UNIVERSITI TEKNIKAL MALAYSIA MELAKA

COMPARISON OF HARDNESS PROPERTIES OF OXIDISED AL-ALLOY AND TI- ALLOY FOR DUPLEX COATING PURPOSE

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Engineering Materials) with Honours.

by

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ABSTRAK

Matlamat penyelidikan ini adalah untuk mengkaji perbandingan sifat antara aloi aluminium teroksida dan aloi titanium teroksida untuk tujuan duplex coating. Aloi Aluminum (7075) dan aloi Titanium (Ti6Al4V) telah digunakan secara menyeluruh di dalam aplikasi angkasa lepas dan stuktur pesawat kerana ketumpatan yang rendah, kekuatan yang tinggi, ringan dan ketahanan pada suhu yang tinggi. Bagaimanapun aloi alumium (7075) dan aloi titanium (Ti6Al4V) juga mempunyai kekurangan apabila ia terdedah pada suhu tinggi, aloi aluminium (7075) dan aloi titanium (Ti6Al4V) yang terdedah akan berlaku proses pengoksidaan pada permukaan logam. Lapisan oksida akan terbentuk pada permukaan logam dan meningkat mengikut perubahan suhu. Lapisan oksida mengandungi keliangan yang akan meningkatkan perilaku karatan pada logam. Namun demikian, lapisan oksida mempunyai kekerasan yang lebih tinggi daripada logam tulen atau aloi. Untuk memanfaatkan sifat kekerasan dari lapisan oksida serta mencegah perilaku karatan tersebut, pelapisan duplex adalah satu pendekatan yang digunakan untuk memaksimumkan sifat tersebut. Kombinasi proses pengoksidaan dengan lapisan fizikal deposisi wap (duplex coating) dapat meningkatkan prestasi aloi. Melalui kajian ini sifat aloi aluminium teroksida (7075) dan aloi titanium terokisda (Ti6Al4V) akan dikaji untuk menentukan logam yang lebih sesuai untuk tujuan pelapisan dupleks bagi mengoptimumkan penggunaan logam aloi ini dalam aplikasi angkasa lepas dan struktur pesawat. Dalam kajian ini, uji kekerasan mikro Vickers, Scanning elektron mikroskop dan difraksi sinar-X digunakan untuk mengetahui sifat kekerasan, ketebalan lapisan oksida, morfologi struktur mikro lapisan oksida. Di dapati bahawa pengoksidaan yang berlaku pada titanium aloi lebih baik berbanding aluminium aloi. Titanium aloi pada suhu 700 and 750 selama 5 jam mempunyai kesan signifikan berdasarkan ketebalan oksida dan sifat kekerasan yang terbentuk pada suhu dan masa yang berbeza.

ABSTRACT

This research aims to study the properties of oxidized aluminium alloy and titanium alloy for duplex coating purpose. Aluminium alloy (7075) and titanium alloy (Ti6Al4V) are extensively used in aerospace application and aircraft structure because of low density, high strength, light weight and durability at high temperatures. However aluminium alloys (7075) and titanium alloy (Ti6Al4V) has a disadvantage when it's exposed to elevated temperatures that is an oxidation. Oxide layer is formed on the surface of the metal and growth with temperature behaviour. Respectively oxide layer contain porosity that will increase the corrosion behaviour in metal. Nevertheless, the oxide layer has a higher hardness than pure metal or alloy. To utilize the hardness properties of the oxide layer as well as to prevent the corrosion behaviour duplex coating is an approach to optimize its properties. The combination of oxidizing process with physical vapour deposition coating (duplex coating) can improve the performance of the alloy. Through this research the properties of oxidised aluminium alloy (7075) and titanium alloy (Ti6Al4V) will be studied to determine which metal are more suitable for duplex coating purpose to optimize the usage of this metals alloys in aerospace applications and aircraft structures. In this research, Vickers micro hardness tests, Scanning electron microscopy and X-ray diffraction was used to investigate the hardness properties, thickness of the oxide layer, morphology of the oxide layer microstructure. Found that the oxidation occurred on the titanium alloy is better than aluminium alloy. Titanium alloy at temperature 700^{o}C and 750^{o}C for 5 hours has a significant effect on oxide thickness and hardness properties are formed at different temperatures and times.

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DEDICATION

Dedicated to my dad, Jail Bin Othman and my mother, Sarimah Binti Miswan, To my supervisor, Dr Jariah Binti Mohamad Juoi, lectures and dearest friends for all of their help and friendship.

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LIST OF ABBREVIATIONS

Al	-	Aluminium
Al_2O_3	-	Alumina / Aluminium oxide
C	-	Carbon
Cr	-	Chromium
CRT	-	Cathode ray tube
Cu	-	Copper
EDS	-	Energy Dispersive X-Ray Spectrometer
F	-	Force
Fe	-	Ferrous
GPa	-	Giga Pascal
H2O	-	Water
HV	-	Hardness Vickers
HVOF	-	High velocity oxy-fuel
K	-	Kelvin
L	-	Litre
Li	-	Lithium
MPa	-	Mega Pascal
Mg	-	Magnesium
Mo	-	Molybdenum
N	-	Nitrogen
Na	-	Natrium
Nb	-	Nobelium
O	-	Oxygen
PID	-	Proportional Integral Derivative
PVD	-	Physical vapour deposition
SEM	-	Scanning electron microscope
Si	-	Silicon
Ti	-	Titanium
TiO_3	-	Titanium oxide
UV	-	Ultra Violet

V	-	Vanadium
XRD	-	X-ray diffraction
Zn	-	Zinc
ZnO	-	Zinc Oxide
Zr	-	Zirconia
%	-	Percent
^{o}C	-	Degree Celsius
α	-	Alpha
β	-	Beta
γ	-	Gamma
θ	-	Theta
μm	-	micrometer
ø	-	Diameter

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Now day's aluminium alloy and titanium alloy are the most appropriate materials for industrial application, such as aerospace, aviation, naval and automotive industry because of their low density, high strength to weight ratio and very good corrosion resistance. These alloys have been produced in a wide variety of product from like cast, wrought, bar, sheet and billet. The technologies of manufacturing have recently increased the usage of these alloys in variety applications. These study focus on aluminium alloy and titanium alloy, because of the variety application of this metal alloy. The aluminium alloy and titanium alloy has a low density and high strength to weight ratio but it also have the disadvantages like poor tribological properties, high friction coefficient, no fatigue limit and poor oxidation above 500^oC.

This study is to compare the properties of oxidised aluminium alloy and titanium alloy for purpose duplex coating because duplex coating can be use to improve the mechanical properties such as hardness, friction, load bearing capacity, and sliding wear (Wendler and Pawlak, 2008). Aluminium alloy and titanium alloy oxidized form an oxide layer on the surface of the alloys when expose at elevated temperature. The oxide layer is tougher than the metals alloy as so the oxide layer protects the metal (Bemporad, *et al*, 2005).

The oxide layer forms are aluminium oxide and titanium dioxide. Aluminium oxide and titanium oxide have high hardness properties than the metals alloy. So it wills protect the surface of metals alloy, however oxide layer have the disadvantages such as corrosion and degradation due to gaseous environments because this factor will limiting the life services of metals alloy (Srinadh and Vakil, 2004).

Duplex coating (Oxidizing with Physical vapour deposition coating) is an approach to protect the oxide layer from corrosion and degradation. The long term outcome of this final year project is too carried out duplex coating for aluminium alloy and titanium alloy. However in this particular project, the work is conducted on the properties of aluminium oxidized and titanium oxidized prior to the duplex coating process. Physical vapour depositions (PVD) coating improve quality of the substrate hardness and also improve wear resistant of metals alloy. PVD coating are commercial method for improving properties in variety application which involve high contrast stresses and severe sliding wear (Bemporad et al, 2009).

1.2 Problem Statement

Numerous research efforts in the oxidation process and the surface treatment of aluminium alloy and titanium alloy had been archived and developed. Most of the aerospace, aircraft and automotive application demand high temperature materials with specific strength and resistance again creeps, fatigue and environmental degradation at elevated temperature. Oxidised aluminium alloy and titanium alloy will improve the hardness properties, wear resistant and good oxidation at high temperature.

The advantages of this oxidise aluminium alloy and titanium alloy is that they have high specific strength and high hardness than pure metal and alloys (CES Software, 2005). However they have disadvantages like porous metal and degradation at high temperature environment. When aluminium alloy and titanium alloy has oxidation at elevated temperature the oxide layer will form and growth followed the increasing of temperature. Comparing the hardness properties of oxidised aluminium alloy and titanium alloy will indicate which material is most suitable to be subjected for a duplex coating process by PVD coating. Duplex coating approaches will then be able to be studied in order to improve the properties of light metal alloy for aerospace engine, aircraft structure and automotive application.

1.3 Objective

i. To compare the hardness properties of oxidised aluminium alloy 7075 and titanium alloy Ti6Al4V at high temperature oxidation.
ii. To compare the hardness properties of oxidised aluminium alloy 7075 and titanium alloy Ti6Al4V at high temperature oxidation based upon various heat treatment carried out.

1.4 Research Scope

This is due the capability of this alloy. This research will focus on oxidation at high temperature of aluminium alloy 7075 and titanium alloy Ti6Al4V to improve the hardness properties and surface performance. The hardness properties will be investigate using Vickers micro hardness test, the characterization is involved optical microscope and Scanning Electron Microscope (SEM) equipped with an Energy Dispersive X-Ray Spectrometer (EDS) to analyse the morphological and compositional oxide studies of the scale. The oxidised phases were identified by X-ray diffraction (XRD).

CHAPTER 2

LITERATURE REVIEW

This chapter review related study done by the previous research on light weight alloy application on aerospace engine or aerospace structure and the purpose of duplex coating system. Light weight alloy like aluminium alloy and titanium alloy are widely used in aerospace engine and aerospace structure application because of the thermal, mechanical and physical properties of the light alloy. The literature review will focus on aluminium, titanium and their alloy because of the mechanical properties and theirs strength.

2.1 Introduction

Duplex coating is a term used to denote when two or more coating system are used in conjunction, in order to create superior properties from the combined coating (Avelar *et al*, 2003). The point of duplex coating is the combination of the method for increasing load bearing capacity of the surface layer, but also, obtaining first class wear resistance of the surface. Duplex coating is new solutions for oxidised aluminium alloy and titanium alloy, combining the advantages of oxidised and Physical Vapour Deposition (PVD) coatings looking for a still better performance in service. Duplex coating increased the wear resistance and the hardness properties of metals. Duplex coating adhesion is strongly dependent on the mechanical properties of the duplex coating layer close to the interface (Avelar *et al*, 2003). Duplex coating system is widely used in aerospace industry because of its advantages. For examples, its capability to prevent the corrosion and erosion, the surface layer of duplex coating cans resistance high temperature, high toughness, reduces heat transfer and increase in life time. Nevertheless duplex coating process has the disadvantages due cost of duplex coating process increase than conversional coating and the applicable for only a limited range of geometry where complicated geometry are difficult to duplex coating (Avelar *et al*, 2003).

2.1.1 Application of Duplex Coating

Duplex coating system has wide usage in aerospace application, automotive application, aircraft application and heat exchanger. Duplex coating system is commercial method for improving properties in those applications which involve high contrast stresses and severe sliding wear. Duplex coating may contain a harder and also stiffness interlayer, which provides a better distribution of contact stress, avoiding plastic deformation of the substrate and brittle failure of the coating (Bemporad *et al*, 2009)

2.1.2 Type of Duplex Coating

Duplex coating have many type of coating can be used to combining treatment process with coating process like multilayer Physical vapour deposition (PVD) coating, High velocity oxy-fuel (HVOF) coating with Physical vapour deposition (PVD) coating, Plasma nitriding with PVD coating and etc. These coatings are combining to make a duplex coating system. This duplex coating is providing a different improvement in interlayer or surface layer. Different duplex coating purpose can be used to improve the mechanical properties and the morphology structure.

Table 2.1: Coating available for use in duplex coating system. (Wendler and Pawlak, 2008; Bemporad *et al,* 2009; Konieczny *et al*, 2009; Mikula and Dobrazanski, 2007)

Primary Coating	**Secondary Coating**
Plasma nitriding	PVD coating
HVOF coating	PVD coating
Anodised	PVD coating

2.2 Light Alloy

Aluminium alloy, magnesium alloy and titanium alloy is the several light alloy materials have been used in most of the application like aerospace, aircraft and automotive industry. The light alloys are frequently used to reduce the weight of component and structures. These metals have relative density ranging from 1.7 to 4.5g.cm^{-3} (ASM, 1990), which compare with the iron and copper. The properties of lightness have led to the association of the light metal with transportation and more especially with aerospace which has provided great stimulus to the development of these alloys. The strength to weight ratio have thus been a dominant consideration, and this are particularly important in engineering design. Aluminium, magnesium, titanium and their alloy are widely used for commercial application die to their favourable combination of properties and cost. It also have the advantages more than ferrous metal because of the high weld efficiencies, low elastic modulus, so they will absorb energy with good resistance to dents and has high damping capacities (Cock, 1999).

2.2.1 Aluminium and Aluminium Alloy

Aluminium is a silver white metallic element in group III of the periodic table. The electrolytic reduction of alumina (Al_2O_3) dissolved in molten cryolite was independently developed by Charles Hall in Ohio and Paul Heroult in France in 1886 (ASM, 1990). Alumina refined from bauxite is dissolved in a cryolite bath with various fluoride salt additions made to control bath temperature, density, resistivity, and alumina (ASM, 1990). Aluminium alloys are increasingly used in aerospace engineering and aircraft structure in wide range of application.

Aluminium alloy can be dividing into two categories like cast and wrought composition. Many aluminium alloys are responding to thermal treatment based on phase solubility. The treatments include solution heat treatment, quenching, precipitation, aging, and hardening. Aluminium alloys for casting or wrought can be described as heat treatable. But some casting alloys are essentially not heat treatable and are used only in as cast or in unrelated to solution or precipitation