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LASER MELTING TREATMENT BY OVERLAPPING PASSES OF PREHEATED NICKEL ELECTRODEPOSITED COATINGS ON Al-Si ALLOY

D. PANTELIS, A. HOUNDRI*, S. POLYMENIS* and Y. CHRYSSOULAKIS*

Laboratory MSS/MAT, URA CNRS n° 850, Ecole Centrale de Paris, Grande Voie des Vignes, F-92295 Châtenay-Malabry cedex, France

**Laboratory of Physical Chemistry and Applied Electrochemistry, National Technical University of Athens, 9 Iroon Polytechniou Str., GR-15773 Zografou, Athens, Greece*

Abstract - Microstructure improvements of a Nickel electrodeposited Al-Si alloy were studied after high power laser melting treatment through a single pass or partially overlapping successive adjacent passes. In some cases laser melting treatment was preceded by a 5-hours heating of the specimens at 500°C in an Argon atmosphere furnace. Best results concerning microhardness, microstructural homogeneity, porosity elimination as well as adhesion of the nickel coating on the Al-Si alloy were achieved when the specimens were first subjected to heating at 500°C in an Argon atmosphere furnace for 5 hours and then submitted to a laser melting treatment through successive adjacent laser passes with an overlapping rate of 70%.

I. INTRODUCTION.

There are only a few methods available which can improve the surface properties of the alloys while keeping their bulk properties intact. One of these methods is based on the use of a high power laser beam, by means of which it is possible to melt a predeposited layer on a metal surface containing a particular alloying element. The above methods, however, are reported to display certain problems such as the appearance of cracks, pores as well as structural or chemical heterogeneity in the laser melted zone (LMZ).

The purpose of the present work is to determine any possible improvements in the microstructure and consequently the properties of nickel coated Al-Si alloys after treatment by a high power laser beam.

The nickel electrodeposition was carried out on a rotating Al-Si cathode in a Watts-type bath. The laser melting process consisted of a single laser pass as well as partial overlap among successive adjacent laser passes. This was preceded by heating the specimens at 500°C in an Argon atmosphere furnace so that the nickel coating improves its porosity and adhesion.

II. EXPERIMENTAL PROCEDURE.

II.1. Materials.

A hypoeutectic Al-Si alloy (AS7G03) was employed. Its chemical composition is given below in Table 1.

Table 1. Chemical composition of alloy used

Element wt%	Fe	Si	Cu	Mg	Mn	Ni	Zn	Ti	Pb	Sn
min		6.5		0.25				0.10		
max	0.2	7.5	0.10	0.40	0.10	0.05	0.10	0.20	0.05	0.05

This alloy was prepared by casting a commercially available Al-Si ingot of AS7G03 while adding NaF (0,05 to 0,08% w/w) in order to refine the microstructure of the alloy. The cast product was cut so that the specimens have a disc form (Diameter: 30 mm, Height: 3 mm).

II.2. Electroplating process.

Nickel electrodeposition was preceded by cleaning and conditioning treatments of the Al-Si alloy to provide uniform surface activity [1, 2].

Immediately afterwards the specimen was immersed in a Watts-type bath (300 g/L $\text{NiSO}_4 \cdot 7\text{H}_2\text{O}$, 35 g/L $\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$, 40 g/L H_3BO_3) and it was attached to the cathode which started rotating (1200 rpm). The exposed area of the specimen, that was to be electroplated, was a disc with a diameter of 20 mm. Pure nickel was used as anode, which was covered by a poly-acrylic material leaving an exposed disc area with a diameter of 20 mm.

The bath was operated at 50°C, the current density was 12 A/dm² and the pH was 2.4. The electrolysis duration was calculated according to Faraday's law and the current efficiency [3] so that the thickness of the deposit was 180 μm .

II.3. Laser melting process.

The laser treatment was carried out by using a CILAS 4000 continuous CO₂ laser beam (wavelength: 10.6 μm , maximum output power: 3.2. kW and annular beam energy distribution in TEM₀₁ mode). A special optical set-up was invented to protect the 250 mm focal length lens [4].

Preliminary tests were carried out to determine the values of the parameters for the laser melting process so that the optimal track, concerning porosity and cracking, was obtained. The values of these parameters were the following:

- Incident power density: $Q = 3 \cdot 10^5 \text{ W/cm}^2$
- Interaction time: $t = 66 \text{ ms}$

The defocused distance D_{def} remained constant and equal to 15 mm. Argon was used as an inert gas protection. When the process was carried out by successive adjacent passes, the overlapping rate was 35%, 50% and 70%.

II.4. Heat treatment preceding the laser melting process.

Before laser melting some specimens were heated at 500°C for 5 hours in a furnace in Argon atmosphere. This is the maximum temperature at which specimens can be heated without risking deformation of the substrate but mainly to remain under the Al-Si eutectic temperature (577°C) and Al-Ni eutectic temperature (640°C) [5] and so to avoid local melting.

This heat treatment was performed to improve the adhesion and to reduce the porosity of the deposited nickel layer, since the laser treatment eliminates only part of the pores.

III. RESULTS AND DISCUSSION.

III.1. Macroscale observations.

Adhesion was very poor before the laser treatment because of the initial condition of the substrate surface, the instantaneous alumina film formation and the negligible value of the interdiffusion coefficient due to the low electroplating temperature. After laser treatment, considerable porosity was observed in the laser melted zone near the interface between the laser melted zone and the substrate. This may be attributed to the following facts: a) substrate porosity resulting from casting, b) hydrogen adsorption during electrodeposition or from the air humidity during laser melting and c) argon adsorption from the protective atmosphere during the latter process [6, 7].

In order to eliminate the porosity, two further procedures were tested: laser overlapping passes and preheating.

Laser melting through successive adjacent passes with an overlapping rate of 35%, 50% and 70% reduced the total volume of the pores and pushed them towards the edges of the laser melted zone. This may be attributed to the presence of convection currents in the laser molten pool.

This phenomenon was more pronounced when the overlapping rate was increased up to 70%. A 5 hours preheating followed by a single laser pass reduced the number and size of the pores in the laser melted zone. This is probably due to the elimination of the gases during a process of sintering while heating. A 5 hours preheating followed by a process of laser overlapping passes completely eliminated the pores (figure 1). The total thickness of the laser melted zones lies between 350 and 630 μm .

Fig. 1.- Macrograph of nickel coating on Al-Si alloy with an area melted by three laser overlapping passes with a rate of 50%, preceded by a 5 hours heating at 500°C.

III.2. Microstructure characterization.

III.2.1. Preliminary heating at 500°C without laser treatment.

After heating the specimens at 500°C in an Argon atmosphere furnace for 5 hours a diffusion area appeared. Inside this area two distinct zones between the pure nickel coating and the Al-Si alloy substrate can be observed (figure 2). The first one being next to the nickel deposit showed a rather uniform thickness of about 5 μm . The second one being close to the substrate showed a non uniform thickness varying between 10 and 20 μm .

Figure 3 represents the Ni-Al-Si distribution versus depth carried out by means of energy dispersive spectrometry (EDS). The w/w ratio of Al/Ni calculated within the 5 μm of the former zone was 0.22 while within the 15 μm of the latter zone the above ratio was 0.60. According to the Al-Ni phase diagram [5] AlNi and Al₃Ni phases were identified for the 0.22 and 0.60 ratios respectively. Silicon diffusion is found to be negligible and this is attributed to its inclusion into the eutectic areas of the substrate.

Fig. 3.- Ni-Al-Si distribution versus depth carried out by means of EDS.

III.2.2. Laser melting without preheating.

After laser melting treatment, either through a single pass or successive adjacent overlapping passes, without preheating, the microstructure of the laser melted area is characterized by two distinct zones (figure 4).

X-ray diffraction analysis (XRD) was performed on the upper zone of the laser melted area. This zone was found to contain Al₃Ni₂ as the main phase as well as AlNi phase and Al in small percentages. The upper zone was removed

by polishing and XRD was performed on the new surface of the lower zone of the laser melted area. In this zone Al_3Ni was detected to be the main phase while AlNi phase and Al were found in small percentages.

The Al_3Ni_2 phase had a globular form while the Al_3Ni phase had a very fine dendritic form with an interdendritic space of 1 to 2 μm . Both Al_3Ni_2 and Al_3Ni phases were found to be contained in a matrix consisting mainly of an aluminum solid solution and to a lesser extent of the AlNi phase [8].

Fig. 2.- Microstructure of the diffusion area after a 5 hours heating at 500°C. Etching by HNO_3 50% w/w, CH_3COOH 50% w/w.

Fig. 4.- Microstructure of nickel coating after laser melting process and Al-Si alloy substrate. Etching by HNO_3 50% w/w, CH_3COOH 50% w/w.

III.2.3. Laser overlapping passes preceded by heating.

When the specimens were heated at 500°C for 5 hours and then subjected to successive adjacent laser overlapping passes the resulted melted area consisted of one single zone (figure 1).

XRD showed that in this zone the AlNi was the main phase while Al_3Ni_2 and aluminum were also detected in low percentages.

III.3. Microhardness measurements

Figure 5 shows microhardness measurements as a function of depth, starting from the surface of the specimen, before and after a single pass laser melting process. Microhardness increases considerably after laser surface melting. This certainly results from the formation of new nickel-aluminium phases and the grain refinement. Two comments may be attempted here:

- a fairly large dispersion of the microhardness values occurs in the laser melted zone which is certainly due to the microstructure heterogeneity.
- a rather abrupt transition is observed in the microhardness values starting from the surface of the melted alloy and continuing through the substrate. This is due to the small thickness of the heat affected zone and therefore the range of the diffusion phenomena is also limited [9].

Fig. 5.- Microhardness measurements as a function of depth on pure nickel electrodeposited coating before and after laser melting process without preheating. ($Q = 2 \cdot 10^5 \text{ W/cm}^2$, $t = 46 \text{ ms}$, $V = 2,17 \text{ cm/s}$, $d = 0,1 \text{ cm}$, load: 50g)

After a laser overlapping process, in the overlapping areas microhardness values fall because of the remelting effect, during which temperature differences are smaller and therefore cooling rates are lower resulting in greater grain size and reduced strains. The fall of microhardness values depends on the overlapping rate. When the overlapping rate was 70% the fluctuation of the microhardness values had a narrower amplitude compared to that with a rate of 35% and their mean value was lower.

Figures 6a, 6b and 6c represent microhardness measurements at a depth of 80 μm along the surface of the melted zone when the laser overlapping process was preceded by a 5 hours heating at 500°C. The overlapping rates were 35%, 50% and 70% respectively. In this case also the fluctuation amplitude was narrower (500 HV_{50g} versus 700 HV_{50g}) when the overlapping rate was 70% compared to those with a rate of 35% and of 50% and the mean value was also lower (550 HV_{50g} versus 1100 HV_{50g}). In areas showing high microhardness values (about 1300 HV_{50g}) there is a considerable risk of cracking [10].

Fig. 6.- Microhardness measurements taken at a depth of 80 μm under the surface along the laser melted zone without preheating. 3 parallel passes, $P = 2872 \text{ W}$, $v = 1 \text{ m/min}$, Load: 50 g.

- Overlapping rate: 35%.
- Overlapping rate: 50%.
- Overlapping rate: 70%.

IV. CONCLUSIONS.

- 1) After laser melting treatment, either through a single pass or successive adjacent overlapping passes, without preheating, the laser melted area consisted of two distinct zones. The main phase in the upper one was found to be Al_3Ni_2 while in the lower one the Al_3Ni phase was predominant.
- 2) Considerable porosity was observed in all the laser melted zones. Increasing laser overlapping rate reduced the extent of porosity but it did not eliminate it.
- 3) A 5 hours heating treatment of the specimens at 500°C , without laser melting, yielded two diffusion zones. The upper one consisted mainly of the AlNi phase while the lower one of the Al_3Ni phase.
- 4) Laser overlapping treatment preceded by a 5 hours heating at 500°C yielded completely pore-free laser melted zones consisting principally of the AlNi phase.
- 5) Microhardness values were considerably increased (at least twice) after laser melting treatment.
- 6) The narrowest amplitude of microhardness fluctuation as well as its lowest mean value were achieved when a laser overlapping treatment was employed with a rate of 70%.
- 7) Finally a laser melting treatment by successive adjacent laser passes with a rate of 70% preceded by a 5 hours heating at 500°C yielded best results concerning microhardness, microstructural homogeneity and porosity elimination as well as adhesion of the Nickel coatings on the Al-Si alloy.

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