LASER SURFACE ALLOYING OF PURE ALUMINUM WITH IRON AND NICKEL VIA LOW POWER CO_2 LASER

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I dedicate this work

To my dear parents and brother

Aqeel Salim AL-Shammeri

Maiedah salim

Mohammad Aqeel Al-Shammeri

Whose love, kindness, patience and prayer have brought me this far

To my friends

For their love, understanding and support through my endeavour

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ABSTRACT

Aluminum is extensively utilized in industry due to its light weight, excellent workability and low cost. However, its wear resistance, hardness and mechanical properties are poor in comparison to steel. The technique of laser surface alloying was used to improve the aluminum surface properties such as hardness by modifying the composition and microstructure of the surface. A continuous wave (CW) CO_2 laser beam was utilized for surface alloying in this research. The maximum output power of the CO_2 laser is 27 W. The alloyed materials comprised of micro-powder of iron (Fe) and nickel (Ni). Pure aluminum substrate was pre-coated by a mixture of nickel and iron micro-powder with a ratio of 2:1. Hence, CO_2 laser beam was irradiated on the pre-placed Fe-Ni powder to melt them together with the substrate at various times of exposure (10 - 60 s). The distance from output laser beam into the specimen was 20 cm. X-ray diffraction (XRD) and scanning electron microscope (SEM) were employed to analyze the alloying elements and study the microstructure of aluminum surface respectively. The hardness of alloyed surface was measured by using Vickers hardness tester. SEM analysis showed that the alloyed layer produced by a mixture of different elements is more homogenous and re-solidified. XRD results confirmed that several new intermetallic compounds such as Al_5Fe_2, Al_6Fe, $AlFe_3$, $AlNi_3$ Al_5FeNi, $Al_{0.9}Ni_{1.1}$ and $Al_{76.8}Fe_{14}$ are formed. The existence of these compounds confirmed that the aluminum surface has been alloyed. According to hardness test, the average micro-hardness of the treated surface increases approximately two times than the untreated surface. This technique is possible to alloy the surface of aluminum and improve its hardness.

ABSTRAK

Aluminium digunakan secara meluas dalam industri kerana sifatnya yang ringan, kebolehkerjaan yang sangat baik dan kos rendah. Walaubagaimanapun, rintangan ketahanan, kekerasan dan sifat-sifat mekanikalnya adalah lemah berbanding keluli. Teknik laser ke atas permukaan aloi telah digunakan untuk memperbaiki sifat-sifat permukaan aluminium seperti kekerasan dengan pengubahan komposisi komponenya dan struktur mikro permukaan. Satu gelombang berterusan (CW) cahaya laser CO_2 telah digunakan untuk mengaloi permukaan alumnium dalam kajian ini. Kuasa keluaran maksimum bagi laser CO_2 ialah 27 W. Bahan-bahan aloi terdiri daripada serbuk mikro besi (Fe) dan nikel (Ni). Substrat aluminium tulen telah terlebih dahulu dilapisi dengan campuran nikel dan serbuk mikro besi dengan nisbah 2:1. Oleh itu, cahaya laser CO_2 telah meradiasi ke atas serbuk pra-letak serbuk Fe-Ni untuk mencairkan kedua-dua elemen dengan substrat pada pelbagai masa pendedahan (10-60 s). Jarak daripada keluaran cahaya laser ke sample adalah 20 cm. Pembelauan sinar-X (XRD) dan Mikroskop Elektron Imbasan (SEM) masing-masing digunakan untuk menganalisis unsur aloi dan mengkaji permukaan mikrostruktur aluminium. Kekerasan permukaan aloi diukur menggunakan penguji kekerasan Vickers. Analisis SEM menunjukkan lapisan aloi yang dihasilkan oleh campuran unsur-unsur yang berbeza adalah lebih homogenus dan dipejalkan semula. Keputusan XRD mengesahkan pembentukan beberapa sebatian antara logam yang baharu seperti Al_5Fe_2, Al_6Fe, $AlFe_3$, $AlNi_3$ Al_5FeNi, $Al_{0.9}Ni_{1.1}$ and $Al_{76.8}Fe_{14}$. Sebatian-sebatian ini juga mengesahkan bahawa permukaan aluminium telah dialoikan. Menurut ujian kekerasan, purata kekerasan-mikro permukaan yang dirawat meningkatkan kira-kira dua kali daripada permukaan yang tidak dirawat. Teknik ini boleh digunakan untuk mengaloi permukaan aluminium dan meningkatkan kekerasannya.

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LIST OF ABBREVIATIONS

a	-	Absorption coefficient
A	-	Heat production per unit volume and time
AC	-	Alternating current
Al	-	Aluminum substrate
b	-	Applied load in kilogram-force
c	-	Speed of light in vacuum
Co	-	cobalt
CO_2	-	Carbon Dioxide
C_ρ	-	Heat capacity
Cr	-	chromium
Cu	-	copper
CW	-	Continuous wave
d	-	Diagonal length of indentation in millimeters at the surface
D	-	Diameter
DC	-	Direct current
Fcc	-	face centered cubic
Fe	-	iron
h	-	Depth of penetration of the tip after application and removal load
h	-	Thermal diffusivity
h_o		Depth of penetration of the tip is after the application of the load
HB	-	Brinell hardness
HMV	-	Microhardness Vickers tester

Hv	-	Hardness Vickers
HY-HV	-	family of high voltage power supply of Hongyuan electric
I_0	-	Irradiance on the axis r
K	-	Thermal conductivity
LSC	-	Laser Surface Cladding
LSR	-	Laser surface alloying
Mg	-	Manganese
Mo	-	molybdenum
n	-	Real refractive index
Nd-YAG	-	neodymium-doped yttrium aluminum garnet
Ni	-	nickel
P	-	Force
$q_v(z)$, q_{v0}	-	Imbibed radiation powers per unit volume
R	-	Reflectivity
SEM	-	Scanning Electron Microscope
Si	-	silicon
SiC	-	Silicon Carbide
Ti	-	titanium
TTL	-	voltage level control
w	-	Beam radius
XRD	-	X-Ray Diffraction
z	-	axis in a homogeneous and nonabsorbent medium
θ	-	Angle between opposite faces of the diamond(135^o)
λ	-	Wavelength
ρ	-	Density of material
ω	-	Angular frequency
1SLD	-	One-step laser deposition
2SLD	-	Two-step laser deposition

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CHAPTER 1

INTRODUCTION

1.1 Background

Laser has taken great benefits in industry medicine surgery, operations, scientific research, photography, holography, engineering, data storage, and, military. Also, using lasers led to an extremely of applications in physics, material science, spectroscopy, chemical technology, biochemistry and molecular biology. Material processing is most important fields that uses laser for surface modification of materials.

Laser force can be used to improve the surface properties such as wear resistance, hardness and corrosion by modifying the structure and microstructure of the surface without affecting the properties of the bulk material. The interaction period between the material and laser beam indicates to several processes where these processes are due to different combinations of melting, heat transmission, absorption, powder addition, and speedy solidification.

Among various materials, aluminum is used for many applications in manufacturing, chemical, automotive, food, aerospace industry and railway cars, etc., because it has light weight, low cost, good resistance, workability and its low density. However, they often suffer severe loss under the synergistic attack of corrosion and wear in some violent media, regardless of their good corrosion resistance, and also its hardness and low wear resistance in several application are limiting (Mabhali et al., 2010; Mindivan et al., 2005; Tomida & Nakata, 2003). Therefore aluminum was used to be as a substrate in this research.

1.2 Statement of the Problem

Aluminum is widely utilized for several applications because of its advantages. However, aluminum surface has low corrosion resistance and hardness. Laser surface alloying is recently considered to be the most efficient method for surface modification. Many researches have been achieved to improve the surface properties of aluminum by adding a powder of different materials such as Cr, Ti, Mo, Ni, Fe, or Cu, Si (Pilloz et al., 1991) where it is used to improve surface properties and treatment. Laser surface alloying (LSR) has been successfully technologically advanced to improve the surface properties of different alloys and metals, such as the surface mechanical properties of wear resistance, corrosion, erosion resistance, and cavitation.

There are many kinds of laser applications are usually used long wavelength, high energy, and continuous like Nd-YAG laser. However, the problems with these lasers are not suitable for modifying thin sample. In the current studying, Carbon dioxide laser technique (CO_2) is used for surface alloying (Chuang et al., 2006).

Previously, less research have been conducted using a low power laser for alloying process. This technique offers more cost-effective technique and beneficial to treat thin plate of pure aluminum.

1.3 Research Objectives

The aim of this study is to introduce a technique for modifying aluminum surface by using CO_2 laser. This technique is achieved by the following performance.

1. To prepare the samples (coating the substrate with mixture of Fe and Ni micro-powder)
2. To characterize the modification of aluminum
3. To alloy the samples by using continuous wave CO_2 laser at various times of exposure

1.4 Significance of the Study

Presenting a new technology to create alloyed material will be useful in manufacturing sector. For example, localizing the alloying area is much important in piston application. The material used will be hardening and minimized process may be concentrated. Different times to process required low power to alloy all cost effective or offering an economical in manufacturing, safe, faster and user approachable process.

1.5 Scope of the Study

Lower power CO_2 less than 27 W was used a source of energy in the laser surface alloy process. Pure aluminum plate was utilized as substrate and coating with alloy materials. The materials chosen to alloy the aluminum comprised of iron Fe and nickel Ni micro-powder and then mixed together with a ratio 1:2. The alloyed material was characterized by using XRD and SEM. In addition, the hardness of the laser surface alloy material was quantified based on Vickers hardness test.

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