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Modification of Prepared (Al 2024/Alumina/Mn) Composite by Laser Surface SiC Clad Layer

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Abstract*-The present work shows the cladding process of silicon carbide on the substrate of prepared composite (Al 2024/Alumina/Mn) by using a laser beam (pulsed Nd-YAG). To obtain the desired results, the best laser parameters were chosen. The parameters of the laser beam that have chief affected during the experiments in this work are peak power (1.9)kW, work frequency (8)Hz and pulse duration (5.3)ms, the preplaced powder technique favorite during a cladding process and the results in this work were proved by SEM, micro-hardness, EDS, and chemical corrosion tests. The results of the experimental work have shown that a micro-hardness increased about (28%) times for Aluminum/Alumina composite by silicon carbide cladding compared with the original value of micro-hardness, and thickness of the cladding layer was about (34µm). The resistance of corrosion was enhanced with about (35%) for the Aluminum/Alumina composite with SiC cladding.*

Keywords- Aluminum, Laser cladding, Silicon carbide.

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1. Introduction

There is a need in different industries to improve the performance of the surface of the material under corrosion environments that can't be fulfilled by conventional coatings and modifications of the surface. So to improve the properties of the surface of the material, the laser surface engineering is used [1].

The laser cladding research and development processes for industrial applications are so active during the last years primarily because of the fast development of power laser technology and recent activity of industrial laser coating [2]. This technique which used in remanufacturing parts has different advantages: Low costs, reducing working procedures and enhancing the properties of parts (resistance of corrosion, the resistance of wear, hardness, and fatigue resistance) [3,4]. Laser Cladding employs the heat source of Laser to deposit the thin layer of the chosen metal on the moving substrate in the controlled method [5]. In this process, the effective mechanical properties powder is used.

The very expensive alloys have these properties, so the researchers and scientists find an interesting to reduce the cost and obtain these properties [6]. The chosen material lasers coating is deposited on the surface of the target substrate by using a beam of focused laser [7]. Also, Laser cladding can produce layers with special property on a full or part of the surfaces of common materials. In addition, different applications in the aerospace fields, automobiles, and petroleum and chemical industries for laser cladding remanufacturing techniques [3,4]. The laser cladding process have developed to be the chosen process in different fields such as repairing processes, coating and reworking processes. Comparatively small and/or discrete surface clad with modest thickness (0.05–2) mm can be produced in this process. The principles of cladding laser process are parallel to the other processes that have melting processes of the surface, which allowing the clad surface properties and microstructure to be recognized from data for quick solidification of the alloy used [8].

Laser Cladding is the interdisciplinary technology employed Laser technology, computer-aided design, and manufacturing (CAD/CAM), control and sensors and robotics [5]. The principal parameters that affect process quality include; laser beam parameters (quality of beam, output of power, size of spot, density of power at the focal point, and operation mode), materials parameters (roughness of surface, thermal and optical properties), system of laser beam delivery, scanning speed and system of workpiece positioning [9]. Thermal and surface properties of the material are playing a crucial role in addition to parameters of the laser beam such as the size spot of laser and scanning speed [9].

R. M. Hadi, et al. 2016 they studied a cladding process of Aluminum alloys [Al2024] with Boron Carbide (BR4RC) ceramic powders irradiate by pulsed (Nd-YAG Laser). The results of the experimental work have shown that a micro-hardness increased by (2-2.4) times for Aluminum alloy with Boron Carbide cladding with original value, and a thickness of the cladding layer was about (58μm). The resistance of corrosion was enhanced with about (45%) for the Aluminum alloy with Boron Carbide cladding. The resistance of wear also has been increased compared with pure Aluminum alloy [10].

2. Methods and Processes

The method that used in the experiments was preplaced powder method. This is the simplest method used in laser cladding technology. The advances of the preplaced powder method were: The powder stayed in place pending melted, on the components parts, a particular region can be modified, permits for extra specific treatment and desired powder compositions can be chosen very flexibly.

Usually, all the paste of the preplaced powder method was used to form the clad layer. The blender must be used for mixing the powder in the preplaced powder method. The environment of inert gas used to shroud the area of the working. This method includes the laser beam scanning over the paste of a powder [11]. When the beam of the laser falls on the surface of the powder, melting happens almost instantaneously. A melt front progresses through a powder layer that has low conductivity. When a melt front touches a substrate surface, extremely the heat conduction increases (the substrate material conductivity is higher) producing the melt pool solidification. By applying sufficient energy, low dilution and well adherence were achieved, this energy is necessary to melt a so tinny film of a substrate [12]. The preplaced Laser cladding process is shown in Figure 1.

In this work, the corrosion of this composite had been studied before and after cladding. Corrosion experimentally can be established that electrochemical reactions were collected from two or more partial oxidation or reduction. Because of an electrochemical nature of most corrosion processes, electrochemical methods are useful tools for studying corrosion [13]. Tafel extrapolation method employs information got from measurements of anodic and cathodic polarization. Cathodic information is favored; the device used for the corrosion test is shown in Figure 2 [14].

3. Materials and Experimental Work

Table 1 shows the composite chemical composition percentages according to the standard that used to produce the Al2024 with change 6% of Al with Alumina powder to obtain a composite material.

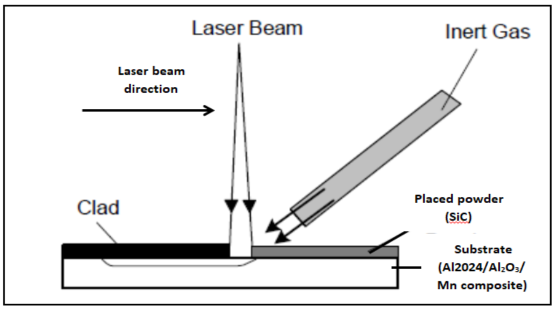

Figure 1: Preplaced laser cladding process

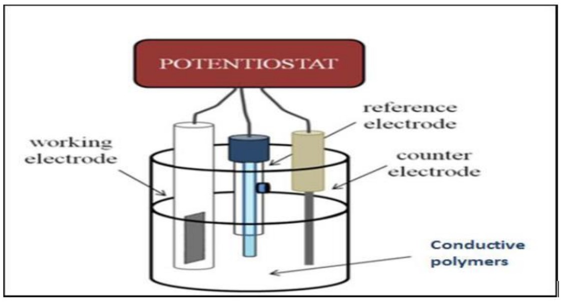

Figure 2: The set-up of the electrochemical experiment

Table 1: The composite percentages.

Al%	Cu%	Mg%	Mn%	Al_2O_3 %
89	4	0.5	0.5	6

The samples had been manufactured by powder metallurgy route, this route includes blending and mixing the powders and then presseing the mixture of powders with pressure about 30 ton into the die of dimensions (70mm× 10mm× 10), Figure 3 shows the sample after pressure stage.

The next step in this metallurgy is sintering the sample into a furnace that has inert gas to prevent the oxidation during this stage. The temperature of the sintering was 600˚C for 1hr with a slow cooling rate in the furnace for 1 hr. The prepared composite (Al 2024/Alumina/Mn) manufactured by the powder metallurgy route used as a substrate cladding material. After sintering, the sample had been cut to the dimensions of the substrate that used in our work and these substrates had dimensions of (10mm ×10mm× 3mm), these dimensions were chosen by experiments that depended on the responsibility of the substrate to the laser beam. 17 substrates used to find the best parameters of the laser beam that used in our work, these parameters were average power (kW), frequency (Hz) and the pulse duration (ms).

In this work, 5 substrates had been used to find the optimum value of each parameter, and 2 substrates that used to find the response of the substrate to the laser beam, Figure 4 shows the substrate used in this work.

Figure 3: The green compact.

Figure 4: The substrate used in this work.

The powder of ceramic material was chosen as the clad material to enhance the surface properties of the base material. Our laser cladding experimental work was carried out by using pulsed wave (λ= 1.064 μm) Nd: YAG laser. (Aluminum- alumina) composites are used as the substrate. The substrates have been sandblasted and cleaned by using alcohol. Silicon Carbide of particle size about (220μm) was used as the reinforcement material.

The substrates gain their movement during the laser cladding process by using a CNC machine that gives micrometer distance scale. On the surface of the substrate, the laser beam focused as a linear shape. The laser beam width was constant as 1 mm, as seen in Figure 5. Three parameters of laser beam experimented and their effect on the substrate during the laser cladding process. These parameters are peak power, work frequency, and pulse duration. The pulse laser with an average power of 1.9 kW, frequency of 8 Hz with the pulse duration 5.3ms was selected as seen in Table 2.

The substrate speed was static to reach the desired pulse of the laser beam on the substrate (0.5 mm/s), this speed had been chosen experimentally, see Figure 6. The (0.03) g of silicon carbide with a small amount of alcohol is mixed to form the paste (to prevents the scatter of clad powder) that distribute on the surface of the substrate uniformly. The converging optical focal plane system was 8.6 cm.

The temperature that generated at the surface of the substrate during laser cladding process with SiC powder is 1702˚C according to equation below [15]

$$Tz,t = \frac{2Fo}{K}\{\left(\sqrt{\propto t}\right)\ \text{iefc}\left(\frac{z}{2\sqrt{\propto t}}\right)\} \quad (1)$$

T: The temperature at distance (z) and time (t),
FO: Surface power density,
K: Thermal conductivity coefficient,
∝: Heat capacity,
z: Depth of layer,
t: Time,
ierfc: Integral of the complementary error function.

Table 2: Best laser working parameters.

Pulse duration Tp(ms)	Pp pulse power (kW)	Freq frequency (Hz).	Energy (J)
5.3	1.9	8	9.78

4. Results and discussion

For characterization, the microstructural of the substrate, cladding layer and the interface, the Scanning Electron Microscopy (SEM) and

Energy Dispersive Spectrometry (EDS) were used. A process optimization involves the measurement and the parameters control for example velocity of the process, the power of the laser beam, and the diameter of the laser beam. The incensement of the processing velocity would cause the decreasing in the temperature of the surface, so the powder can't bind perfectly with a surface. Contrariwise, the decreasing in the processing velocity, the temperature of the surface becomes higher, which that causes more penetration and that leads to develop dilution and lesser mechanical properties. To evade such problems, the processing velocity value was used. In this process (laser cladding), the powders with bigger size required more heat to reach the necessary melting, this referred to the incensement in the power of the laser beam or lower in the velocity of the traveling of the sample. The powders with the particles have smaller size are melt easily. The device and the setup of the experimental work shown in Figure 5 and Figure 6 respectively.

By using the SEM image, the Al-Al_2O_3 composites with SiC powder microstructures were studies. The clad layer thickness of Al2024/Al_2O_3/Mn composite with SiC which appear growing at SiC layer after laser cladding process as shown in Figure 7 and this thickness is about 34.17 µm as average.

The clad layer thickness value shows a very significant role in the mechanical characterizations of the surface, when the thickness of the clad layer becomes large that decreases the micro-hardness of the surface because of the increase in the penetration. So the value of the thickness of clad layer must observe to obtain a high value of hardness. In Figure 8, the different surface topography magnifications of the clad layer are shown.

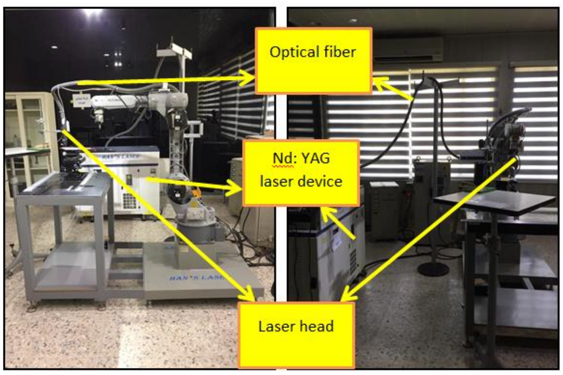

Figure 5: The device used in the laser cladding process

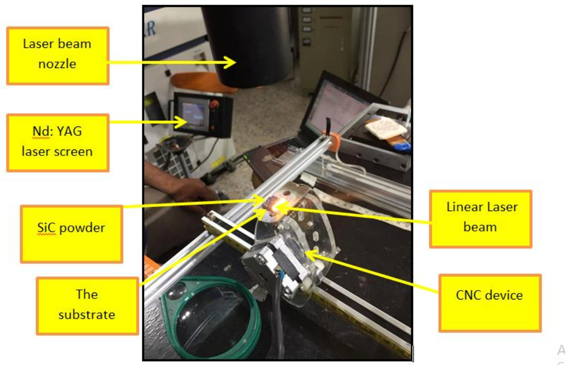

Figure 6: The experimental setup of preplaced laser cladding

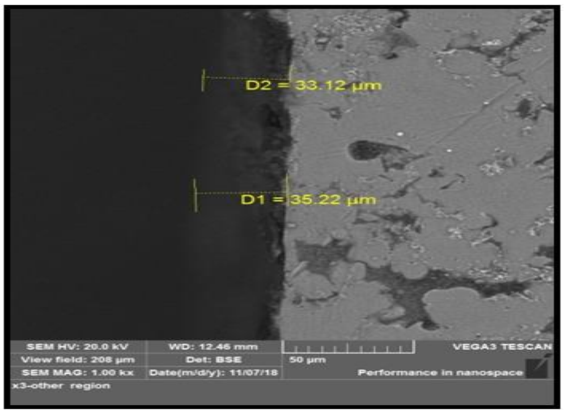

Figure 7: SEM for the Al2024/Al2O3/ Mn composite cladding with SiC powder cross-section

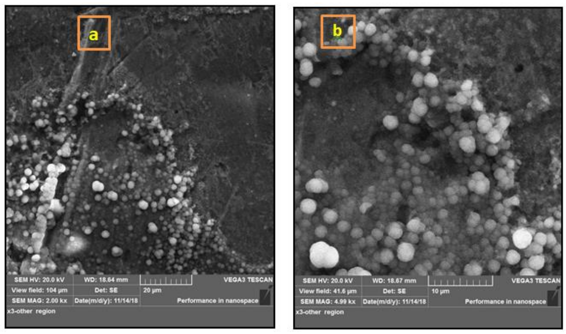

Figure 8: The SEM images for the Al2024/Al2O3/ Mn composite cladding with SiC powder (a) 2kX magnification, (b) 4.99kX magnification

The SiC percentage content appears into the Al2024/Al_2O_3/ Mn composite by using EDS analysis. The EDS analysis shows the mixed of the cladding powder particulate with the base completely. SiC spherical particles with average particles size (2µm), aggroupment in the surface of the cladding. Some of it penetrate the surface to a depth of the substrate. SiC appeared as Si and C in the EDS analyzed in Figure 9, and in EDS map in Si (blue) color, C (purple) color with homogenous distribution and agglomerate in some patterns, this map is shown in Figure 10.

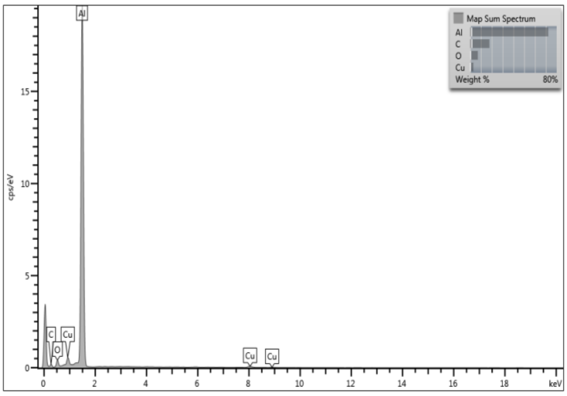

Figure 9: the EDS of the Al2024/Al_2O_3/ Mn composite with SiC powder

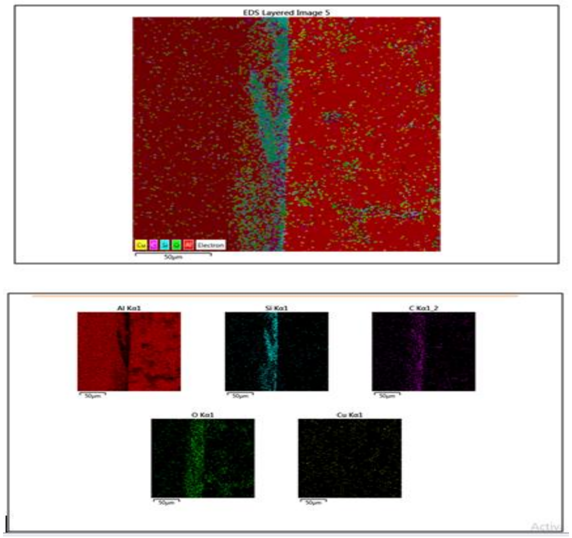

Figure 10: EDS a cross-section map

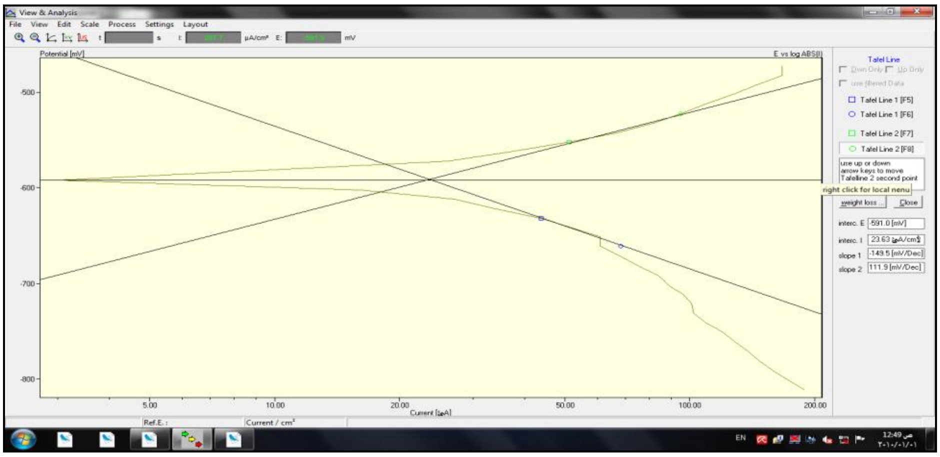

Figure 11(a): Tafel plot in the Al2024/Al_2O_3/ Mn composite substrate.

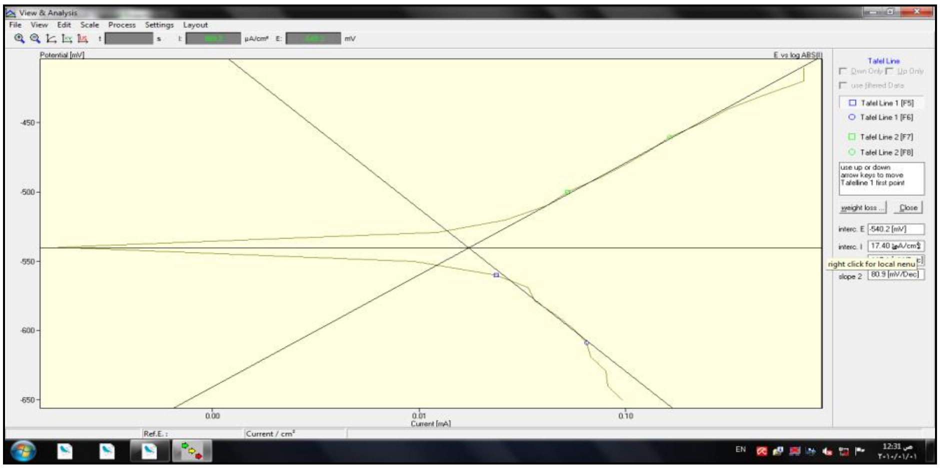

Figure 11(b): Tafel plot in the Al2024/Al2O3/ Mn composite substrate after cladding by SiC powder

The corrosion test of Al2024/Mn alloy prepared by powder metallurgy method and the corrosion test of Al2024/Al_2O_3/ Mn composite after cladding by SiC powder are shown in Figure 11(a) and Figure 11(b) respectively.

Figure 11(a) shows the Tafel plot for the substrate which has a SiC cladding layer and makes this substrate less active and near to the inert elements behaver to the corrosion attack.

Figure 11(b) shows the Tafel plot for substrate 6% Alumina that has not SiC cladding layer, make this specimen more active to the corrosion attack.

More active without a cladding layer

From Tafel plot:

Table 3: The results of the corrosion test for without cladding.

i_{corr} (mA/cm^2)	E (mV)	Slop 1(mV/Dec)	Slop 2	C_R (mpy)
23.63	-159.0	- 149.5	111.9	10.23

Less active with a cladding layer

From Tafel plot:

Table 4: The results of the corrosion test with cladding.

I_{corr}(mA/cm^2)	E (mV)	Slop1(mV/Dec)	Slop2(mV/Dec)	C_R (mpy)
17.4	- 540.2	- 117.1	80.9	7.54

Table 3 represented the corrosion test for the specimen without a cladding layer, the table indicates that the value of the current density is 23.63mA, the potential (E) -159mV and the corrosion rate (C_R) is 10.23 mpy, while Table 4 listed the result of corrosion test of the specimen with a cladding layer. The value of current density (i_{corr}) is 17.4mA and the potential (E_r) -540.2 mV and the corrosion rate is 7.54 mpy. The results of the corrosion test in the above tables show that the Corrosion resistance of specimen with cladding layer lave higher than specimen without cladding. The improvement of corrosion resistance is 35.67% with a cladding layer of SiC using a laser beam.

5. Conclusions

The Al2024/Al_2O_3/ Mn composite microstructure and properties that modified by laser cladding process depend on the parameters of the laser beam (pulsed Nd-YAG), mainly the density of the power of the laser beam and interaction time . Also, there was an improvement in resistance of corrosion about 35% for the aluminum-alumina composite with SiC cladding.

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