Faculty of Manufacturing Engineering

EFFECT OF QUARRY DUST COMPOSITION ON THE PROPERTIES OF NICKEL-QUARRY DUST COMPOSITE COATINGS

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DECLARATION

I declare that this thesis entitled "Effect of Quarry Dust Composition On The Properties Of Nickel-Quarry Dust Composite Coatings" is the results of my own research except as cited in references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in term of scope and quality for the award of Master of Manufacturing Engineering (Quality System Engineering).

Signature	:	………………………………
Supervisor's Name	:	Dr Intan Sharhida Binti Othman
Date	:	………………………………

ABSTRACT

The rational of this research is to study the effect of quarry dust composition on the properties of nickel-quarry dust (Ni-QD) composite coating on aluminium alloy 6061 (AA6061) substrate. AA6061 is widely used in aircraft industries due to its low density to weight ratio and high strength. As aluminum operates in aggressive environments in atmospheric air, the aluminium must be coated to prevent corrosion. However, aluminum and its alloys have a high affinity to oxygen which means it always be covered with a thin oxide film growing rapidly. Thus, surface pre-treatment should be done before proceed to electrodeposition. The composition of quarry dust in nickel Watt's bath is varied from 10g/l to 50g/l. The characterization of quarry dust particles and Ni-QD composite coating on AA6061 substrate was characterized using X-Ray Diffraction (XRD), X-Ray Fluorescence (XRF) and Scanning Electron Microscopy (SEM). Ni-QD composite coating also being tested to investigate the wear and hardness properties. From the results, the hardness of Ni-QD composite coating increased by increasing the quarry dust composition. Other than that, Ni-QD composite coatings also showed a good result in wear testing where the average of COF of Ni-QD composite coatings is lower than bare AA6061.

ABSTRAK

Rasional kajian ini adalah untuk mengkaji kesan komposisi debu kuari ke atas sifat salutan komposit debu kuari dan nikel pada aloi aluminium 6061 (AA6061) substrat. AA6061 digunakan secara meluas untuk pembuatan kapal terbang kerana ketumpatan yang rendah kepada nisbah berat badan dan kekuatan yang tinggi. Oleh kerana aluminium beroperasi dalam persekitaran yang agresif dalam udara atmosfera, aluminium mesti bersalut untuk mencegah kakisan. Walau bagaimanapun, aluminium dan aloi mempunyai afiniti yang tinggi kepada oksigen yang bermakna ia sentiasa ditutup dengan filem oksida. Oleh itu, pra-rawatan permukaan perlu dilakukan sebelum meneruskan untuk pengenapan. Komposisi debu kuari adalah berbeza-beza dari 10g/l sehingga 50g/l. Pencirian zarah debu kuari dan salutan komposit debu kuari dan nikel pada aloi dilakukan menggunakan XRD, XRF dan SEM. Ujian juga dilakukan bagi mengenalpasti sifat haus dan kekerasan salutan komposit debu kuari. Berdasarkan hasil ujian, kekerasan salutan komposit debu kuari dan nikel meningkat dengan meningkatkan komposisi debu kuari itu. Selain daripada itu, salutan komposit debu kuari dan nikel juga menunjukkan keputusan yang baik dalam ujian haus di mana purata COF lapisan komposit debu kuari dan nikel adalah lebih rendah daripada AA6061 terdedah.

DEDICATION

To my beloved family and Iswandie, I love you ❤

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LIST ABBREVIATIONS, SYMBOLS, NOMENCLATURE

%	-	Percent
˚C	-	Degree Celsius
μ	-	Micro
A/dm2	-	Ampere per decimetre squared
Al	-	Aluminium
cm	-	Centimetre
g/l	-	Gram per litre
HV	-	Hardness Vickers
ml	-	Millilitre
mm	-	Millimetre
N	-	Newton
NaCl	-	Sodium Chloride
NaOH	-	Sodium Hydroxide
Ni	-	Nickel
wt.%	-	Weight percent

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Increasing applications in aerospace and allied fields of aluminium alloy 6061 (AA6061) is due to the inherent properties like lightness and good strength-to-weight ratio. It replaces many metals in applications where weight is considered as a major factor since its density is one third of the steel. As one of the important applications, AA6061 is employed in aerospace structural fastened joints where wear and fatigue damages can cause catastrophic failures under fluctuating loads (Gupta et al., 2014).

Aluminium is a reactive metal that owes its corrosion resistance to a thin, protective oxide surface layer, which is generally stable in air and aqueous solutions. Although aluminium oxide is generally protective, pores and other defects caused from alloying elements can lead to localised corrosion (Paloumpa et al., 2004). One possibility to increase the durability and performance of materials for different applications is to protect those using composite coatings. In recent years, there has been a growing interest in the development of composite coatings (Shrestha et al., 2001).

Hafiz et al. (2010) mentioned that due to the low mechanical strength, pure aluminium cannot be used as a structural component. Usually, it is combined with various alloying elements to produce grades which are suitable for a large number of applications. Due to their light weight and high thermal conductivity, aluminium alloy have also been considered for tribological application for example in engine parts and sports products. However, their use has been limited because of rigidity and lack of wear resistance and adequate strength. Also, due to their low melting points, exposure of aluminium alloy to moderately elevated temperatures can cause extensive surface degradation. There is a need for surface protection systems with adequate combined mechanical strength and heat resistance capability for demanding application.

One way to improve the response of aluminium alloys to friction and surface degradation is to cover the surface of aluminium alloys with nickel coatings. Previously, cadmium and hard chromium have been used extensively as protective coatings but cadmium is highly toxic in its metallic form. Both coating and the deposition process are potentially harmful. In this study, nickel is used to replace hazardous chromium and cadmium. Nickel which possesses high tensile strength and good toughness is a popular choice as a matrix material and also it can disperse both soft and hard reinforcements (Gupta et al., 2014).

Significant interest on electrodeposition of nickel on AA6061 has increased considerably due to the fact that coating can eliminate the disadvantages of uncoated aluminium to some extent. Among various process technologies for composite coatings, electrodeposition has advantages such as cost-effectiveness relative to spray and sputtering processes (Chen et al., 2002). This technique can provide special surface properties, like increase hardness, abrasion and corrosion resistance, low friction coefficient to meet the requirements of advanced materials.

Therefore, in this study, nickel-quarry dust (Ni-QD) composite coating will be deposited on AA6061 through electrodeposition technique using various compositions of quarry dust. The effect of various composition of quarry dust on Ni-QD composite coatings to tribological, hardness and corrosion resistance will be covered.

No research has been done on studying the effect of quarry dust as reinforcement to the properties of the composite coating. Therefore, the literature review is only referring to the composite coating reinforced with conventional ceramic particles or fly ash.

1.2 Problem Statement

Nickel matrix composites have commonly been reinforced with most conventional ceramic particles such as SiC, Al_2O_3, TiC, B_4C, MgO, Si_3N_4 and AlN. However, the cost of manufacturing these composites is high and this limits their utilization in several engineering designs. Hence, continuous attempts being made to produce low cost of metal matrix composites. Recently, aluminium alloy composites reinforced with fly ash, a waste by-product of combustion, has been engineered (Rohatgi *et al.*, 2010), as potential substitutes to conventional composites in a few applications.

Tremendous efforts have been done in the area of coating technology to study the utilization of by-products and waste material which can be used as inert particles that act as reinforcement of metal matrix. Quarry dust as by-products from crushing of course aggregates during quarrying activities has received considerable attention to enhance the properties of nickel matrix composite coatings.

Quarry dust is crushed dust obtained from stone boulders in stone crushers during the production of coarse aggregates. The quarry dust consists of excess fines and is dumped in open fields that cause environment pollution. In the recent past good attempts have been made for the successful utilization of various industrial by products such as fly ash, silica fume, rice husk ash, foundry waste to save environment (Yap et al., 2013).

Quarry dust have gained attention to be used in various industries such as construction industry manufacturing of building material industry due to the high percentage of ceramic particles in quarry dust itself, SiO_2 and Al_2O_3. Due to the high contents of SiO_2 and Al_2O_3 in quarry dust, fundamental study on the formulating of nickel matrix composite coating utilizing quarry dust as reinforcement will be formed. Limited research has been carried out on nickel reinforced with natural resource by product. However, the information regarding composite coating that use quarry dust as reinforcement element in metal matrix composite coating has not been reported.

Therefore, this research will be focused on the effect of varying quarry dust content on the Ni-QD composite coatings deposited on AA6061 through electrodeposition technique in order to enhance the mechanical properties of pure AA6061.

1.3 Objectives

1. To characterize the effect of various composition of quarry dust particle on the surface morphology of Ni-QD composite coating by using Scanning Electron Microscopy (SEM), X-Ray Diffraction (XRD) and X-Ray Fluorescence (XRF).
2. To investigate the effect of various composition of quarry dust on the wear properties of electrodeposited Ni-QD composite coatings on AA6061 substrate.
3. To examine the effect of various composition of quarry dust on the hardness of electrodeposited Ni-QD composite coatings on AA6061 substrate.

1.4 Scope of Study

The scope of this study is to investigate the effect of varying the composition of quarry dust as reinforcement and annealing treatment process on the hardness, wear behaviour, and corrosion resistance of Ni-QD composite coating on AA 6061 substrate. In this study, nickel and AA6061 were selected as anode and cathode respectively. The electrolyte was prepared by using fixed amount of nickel salt and various composition of quarry dust. AA6061 substrate was undergone surface pre-treatment using mechanical pre-treatment which is grinding and polishing prior to the electrodeposition process. The samples were produced using five composition of quarry dust (10g, 20g, 30g, 40g, and 50g) in order to find the optimum composition of quarry dust. The characterization of the quarry dust particles and coatings was carried out using SEM, XRD and XRF. The effect of quarry dust composition on the coating properties will be investigate using a hardness test and wear test.

CHAPTER 2

LITERATURE REVIEW

2.1 Composite Coating

2.1.1 Introduction

Composite is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure.

Composites coatings fulfill many technical and decorative functions. Composite coatings working initially on systems designed for helicopters. Since then, many company has cooperated with designers and engineers from aerospace companies to provide coatings for the variety of the composites now used in many aircraft.

Composite coating has been well developed. The advantages of such coating are quite clear. Composite coatings are widely applied to mechanical component due to their high mechanical, chemical and tribological properties, as well as excellent corrosion resistance (Wan et al., 2015). Kan et al., (2015) found that the simultaneous deposition of the non-metal inclusions and metal phases to form composite layers brings a significant improvement to physical and mechanical properties of the coatings. Particles- reinforced composite coatings produced by electrodeposition have been widely used due to their high hardness, good wear and corrosion resistance compared to pure metal or alloy coatings (Ewa et al., 2010).

2.1.2 Types of Composite Coatings

(a) Ceramic Matrix Composite Coatings

Ceramic matrix composite (CMC) coatings are outstanding in their ability to withstand high temperatures, in addition their hardness and wear resistance. As mentioned by Gavalda et al. (2017), CMC have increased in demand in many different industries because of their excellent mechanical characteristics such as the strength-to-weight, stiffness-to-weight, corrosion and fatigue resistance.

Commonly, one of the materials acts as a matrix and the other one as reinforcement. The matrix is in charge of spreading the stress to the fibres and protecting them from external damages while providing the final shape of the component. Besides, reinforcement provides greater mechanical properties (Teti, 2002).

(b) Polymer Matrix Composite Coatings

Polymer matrix composites (PMCs) are comprised of a variety of short or continuous fibres bound together by an organic polymer matrix. Unlike CMC, in which the reinforcement is used primarily to improve the fracture toughness, the reinforcement in a PMC provides high strength and stiffness.

PMCs are often divided into two categories which are reinforced plastics and advanced composites. The distinction is based on the level of mechanical properties (usually strength and stiffness). Reinforced plastics, which are relatively inexpensive, typically consist of polyester resins reinforced with low-stiffness glass fibres. Advanced composites, which have been in use for only about 15 years, primarily in the aerospace industry, have superior strength and stiffness, and relatively expensive (Rodney et al., 1988).

(c) Metal Matrix Composite Coatings

Metal matrix composite (MMC) coatings possessing excellent tribological properties, good corrosion resistance and higher fatigue life are gaining widespread popularity (Ramesh et al., 2003).

Mentioned by Panagopoulos et al. (2011), MMC have been the subject of significant research and development effort over past decades, as they offer many advantages over conventional metallic alloys. Their most important characteristics are high specific strength and stiffness, enhanced mechanical properties, increased elevated temperature strength, improved wear resistance and control over thermo-physical properties (thermal expansion and conductivity).

Therefore, MMC coatings are considered as important engineering materials for many industrial and technological applications. However, in order to reduce the cost and improve the properties of MMC coatings, new materials and production produced have been used. The utilization of natural resources such as fly ash, quarry dust and etc which is by-product material that contain most conventional ceramic particles such as Al_2O_3 and SiO_2 for the production of MMC coatings was introduced by Rohatgi (Panagopoulos et al. 2011).

2.1.3 Nickel Composite Coatings

Nickel, being an engineering material, is the widely used metal matrix in aerospace and automotive industries due to their high specific strength, good toughness and corrosion resistance (Zhong et al., 2012). Besides, nickel which possesses high tensile strength and good toughness is a popular choice as a matrix material and also it can disperse both soft and hard reinforcements (Pradeep et al., 2014).

It is well known that the properties of the composite coatings are heavily dependent upon the degree of particles incorporation in deposit. Higher incorporation percentages and more uniform distribution of inert particles in the metal matrix lead to the improvement of the mechanical, tribological, anti-corrosion and anti-oxidation properties coatings. (Qiuyuan et al., 2008).

Mechanical and chemical properties of nickel can be improved by adding the second phase particles into nickel based composite system (Hongmin et al., 2015). Furthermore, Chang et al. (2015) stated composite coatings containing fine abrasive particles like SiC, Al_2O_3, Si_3N_4, diamond etc. can be remarkable to increase the hardness and reduce the friction coefficient as well as the wear rate of the mechanical component.

Addition of ceramic particles to synthesize composite coatings act as a barrier to dislocation movement and grain boundary sliding thus enhanced hardness of composite coatings. The hardness of composite coatings mainly influenced by two aspects such as hardness of metal matrix which is determined by microstructure of coatings and volume content of reinforced particles in the composite coatings (Ramesh et al., 2003).

A comparison of Vickers microhardness for a wide range of nickel composite coatings is shown in Figure 2.1. It clearly shows significant improvement in hardness of composite coatings compared to pure nickel coatings. The microhardness of composite systems increased with increase in volume percent of the reinforcements.

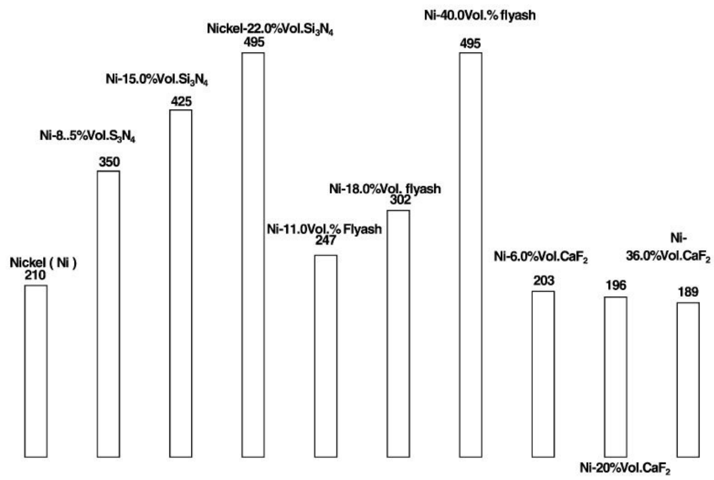

Figure 2.1: Hardness of nickel composite coatings. (Ramesh et al., 2003)

The improvement in microhardness as well as wear resistance of composite coatings mainly depends on reinforced second phase particles in the nickel matrix act as a physical barrier to nickel grain growth and plastic deformation of nickel matrix under loading promotes grain refining and dispersive strengthening effect to improve microhardness as well as wear resistance composite coatings (Vaezi et al., 2008). The increase in microhardness and decrease in the wear rate of composite coatings is due to combination of grain refining and dispersion strengthening effect.

The variation of the wear rates of nickel composite coatings with completely different volume fractions of calcium fluoride, silicon nitride, and fly ash are shown in Figure 2.2 It is observed that all composite coating systems studied exhibits lower wear rates in comparison with nickel coating. Wear rates of all the composite coatings decreases with increase in volume fraction of the reinforcement. Nickel–calcium fluoride composites possess the lowest wear rate.