FORMATION OF FE–NI COMPOSITE ON PURE ALUMINUM SUBSTRATE BY LASER SURFACE ALLOYING

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ABSTRACT

Aluminum is recently attracted the attention of several researchers due to its unique properties; however, it has low hardness, corrosion and mechanical properties. The technique of Laser surface alloying of aluminum substrate with nickel and iron under various processing conditions has been studied. In this paper, a low power CO_2 laser was used to alloy pure aluminum substrates with Fe-Ni mixture of various exposures between 10-60 s. It indicates that the laser surface alloying technique using mixed powder with a ratio of 66.67%Ni–33.34%Fe can considerably enhance the hardness of aluminum surface. Microstructures of alloyed layers were studied by scanning electron microscope, optical microscope and the phases were identified by X-ray diffraction analysis. In addition, the micro-hardness of the surface alloyed layer was measured. The hardness was increased from 27 HV0.1 for untreated surface to as high as 53.9 HV0.1 for treating surface due to the formation Al_6Fe, Al_5Fe_2, $AlFe_3$, Al_5FeNi, $Al_{0.9}Ni_{1.1}$ and $Al_{76.8}Fe_{14}$.

KEYWORDS: Fe–Ni alloys; Laser surface alloying; Aluminum; micro-hardness.

INTRODUCTION

Aluminum alloys have important advantages on construction material, particularly; by their low specific weight, good formability, relatively low costs, their corrosion resistance and their good thermal conductivity [1]. For this reason, aluminum alloys have found an extensive range of applications specially in the transport industry, such as aircraft, railway, aerospace and vehicles ([1] and [2]). However, the tribological characteristics of aluminum alloys are very poor that hinder their uses in several other applications. One feature of aluminum is its ability to form several intermetallic phases with most common elements, such as Co, Fe, Ni, Cu, Cr and Ti. The iron and nickel aluminides intermetallics, thoroughly, have received the most attention in recent studies [3-5]. To improve the aluminum surface properties, a diversity of surface modification technologies have been offered and examined. The laser surface alloying of aluminum is a useful surface treating technique and particularly efficient for producing surface layers with improved the hardness on aluminum alloys, since it offers the advantage of localized processing and results in homogenous surfaces resolutely bonded to the substrate [5-7].

In this paper, the process involves pre-coating the substrate surface by a mixture of micro-powder (Fe-Ni) alloying material. The alloying process can be done by several techniques but laser surface alloying is considered to be the most effective technique for surface modification. Therefore, the aim of the this work was to produce a thin Fe-Ni layer of laser alloyed on aluminum substrate is reported by using low power CO_2 laser. The microstructure analysis of aluminum substrates has been studied by using scanning electron microscope (SEM) and optical microscope (OM), the phase of alloying materials have also studied by X-Ray diffraction (XRD). In addition, micro-hardness of the treated surface was measured using Vickers micro-hardness tester.

METHODOLOGY

Sample Preparation and Materials Used

Pure aluminum plate was used as a substrate. The plate was cut into six small pieces with dimensions 200× 200×2 mm^3, with each single piece having surface area of about 2 cm^2. The six pieces of pure aluminum plate were mechanically polished by using polisher grinder machine SA330, in order to produce a smooth surface finish and then chemically washed with acetone using ultrasonic bath. Commercial Ni and Fe powders with 66.67% Ni and 33.33%Fe were used as alloying material. The purity of nickel and iron micro-powder were 99.99%. Suitable silicon RTV 174493A was used to pre-paste the mixture of Ni and Fe micro-powders onto the surface of aluminum substrate. The powder mixture was sprayed on the aluminum substrate by using Coating machine gun 10198, the average amount of the powder that was homogeneously distributed on each piece was almost 0.005g. The pasted specimens were then dried in electric furnace at a temperature 300^oC for approximately 1 hour before the experiments.

Laser Alloying Process

The hongyuan continuous wave CO_2 Laser beam with a maximum output power of 27 W was used for laser surface alloying. This laser was operated in continuous mode, the input voltage of power supply is AC 220 V and the maximum output power supply of DC 25 KV with maximum output current DC 20 mA. The laser beam was focused with water cooling system for operating the temperature (10~40°C), in order to stabilize the output laser during the experiments. Figure 1 shows a schematic diagram of the experimental set-up.

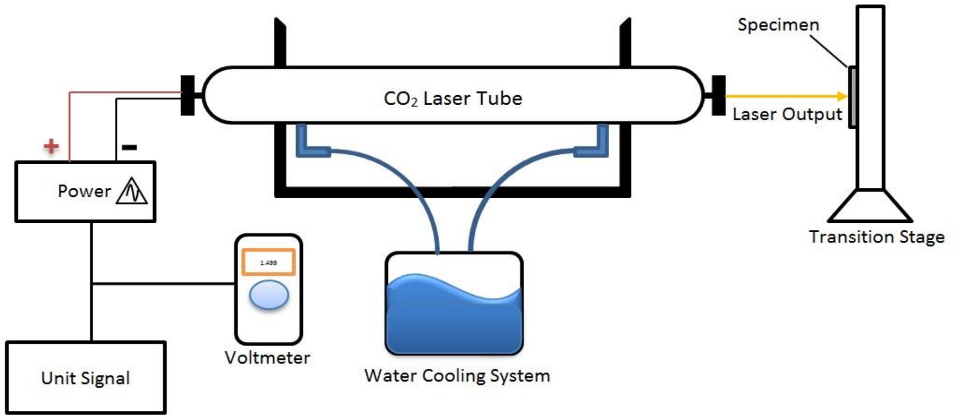

Figure 1. Experimental set-up for CO_2 Laser

The lease beam with wavelength 10600 nm was irradiated directly toward the specimen located on a linear transition stage. Experiments were carried out with different distances to determine the suitable position of samples with respect to output laser beam. 20cm was chosen as the optimum distance between the output laser beam and specimen. The output beam diameter supplies a spot area of approximately 3 mm over the base material. Six samples were alloyed by using CO_2 laser at various time of exposure (10 – 60 sec). The greatest time was mentioned at 50 seconds of laser exposed. After laser alloying process, the samples were cut into lengthways and prepared for microstructure and metallographic observation by using scanning electron microscopy (SEM) and optical microscope (OM).In addition, phase identification was performed by X-ray diffraction using a Siemens Diffractometer D5000 System , The incident angle (2θ) ranged over 20–90◦ for the XRD analysis. The strength of modified surface under a load 49.03 N (0.5 H_V) was measured by means of Vickers micro-hardness tester with a suitable test time of 10 second. At least, 4 indents were made on each sample. The average of the indentations was calculated to find the hardness for each individual sample.

RESULTS AND DISCUSSION

The typical of microstructure for aluminum surface substrate has been analyzed by scanning electron microscope (SEM), optical microscope (OM) and X-ray diffraction equipped. Figure 2(a) is a photomicrograph of 3-dimensions top-view surface using optical microscope that shows the untreated surface has reported to display certain problems such as the appearance of pores, cracks as well as chemical heterogeneity or structural in the laser melted zone.Furthermore, the SEM photomicrogrph of cross-section surface in the Figure 2(b) shows untreated zone of an aluminum substrate before expose to laser for comparison with Fe-Ni depostion laser alloying on the aluminum suface substates as shown in Figure 6(a), in order to understand the relationship between properties and microstructure of alloying zones

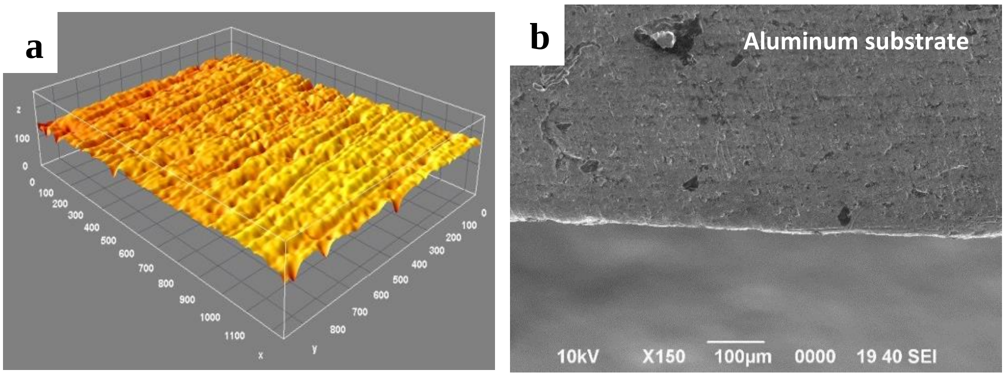

Figure 2. Micrograph of the structures of untreated aluminum surface shows **(a)** 3-dimensions top-view surface by optical microscope, **(b)** cross-section at magnification X150 by scanning electron microscope

According to XRD analysis was performed to determine the phases present, the X-ray diffraction results shown in Figure 3, only 5 Al peaks were observed proving that the sample was a pure aluminium [8].

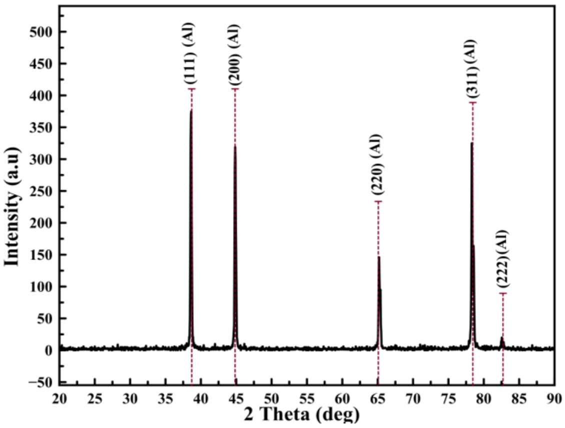

Figure 3. The XRD analysis of aluminum substrate before deposition process

After alloying process, the 3-dimensions photograph of treated surface in Figure 4(a) is shown some dramatic changes in microstructures of the alloyed surface comparing to the original one as shown in Figure 2(a). Beside, the SEM microstructures of cross section of the treated surfaces at magnification X150 in Figure 4(b) is obviously showed that the heat affective zone is formed which are thus frozen in upon rapid solidification of the melt pool.The mixed powders (Ni –Fe) with a constant ratio 66.67% Ni and 33.34%Fe were rapidly melted on the aluminum substrate caused by irradiating a maximum output 27W CO_2 laser for 50 seconds of laser exposure .The large differences in the melting points of Fe (1538^{o}C), Ni (1455^{o}C) and the Al alloy (660.32^{o}C) allow the aluminum substrate to be preferentially melted and then produced a new thin layer upon Al surface substrate.Figure 4(a) is illustrated the yellow regions refer to original surface of aluminum substrate and which have not exposed for any alloying process, whereas the purple regions refer to alloyed zones which have completely alloyed, due to the mixture of powder melted and mixed with Al substrate. Moreover, the alloyed zone formed a deep pool and produced a thin alloyed layer on substrate as marked a white arrow in Figure 4(b) which shows a melt pool and solidified surface. According to XRD results, the alloyed layers were dominated by the formation of $Al_{76.8}Fe_{14}$, Al_5FeNi and $Al_{0.9}Ni_{1.1}$ compound phases. This is an indicator showed that the aluminum surface has been alloyed and improved its hardness

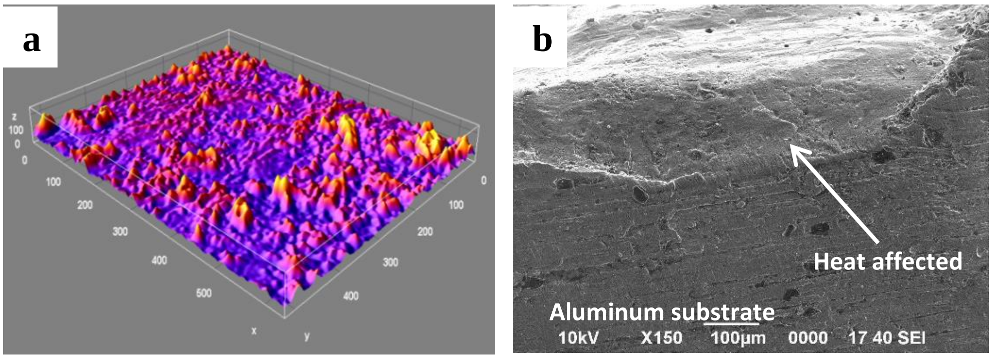

Figure 4. Micrograph of the structures of treated aluminum surface shows **(a)** 3-dimensions top-view surface by optical microscope, **(b)** cross-section at magnification X150 by scanning electron microscope

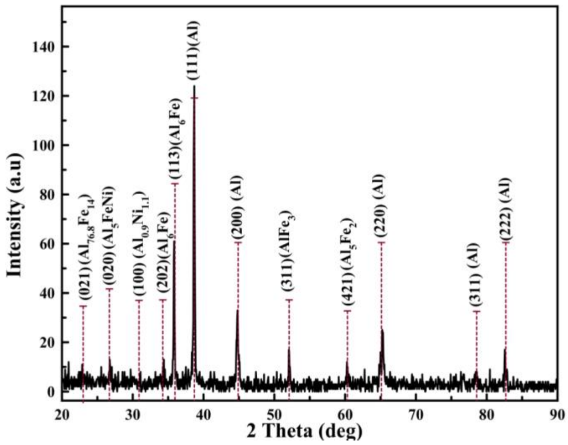

Figure 5. The XRD analysis of aluminum modified surface with Fe-Ni at 50 seconds of laser exposure

In the Figure 7, the phases formed were determined by X-ray diffraction. Fe formed binary alloyed with Al like Al_6Fe, $AlFe_3$, Al_5Fe_2 and $Al_{76.8}Fe_{14}$ ternary alloyed as Al_5FeNi. These compounds are in good agreement with results obtained by other researchers [9].The highest peak obtained is referred to Al (111).In addition, the other peaks with miller indices (222), (311), (220) and (200) refer to Al with different planes. The planes of (021), (020) and (100) are referred to $Al_{76.8}Fe_{14}$, Al_5FeNi and $Al_{0.9}Ni_{1.1}$ respectively. These new peaks of Fe-Ni formed with Al that implies, the aluminum alloyed has greatly achieved with increasing its hardness. Furthermore, the other planes (113), (202), (311) and (421) are presented the Al_6Fe, $AlFe_3$and $Al_5Fe_2$with Al respectively.The alloyed layer using mixture of different materials is estimated to be more homogenous than that using one element.

On the other hand, the modified surface was examined by using Vickers micro-hardness Test. The results achieved from this experiment are presented in Figure 8. The hardness of the laser Fe-Ni alloyed surface is found to be linearly increases with the time of exposure. According to XRD results, the average hardness of treated smaple has accomplished within this range is 53.9 Hv0.1 at 50 seconds of laser exposure compared to untreated sample (hardness of about 27 $Hv_{0.1}$), the compounds peaks observed such as $Al_{76.8}Fe_{14}$, Al_5FeNi, $Al_{0.9}Ni_{1.1}$, Al_6Fe, $AlFe_3$,Al_5Fe_2 were verified. This means the more energy absorbed on the coated surface, the more Fe and Ni will be melted and more metastable phases will be formed. As a result, the surface become harder than the untreated surface.But after achieving the super-lateral critical energy, the hardness drastically changes. This result is in good agreement with previous research [6]. This indicates during alloying process, the delivered energy to the target is higher than critical point as a result during cooling no recalescent regions is occurred [6]. As a result no composite is able to form consequently the hardness is less and sooner or later it back to be similar as original substrate value.

SUMMARY AND CONCLUSION

A method to harden pure aluminum is performed by using laser surface alloying via the application of low power CO2 laser. The quenching rate introduced by the CO_2 laser is the mechanism responsible to alloy the surface. The most probable cause for this strain (and increase in hardness) is work hardening due to the thermal stress originated due to the difference in the expansion coefficients of Ni-Fe. The delivered power was enough to melt and create some new metaphases including alumunum-nickle $Al_{0.9}Ni_{1.1}$,aluminum-iron, Al_6Fe, $AlFe_3$, Al_5Fe_2 and $Al_{76.8}Fe_{14}$ aluminum-nickel-iron Al_5FeNi phases. These phases are responsible to modify the surface and improved the hardness. The critical energy of 1080 J is achieved to optimize the alloying process. Greater than this limit, the surface alloyed was destroyed and original surface was exposed for damaging.

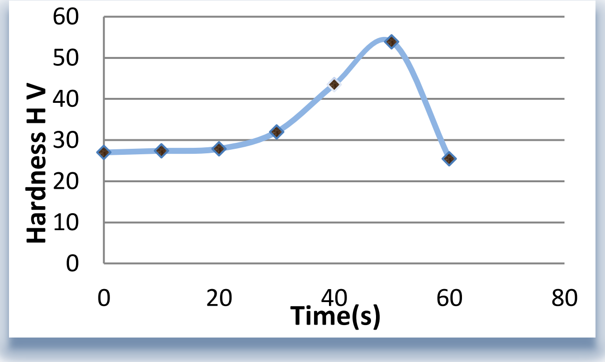

Figure 6. Hardness of Fe - Ni deposited surface treated by different times of laser exposure

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