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Enhancement Surface Mechanical Properties of 2024 Al-Alloys Using Pulsed Nd:YAG Laser Cladding

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Abstract

The present work shows that the cladding process of aluminum alloys (Al 2024) with boron carbide (B_4C) ceramic powders irradiate by pulsed Nd-YAG laser. The optimum parameters of laser are selected to obtain best results. Peak power, pulse duration and frequency are the main parameters affected during the experiments. The results demonstrated by Scanning electron microscope, micro-hardness, energy dispersive spectroscopy (EDS), wear test and chemical corrosion. Pre-placed powder cladding method adapted during the process. The experimental results have shown that the micro-hardness increased 2-2.4 times for Al alloy with B_4C cladding with original value and the thickness of the cladding layer was about 58 µm. The topography and EDS show the powder percentage of the powders on the surface. The corrosion resistance was enhanced with 45% for the aluminum alloy with B_4C cladding. Also, the wear resistance has been improved compared with pure aluminum alloy.

Keywords: laser cladding – aluminum- boron carbide

Introduction

For many years, there has been more attention of laser cladding technology due to many reasons, simple, efficient and almost low-cost technology. For the mechanical properties enhancement, it improves wear and corrosion resistance, hardness, fatigue and stiffness beside the strength. It's a processing technique used for adding one material to the surface of another in a controlled manner [1]. This process uses a specific powder with efficient mechanical properties. Alloys with these mechanical properties are usually very expensive and it's of a great interest to reduce the cost of parts with these material properties [2]. The focused laser beam is scanned across the target surface making lasers coating of the chosen material [3]. Recently, the increasing in demands for lightweight alloys in the aerospace, automobile, and ship industries have led to the development of novel materials and advanced processing techniques, which exploit processing of materials at far-from equilibrium conditions or non-equilibrium conditions [4,5]. Therefore, the application of aluminum alloys offered the potential to lower the weight of structures by over 50% in comparison with those made of low carbon steel, which allowing it to design of narrower products as well as the fuel efficiency becomes the important goal [6]. Laser cladding has become the process of choice in many applications involving coating, repair and reworking. It is a particularly suitable process for the production of relatively small, discrete surface clad with moderate thickness (50μm–2mm). The process principles are similar to those of other surface melting processes, enabling the microstructure and properties of the clad surface to be established from data for rapid solidification of the alloy used. Practical processing has been simplified by the development of coaxial alloy delivery systems, which permit cladding of complex three-dimensional components in various orientations. Analytical modeling aids in understanding the process principles and empirical data can be used to calibrate parameter selection diagrams to particular cladding geometries. Novel manufacturing methods, notably rapid manufacturing by various means of direct metal deposition, have been developed based on the process [7].

In this paper, preplaced powder method used during the experiments is the simplest method of the laser cladding technology provided that the powder can be made to remain in place until melted. There are many advantages for method. Firstly. It's capable to modify specific region on the parts of components, which allows for more precise treatment, moreover, this method is very flexible in the selection of desired powder compositions. In addition, the efficiency of pre-placed powder was higher than that of other laser cladding methods almost all of the pre-placed powder paste can be used in the cladding reactions. The powder is thus must be mixed with a binder. The working area is shrouded by an inert gas. The preplaced powder method involves scanning of the laser beam over the powder bed [8]. When the laser beam is incident on the powder surface, melting occurs almost immediately. The melt front advances through the low conductivity powder layer. As the melt front reaches the substrate, heat conduction increases drastically (due to higher conductivity of the substrate material) causing solidification of the melt pool. Good adherence and low dilution are obtained by supplying enough energy to melt a very thin layer of the substrate [9].The schematic of the method has shown in Figure (1).

The aluminum alloys, as the base cladding material, involved in our work where 1.5mm thickness of Al 2024 was used. The sample dimensions were 10×10× (1.5, 2) mm. To prepare the sample, pure alcohol are used for removing dirt and oil then grinding the sample with the same direction using different grades of abrasive silicon carbide papers of grad (600, 800, 1000 and 2000) grain/cm^2. Finally, the sample washed by pure alcohol and then drying it to prevent surface oxidation for longer time as possible before cladding. The ceramic powders were selected as a clad material to improve the reactivity of the clad layer with base.

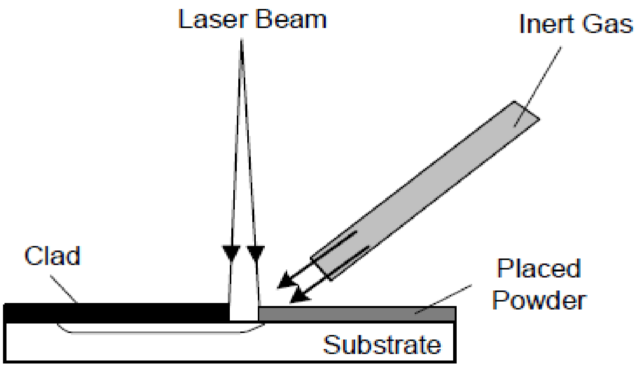

Figure 1 : the schematic of preplaced laser cladding

The laser cladding experimental work were carried out using pulsed wave Nd:YAG laser (λ= 1.064 µm). Aluminum alloys are used as substrates. Prior to deposition, the substrates were sandblasted and cleaned in alcohol. Boron carbide (the reinforcement material) are about 75µm in thickness. A pulse laser with average power of (0.6) kW, (11) Hz with pulse duration (8.3ms) was chosen. The samples were placed on a three-axis manual movement table with micrometer distance scale. In all the experiments, the laser beam was focused on the sample surface with a spot shape. Diameter of the laser beam was fixed as (0.9) mm. Experimental work were conducted to identify the effect of peak power and pulse overlapping with constant pulse duration. Frequency was selected such that the average power did not cross the laser machine average power limit. Laser beam of Gaussian shape was used to scan over the specimen by the moving table. Velocity of the work piece was fixed to achieve required pulse overlapping (0.5mm/s). A proportion of B_4C was uniformed on the samples and the distance between the sample surface and the focal plane of the converging optical system was 10 mm. The sample surface was located below the focal plane of the focusing optics. Coatings were produced by lateral overlapping. Scanning electron microscopy (SEM) and Energy dispersive spectrometry (EDS) were used for micro structural characterization. The optimization of the process requires the measurement and the control of some parameters such as process speed, laser power, beam diameter and the distance between two layers. An increase in the speed processing would lead to a decrease in the surface temperature and the powders would not correctly bind to the surface. Inversely, for a slower speed processing, the surface would reach higher temperature, leading to a deeper penetration thus a higher dilution and lower mechanical properties. A value of speed processing was used to avoid these problems. In the laser cladding process, large size of powders needs more heat for melting, which means increasing the laser power or decreasing the travelling velocity is needed. Smaller particle size powders are easy to melt and when the particle size is larger, the feeding process will cause difficulties in the laser cladding process. The experimental setup has shown in figure (2).

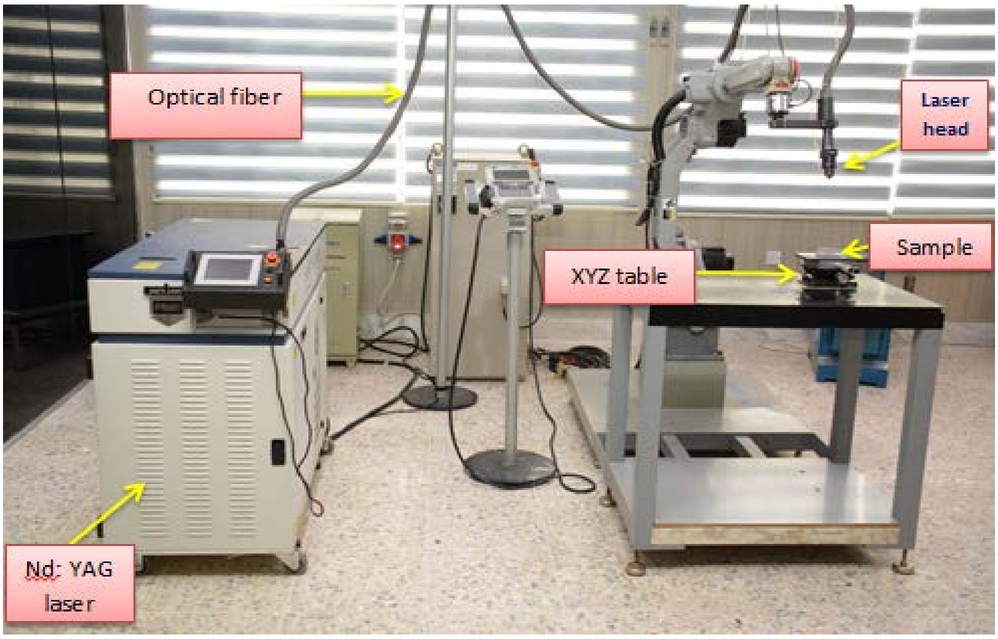

Figure 2: the experimental setup of preplaced laser cladding

The microstructures of samples with B_4C powder of aluminum alloy composition was investigated by using a scanning electron microscope. Figure (3-a) has shown the microstructure of Al- 2024 alloy with B_4C powder and Figure (3-b) shows the thickness of the clad layer in different locations and the average value is determined to be 58.38 µm.

The thickness value of the clad layer plays an important role in mechanical surface characterizations. During our work, we found that there is a trade-off between input peak power cladding layer of the laser beam and the value of hardness. With increasing the clad layer thickness the micro-hardness decreases, which means that the high input peak power leads to increase the penetration depth and the powder particles immersed inside the alloy and the Al-alloy surface will appears. Therefore, there is an effective and suitable value of thickness to obtain high value of hardness.

Indeed, Figure (4) shows the different magnification of surface topography of the clad layer. According to energy dispersive spectroscopy (EDS) analysis, the percentage content of B_4C appear inside

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Al-alloy. It can show that the powder particle was completely mixed with molten Al-alloy.

Figure (5) shows Corrosion test of pure Al-alloy and after cladding and figure (6) the EDS of 2024 Al alloy with B_4C cladded while table (1) describes the concentrations of elements on the surface. The wear test for Al-2024 cladded with B_4C is illustrated in Figure (7). The wear Figure shows the relationship between wear rate and time. When time is increasing, the wear rate increases with different percentage rate. The percentage of wear rate for the cladded layer alloy thickness played an important role in the wear. It has been decreased as compared with the base alloy. The applied load in this test was 500g. After 7min, the value of wear rate of original alloy and cladding layer were equal.

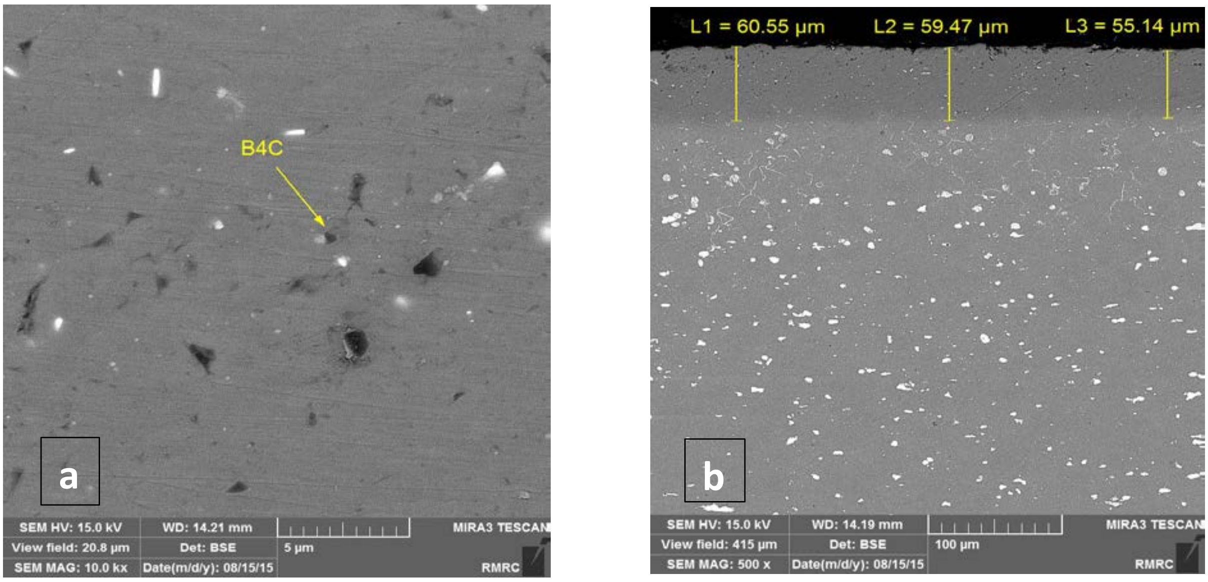

Figure 3: (a) SEM of 2024 Al-alloy cladded with B_4C powder; (b) SEM for the cross section of SEM of Al 2024 with B_4C

Table (1): components results of Al 2024 cladded with B_4C

Elements	W%	A%
B	66.97	46.50
Al	16.74	29.01
C	15.52	24.21
Si	0.09	0.06
Fe	0.67	0.23
Total	100.00	100.00

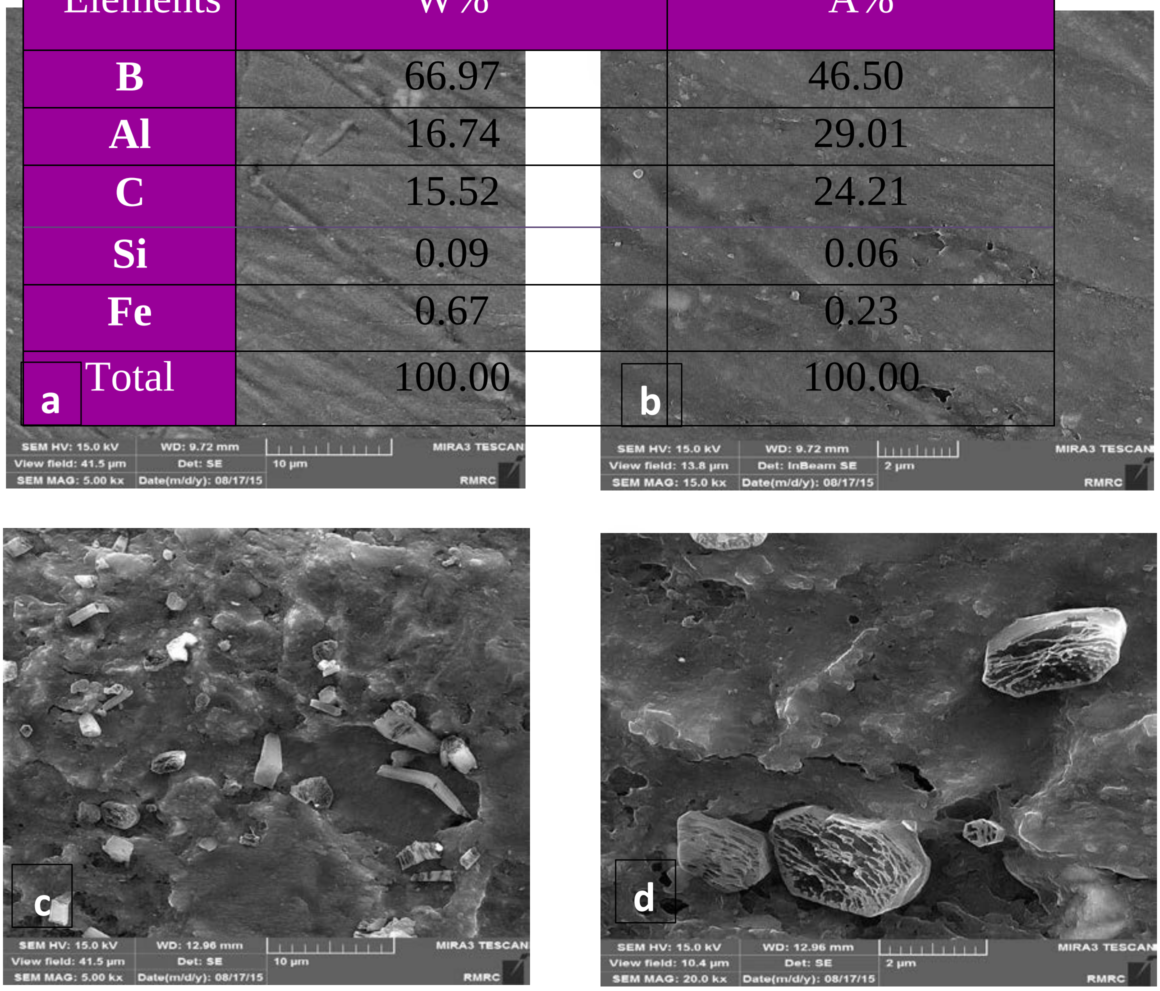

Figure 4: SEM images for 2024 Al alloy with B_4C powder (a) 500 x magnification, (b) 5.00kx magnification (c) 15.0kx magnification (d) 20.0kx magnification

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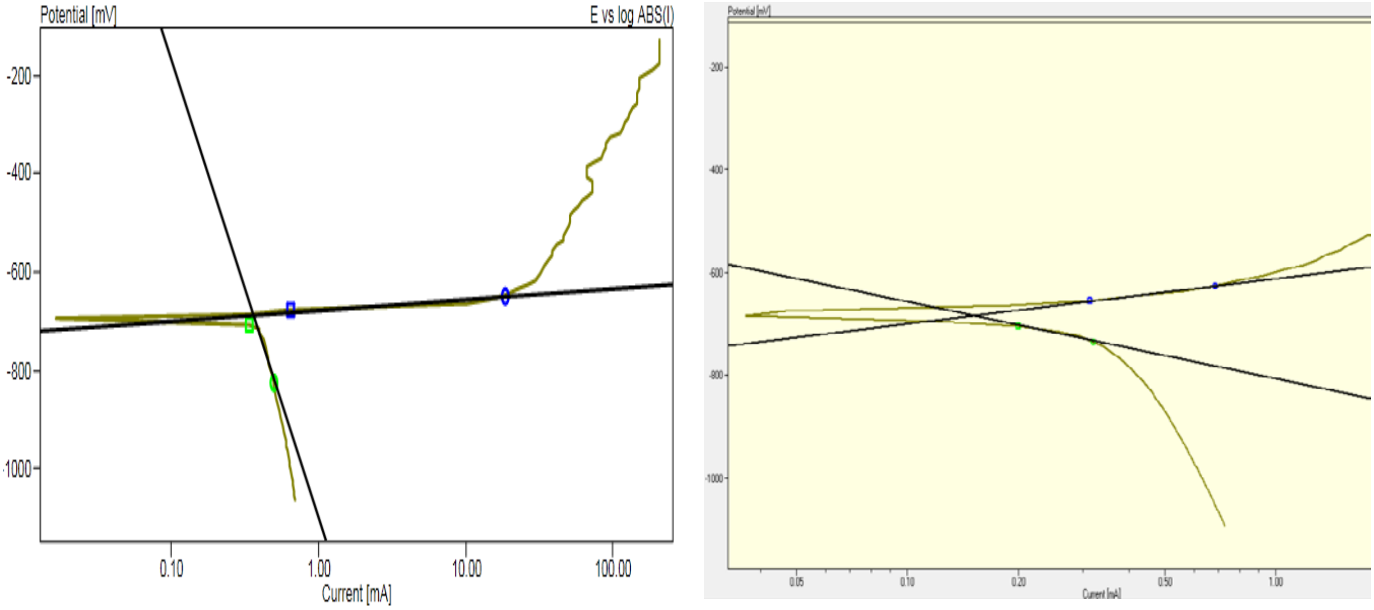

Figure 5: (a) Corrosion test of pure Al 2024 alloy (I_{corr} = 362µAm); (b) Corrosion test of Al 2024 alloy with B_4C (I_{corr} = 152µA)

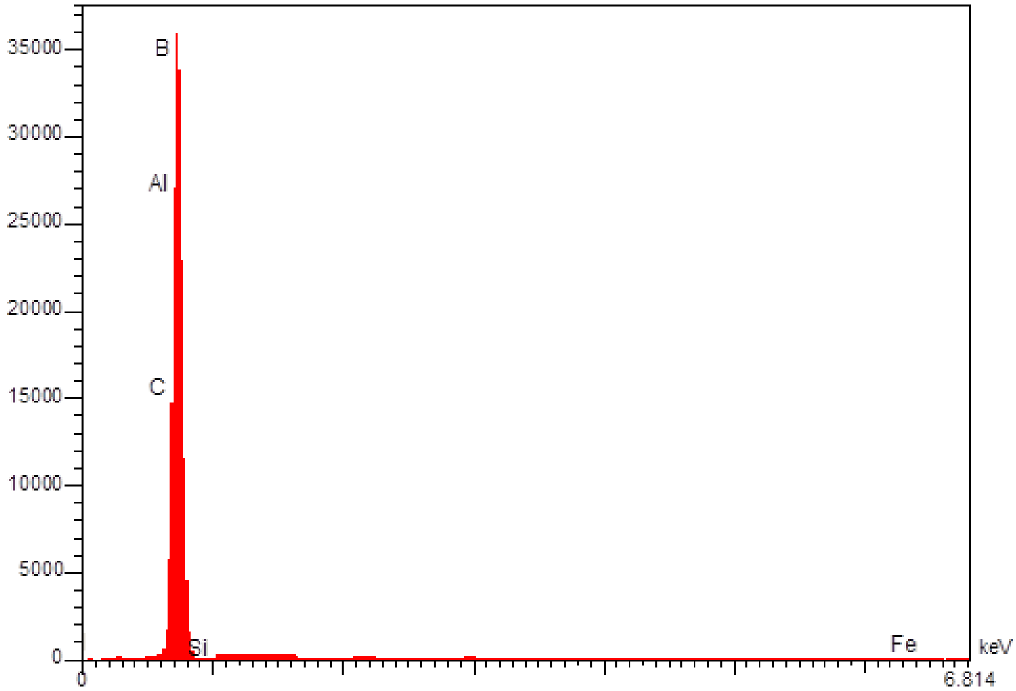

Figure 6 : EDS for Al 2024 cladded with B_4C

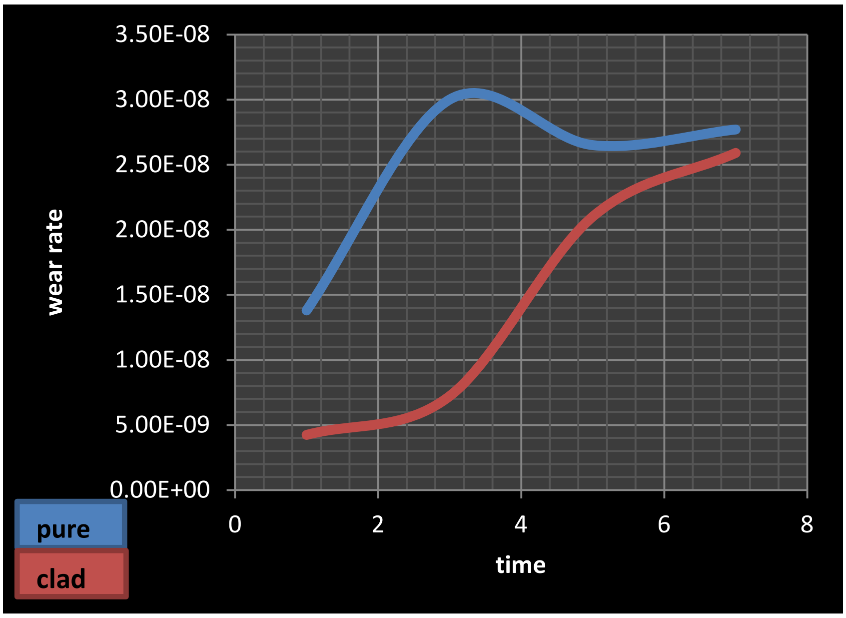

Figure 7 Wear test Al (2024) alloy with B_4C cladding

Conclusion

The microstructure and properties of Al-2024-B4C cladded by laser cladding technology, depends strongly on the processing parameters of laser (pulsed Nd-YAG), particularly power density and interaction time. Also, there was an enhancement for the corrosion resistance of about 45% for the aluminum alloy with B_4C cladding and wear resistance is also improved.

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