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Microstructural and electrochemical characterization of laser deposited 18-10 austenitic stainless steel clad layers

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ABSTRACT

The present work reports on 18-10 stainless steel coatings produced by laser powder cladding technique on a mild steel. Uniform clad layers - about 600 μm thick - have been produced through partially overlapping single cladding tracks. The clad layers thus obtained show excellent adherence, no cracks, few porosities and good chemical homogeneity. The microstructure is dendritic or cellular. Dendrites or cells have an austenitic structure and a small amount of δ -ferrite is detected in the interdendritic areas. The corrosion resistance of the clad layers is tested by electrochemical techniques in various neutral or acidified aqueous saline media, deaerated or naturally aerated. In every case, the coatings show an excellent uniform corrosion resistance.

INTRODUCTION

In a previous work, we produced corrosion resistant coatings by laser melting of a twin nickel and chromium electrodeposit on a mild steel [1]. Surface alloys thus obtained were austenitic stainless steels with an excellent uniform corrosion resistance. Nevertheless, the laser alloying technique that requires predeposits is a very expensive method to get coatings on large surface areas. So other methods must be considered to produce such coatings. At present time, laser powder cladding is a technique frequently used to realize wear or corrosion resistant coatings on different materials [2, 3, 4]. The present work aimed to characterize the main metallurgical features of laser clad layers of type 304 austenitic steel deposited on a carbon steel. The investigated features included microstructure, compositional homogeneity, degree of dilution and corrosion behaviour.

EXPERIMENTAL PROCEDURE

The stainless steel powder used had a grain size of between 50 and 100 μm . The chemical composition of the powder is given in table 1. The substrate was 0.15 wt % carbon steel. The samples were of parallelepiped form (70 x 35 x 20 mm³). The cladding powder was transported in pressurised argon and injected under the laser beam near the substrate surface with an injection angle, with respect to the horizontal, of 55° as shown on figure 1. The laser used was a 1.5 kW continuous wave CO₂ laser. Laser device and processing conditions were described in more details elsewhere [5, 6]. Uniform clad layers - approximatively 600 μm thick - were produced through partially overlapping single cladding tracks. The following processing parameters were used : beam diameter 2 mm, injection nozzle diameter 2 mm, inter-track advance 1 mm, scanning speed 700 mm/min and powder feeding rate 6 g/min.

The microstructure was studied on cross-sectioned samples by means of optical and scanning electron microscopy, after etching in appropriate reagents. Chemical composition homogeneity was investigated using EDS microanalysis. X-ray diffraction structure determinations were also carried out.

The corrosion properties of the laser deposited 18-10 austenitic stainless steel clad layers have been tested by means of electrochemical techniques in four different aqueous saline media : deaerated 0.1 M Na₂SO₄ (neutral and pH=3) and 30 g/l NaCl (aerated and deaerated). The tests were carried out on clad layers either in the as-produced conditions or after planing. For comparison, carbon steel and massive 304 stainless steel were also tested. Details about used techniques, sample preparation and experimental procedure have been published in [1].

MICROSTRUCTURAL CHARACTERIZATION

The optical micrograph of figure 1 shows that the clad layers obtained had a uniform thickness and were free of cracks. They were also nearly free of porosities except sometime for cavities between adjacent overlapped tracks near the cladding / substrate interfaces, as shown on figure 2.

Figure 1 : Longitudinal-section optical micrograph of the clad layer (3% nital etching)

Figure 2 : Cross-section secondary electron image near cladding / substrate interface

The substrate was melted to a depth of less than 10 μm in such a way that the dilution of the cladding material was almost zero. EDS chemical composition determinations, reported on table 1, show that the chemical composition of the clad layer is practically the same as that of the injected powder, what confirms that the dilution was weak. Nevertheless, the metallurgical bonding between the clad and the substrate was very good. The concentration profiles for the main elements through a cross section of the clad layer are drawn on figure 3. They show the correct iron, nickel and chromium homogeneity in the coating.

Table 1 : EDS Chemical composition measurements (weight %)

Analysis	Fe	Si	Ni	Cr	Balance
powder 304	67.6	1.0	11.4	19.7	0.3
clad layer	68.4	0.9	11.3	19.0	0.4
austenitic cells	67.8	0.9	12.4	18.4	0.5
ferritic rich areas	68.8	0.5	8.0	21.8	0.9

Figure 3 : Fe, Ni, Cr concentration profiles obtained through a cross section by EDS

X-ray diffraction analysis (figure 4) showed that the structure was mainly austenitic, with a low content of δ -ferrite; it also revealed a texture effect for austenite, γ (200) peak being higher than γ (111) one. Metallographic investigations pointed out that the clad layer microstructure was dendritic or cellular with an interdendritic distance and a cell size of between 5 and 10 μm as shown on figure 5.

Figure 4 : X-ray diffraction pattern

Figure 5 : Cross-section secondary electron image (HCl + 4% H_2O_2 etching)

Dendrites and cells had an austenitic structure and it can be seen on figure 6 that δ -ferrite has been formed at the end of the solidification in the intercellular spaces containing a higher chromium content as revealed by EDS microanalysis (table 1). Nevertheless δ -ferrite was not uniformly distributed as shown on figure 7. Indeed in each track, due to overlapping, a region is heat affected by the following deposit track, in such a way that an autenitisation occurs leading to a fully austenitic structure after cooling. Hence two different structures are observed on each side of the cladding / cladding overlapped interface (Fig. 7).

Figures 6 et 7 : Optical micrographs of the clad layer surface (Kalling reagent etching)

CORROSION BEHAVIOUR RESULTS

Table 2 summarizes the observed results in the various media and gives both the free corrosion potential E_{cor} , determined after stabilization, and the corrosion current density obtained by extrapolation of the polarization curves recorded at a 1 mV/s rate, after obtaining stabilized E_{cor} .

Table 2 clearly shows that the coated specimens present a corrosion resistance better than the substrate (mild steel carbon), and as good as massive 304 stainless steel, even better in case of immersion inside neutral aerated NaCl solution (30 g/l). This behaviour is even enhanced in case of surface polishing, the clad layer being thick enough to allow this post-treatment. The corrosion potential values are even more noble in this case, maybe due to the elimination of surface impurities, defects or chemical homogeneity lack. Indeed, the laser treatment leads to realize an overlapped coating.

Table 2 : Electrochemical measurements

specimen	E _{cor} (mV/ SCE)				I _{cor} (μA /cm ²) #			
	Deaerated Na ₂ SO ₄ *		neutral NaCl **		Deaerated Na ₂ SO ₄ *		neutral NaCl **	
	neutral	pH = 3	Deaerated	aerated	neutral	pH = 3	Deaerated	aerated
mild carbon steel	- 750	- 600	- 770	- 570	1.0	30.0	1.2	20.0
304 stainless steel		+ 324		- 370		0.2		3.0
304 layer laser deposited (no polishing)	- 427	- 470	- 481	- 221	1.5	6.0	0.2	0.9
304 layer laser deposited after polishing	- 70	- 126		- 144	0.02	0.15		0.4

1 μA / cm² ==> 10 μm / year* Na₂SO₄ 1.0 mol.L⁻¹ -- ** NaCl 30 g.L⁻¹

A long immersion test has been carried out in aerated NaCl solution with a clad 304 layer specimen without polishing. The results are given in table 3. The I_{cor} values are determined from polarization curves recorded only near the corrosion potential value (-100 up to + 75 mV/ E_{cor}) in order to prevent the risk of artificial corrosion. We can notice that the corrosion rate is very low during the whole immersion duration, even if the E_{cor} values become more negative.

Table 3 : Electrochemical results of long immersion test

	E _{cor} (mV/ SCE)	I _{cor} (μA /cm ²)
at the immersion	- 184	0.09
after 24 h of immersion	- 157	0.01
after 32 h of immersion	- 286	0.10
after 48 h of immersion	- 345	0.15

CONCLUSION

The laser powder cladding technique allowed to produce 18-10 stainless steel clad layers with a good metallurgical bond with the substrate and a low level of dilution. These layers were sound, crack-free and with few porosities so that the corrosion properties could be tested. In every case, even in an aerated saline medium, the corrosion current densities were very low indicating an excellent uniform corrosion resistance, comparable to, or even better than, that of a massive stainless steel of the same type.

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