content, the COF value decreased. Therefore, the optimum experiment's parameters are current density at 6 A/dm^2 and a quarry dust content at 45g/L.

ABSTRAK

Kajian secara eksperimen untuk mengkaji kesan pelbagai ketumpatan arus elektrik dan kandungan debu kuari pada sifat permukaan dan sifat tribologi saduran komposit nikel-debu kuari melalui proses elektrodiposisi ke atas keluli berkelajuan tinggi (HSS). HSS digunakan secara meluas sebagai alat pemotong berkelajuan tinggi kerana kekerasan merah yang sangat baik dan rintangan haus yang baik. Debu kuari digunakan dalam kajian ini kerana kandungan silika dan alumina yang tinggi, yang membantu meningkatkan sifat saduran. Untuk mendapatkan saiz debu kuari yang lebih halus, debu kuari telah melalui proses pengilingan bola sebelum proses elektrodeposisi. Ketumpatan arus elektrik dari 2 A/dm2 hingga 8 A/dm2 dan kandungan debu kuari diantara 15 g/L hingga 60 g/L digunakan dalam kajian ini kerana nilai yang berbeza mempunyai hasil yang berbeza. Hasil saduran komposit telah dicirikan menggunakan Pengimbas Mikroskop Elektron (SEM) dan difraksi sinar X (XRD). Perbezaan ketumpatan arus dan kandungan debu kuari telah dikaji menggunakan ujian kekerasan dan ujian kehausan. Apabila ketumpatan elektrik dan kandungan debu kuari meningkat, kekerasan substrat akan meningkat. Nilai kekerasan tertinggi diperoleh apabila ketumpatan arus elektrik adalah 6 A/dm2 dan kandungan debu kuari 45 g//L. Ia sama seperti keputusan ujian kehausan kerana panjang trek haus lebih kecil dan haus berlaku pada permukaan. Dengan peningkatan ketumpatan arus elektrik dan kandungan debu kuari, nilai COF menurun. Oleh itu, keadaan ideal eksperimen adalah pada ketumpatan arus 6 A/dm2 dan kandungan debu kuari 45g/L

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LIST OF ABBREVIATIONS

AMCHAL	-	Advanced Materials and Characterization Laboratoty
CMC	-	Ceramic Matrix Composites
CNT	-	Ni- carbon nanotubes
COF	-	Coefficient of Friction
DC	-	Direct Current
EDM	-	Electrical Discharge Machining
EPD	-	Electrophoretic deposition
FKM	-	Fakulti Kejuruteraan Mekanikal
HSS	-	High Speed Steel
HVOF	-	High Velocity Oxygrn Fuel Spray
MMCs	-	Metal Matrix Composite
PC	-	Pulse Current
PRC	-	Pulse Reverse Current
PSA	-	Particle Size Analyzers
QD	-	Quarry Dust
SEM	-	Scanning Electron Microscope
UTeM	-	Universiti Teknikal Malaysia Melaka
XRD	-	X-Ray Diffraction

LIST OF SYMBOLS

A/dm^2	-	Ampere per square decimeter
Al	-	Aluminum
Al_2O_3	-	Alumina
Al_2O_3-SiO_2	-	Mullite
cm	-	Centimeter
cm^2	-	Centimeter squared
C	-	Carbom
Co	-	Cobalt
Cr	-	Chromium
Fe	-	Ferum
g	-	Gram
g/L	-	Gram per liter
HCL	-	Hydrochloric acid
Hr	-	Hour
Min	-	minutes
N	-	newton
NaCl	-	Natrium Chloride
Ni	-	Nickel
rpm	-	revolution per minutes
Si	-	Silicon
SiC	-	Silicon Carbide
SiO_2	-	Silicon Oxide
µm	-	Micrometer

CHAPTER 1

INTRODUCTION

This chapter explains the overview of background of study, problem statement, objectives, scopes of study and significance of study.

1.1 Background of Study

High-speed steels (HSS) are widely used in making high-speed cutting tools, which always require high hardness, good wear resistance, and good thermal fatigue resistance at elevated temperatures (Liu et al., 2021; Michalcová et al., 2021). This kind of wear-resistant and heat-resistant tool steel with secondary hardening characteristics contains a large amount of tungsten, molybdenum, vanadium, chromium, and other alloy elements (Michalcová et al., 2021). At present, HSS cutting tools continue to dominate the tool market (Shaojun et al., 2018). Despite the rapid development of tipped carbide cutting tools and the grinding of cemented carbide cutting tools, other types of cutting tools continue to primarily use HSS material (Shaojun et al., 2018).

Cutting tools are subjected to an extremely severe rubbing process (al Kindi et al., 2018). They are in metal-to-metal contact between the chip and the workpiece which when exposed to high stress and temperatures, causes wear and eventually results in cutting tool failure (Patil & Shinde, 2013). A coating process could be used to improve the properties of the cutting tool in terms of hardness and wear resistance, potentially extending the life of the cutting tool. To improve the mechanical properties of HSS as a cutting tool, an electrodeposition process can be introduced to the substrate by electrodeposition process.

Electrodeposition is one of the most technologically feasible and economically superior technique for producing metal matrix composite coatings (MMCs) (Borkar, 2010). MMCs often exhibit superior surface characteristics including corrosion resistance in a wide range of temperatures, improved physical, mechanical, and tribological properties. Nickel-based composite coatings reinforced with embedded particles (e.g., oxides, carbides, nitrides, and solid-state lubricants) are among the most studied MMCs because of their industrial applications as protective and corrosion-resistant coatings with desirable wear and friction properties (Sajjadnejad et al., 2021).

The properties of composite coatings are determined by the matrix phases as well as the amount and distribution of co-deposited particles within the matrix. Quarry dust was used as a reinforcement for the composite coating in this study. Quarry dust is one of the by-products from the crushing process during quarrying activities, which have gained attention to be used for various application (Kapgate & Satone, 2018; Othman et al., 2019; Zharif et al., 2021). Recently, the utilization of quarry dust which is high in silica and alumina contents have been extended to be used as a reinforcement for MMCs due to high cost of conventional ceramic particles. The quarry dust can be employed as inexpensive strengthening particles which can increase wear resistance and enhanced micro-hardness and have low density (Farhan et al., 2019).

Increasing current density will increase the incorporation of particles content in the composite (Farhan et al., 2019). The deposition of metal matrix with increasing current density is fast enough to entrap and occlude some of the particle and incorporate them into deposits (Farhan et al., 2019). Therefore, this study will investigate the influence of various current densities and various quarry dust content on the characteristics and tribological properties of composite coatings.

1.2 Problem Statement

In industrial production, there are many factors that can lead to the failure of machinery and equipment, such as wear and corrosion, which will cause waste of resources, environmental pollution and economic losses. HSS is commonly used as a cutting tool. HSS will wear out during the machining process due to friction with the workpiece. Surface treatment is one of the solutions to overcome this problem. Electrodeposition is widely used as a simple, effective and economical surface treatment technology. Electrodeposition parameters greatly influence the enhancement or decline of the mechanical properties and wear resistance of the fabricated coatings. On the other hand, the right parameter will lead to produce coatings containing well dispersed inert particles in metal matrix. Besides, it is also well established that the combination of multiple types of reinforcing secondary phases makes it possible to tune the properties of the fabricated coatings for the desired application, with a high level of flexibility. However, a limited study has been carried out on nickel reinforced with natural resource by product and effect of electrodeposition parameter to the composite coatings. Quarry dust is one of the by- product from the crushing process during quarrying activities, which contain high percentage of ceramic particles, SiO_2 and Al_2O_3. The environmental concern is currently rising as one of the main issues that lead to dust pollution and environmental deterioration and by converting the quarry dust into utilizable raw materials for usable application will help to improve the environmental. Therefore, this study will be investigating the effect of various current density and various quarry dust content towards Ni-QD composites coatings.

1.3 Objectives

The objectives that have been identified as follow:

1. To study the effect of various current density and various quarry dust content on the surface properties of electrodeposited Ni-QD composite coating.
2. To investigate the effect of various current density and various quarry dust content on the tribological properties of the electrodeposited Ni-QD composite coating.

1.4 Scope of Study

The scope of this study is to investigate the influence of different current densities and quarry dust content on the characteristics and tribological properties of composite coatings on Nickel recycle quarry dust substrates. Nickel and HSS were chosen as anode and cathode in this study, respectively. The electrolyte was created by combining a fixed amount of nickel and a variety of quarry dust content. The coatings were electrodeposited on the substrate at various current densities ranging from 2-8 A dm^2 and quarry dust compositions ranging from 15-60 g/L. The quarry dust particles and coatings were characterized using scanning electron microscopy (SEM), X- Ray Diffraction (XRD) and a Particle Size Analyzer (PSA). The effect of current density and quarry dust content on the coatings were investigated using hardness test and wear test.

1.5 Significance of Study

The findings of this study will help to provide the information on mechanical characteristic and tribological properties of HSS after electrodeposited on nickel quarry dust composite coatings. During the process, various current densities and various quarry dust content were applied into the HSS. The hardness of the HSS can be determined using Vickers micro-hardness test while, the coefficient of friction can be obtained through the wear test.

CHAPTER 2

LITERATURE REVIEW

This chapter provides an overview of previous study regarding the electrodeposition process, composite coatings, high speed steel, current densities nickel watt's bath and quarry dust.

2.1 Electrodeposition Process

2.1.1 Introduction

Electrodeposition is a type of electrochemical process used to modify the surface structure (Mbugua et al., 2020) It is a process of coating a thin layer of one metal on top of a different metal to modify its surface properties, by donating electrons to the ions in a solution (Ubaidah Saidin et al., 2010). This process has several advantages over the other fabricating techniques which includes low cost, simplicity of operations, adaptability, flexibility, high production rate, and industrial applicability (Paul, 2020; Rashidi & Amadeh, 2008). According to Mbugua et al., (2020), surface finish and tribological properties of the coatings can be further improved by the addition of suitable agents and control of deposition operating conditions. Many researchers have studied the electrodeposition of composite coatings in order to develop and fabricate advanced surface coatings that can withstand physical, chemical, and mechanical deterioration (Aliofkhazraei et al., 2021) and have discovered that adding certain chemical agents to the electrolytic solution reduces particle agglomeration and increases particle incorporation into the matrix (Paul, 2020). Lelevic and Walsh (2019) found that electrodeposition of homogeneously dispersed second phase particles within the Ni-P matrix can enhance deposit properties and with the aid of thermal treatment, the hardness of coatings can be improved. Besides, Guo et al. (2008) in the study on influences of surfactants on electrodeposition of Ni- carbon nanotubes (CNTs) found that coatings with surfactants become more homogenous and increased hardness of the composite coatings and improved adherence of the coating onto the matrix.

2.1.2 Electrodeposition Parameters

The electrodeposition of metals consists of the reduction of metal ions from different electrolyte solutions on top of a surface to be coated. Figure 2.1 describes the electrodeposition process of the Ni/ diamond coatings under mechanical stirring. In this approach, diamond particle surface was positively charged by absorbing Ni^{2+} ions and with aid of electric field and magnetic stirring, the Ni^{2+} ions and the particles have been transported to and absorbed on the cathodic surface (Li et al. 2021) Then, Ni^{2+} ions acquired electrons and were reduced to Ni atoms. Subsequently, the diamond particles were strongly wrapped by the formed Ni grains. Li et al. (2021) reported that this process is consistent with the Guflielmi model.

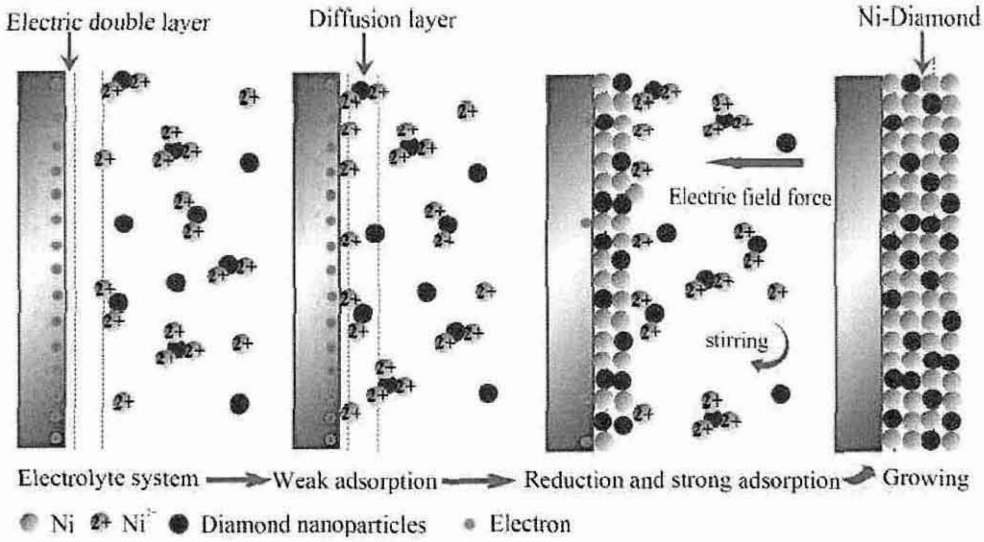

Figure 2.1 : Schematic diagram of electrodeposition process for the Ni/diamond coatings (Li et al., 2021)

a) Direct Current (DC) electrodeposition

According to Lelevic and Walsh (2019), constant direct current is the most commonly applied regime in which metallic coatings are deposited.In direct current (DC) electrodeposition, an electric current is continuously transferred through the system without any interruptions (Mbugua et al., 2020). Due to high deposition rates, the DC mode is used to make thick coatings with short deposition times. However, due to irregular composition, grain boundary mismatch, and other structural defects DC mode coatings are also prone to cracking (Paul, 2020). Mandati et al.(2018) highlighted that, apart from its disadvantages, DC electrodeposition remains a top method for the production of single element deposits and binary alloys.

b) Pulse Current (PC) and Pulse Reverse Current (PRC) electrodeposition

Pulsed electrodeposition, the deposition is carried out using current pulses of large current densities, the duration of which is of the order of a one to a few