CHARACTERIZATION OF NICKEL-BASED C276 ALLOY COATINGS by PLASMA TRANSFERRED ARC (PTA) on DIFFERENT STEEL SUBSTRATES

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ABSTRACT

Nickel-based coatings by plasma transferred arc (PTA) for protection of components are widely applied to withstand operations under corrosion in different media. This paper characterized Nickel-based C276 alloy coatings obtained by Plasma Transferred Arc (PTA) on two different substrates, AISI 316L and API 5L X70 steels, correlating their features to hardness. Coatings were deposited utilizing three different intensity current levels, 120, 150 and 180 A and were characterized by optical, Laser confocal and scanning electron microscopy and X-ray diffraction. Vickers hardness profiles on transversal section were carried out. Produced coatings exhibited a microstructure of austenite (FCC) dendrites with interdendrictic regions with carbides. Dilution levels from 4,9 to 41,5 % leaded to hardness ranging from 225 to 283 $HV_{0,5}$*, showing coatings dependence on intensity current level and substrate.*

Keywords: Microstructure, Hardness, Nickel-based Coatings, C276 Alloy, Plasma Transferred Arc.

1. INTRODUCTION

Coatings have been applied for surface components protection in order to extend the service life in different applications. On oil extraction facilities different and aggressive operation environments are present: corrosion in different media, stress corrosion cracking (SCC) and / or corrosion-fatigue (1,2).

Nickel-based alloys are used to extend service life of engineering components in many industrial areas, including chemical processing, marine engineering and oil and gas industry, mainly involving corrosion resistance and/or heat resistance (3).

The nickel-chromium-molibdenum alloy, Hastelloy C276, presents high molybdenum content on chemical composition, added to improve chloride attack resistance and resulting in higher pitting resistance. Tungsten is a strong solid solution strengthener and, together with molibdenum, provides high strength without heat treatment. Tungsten, as a strong carbide former, also contributes to enhance mechanical properties throughout formation of this hardening phase (3). To improve both, oxidation and carburization resistance at temperatures exceeding 760^{0}C, chromium content higher than 15% is used, promoting the formation of a protective oxide on the surface. The nickel base of the alloy helps the retention of formed surface protective layer, especially on cyclic exposures at high temperature (3, 4–8). Besides, NiCrMoW alloy also exhibits good weldability, facilitating hardfacing procedures.

Cladding process by rolling is largely utilized to produce components attending these corrosion requirements. However, welding processes like plasma transferred Arc (PTA) have been studied as an alternative due to the high quality of deposits (3, 9-11).

However, the effect of deposition parameters and chosen substrate has to be taken into account when a welding process is involved due to dilution that alters chemical composition of coatings and, consequently, microstructure, impacting on coatings performance (5– 8, 12, 13).

This work evaluated the effect of the main arc deposition current and steel substrate on characteristics of NiCrMoW alloy (Hastelloy C276) coatings by plasma transferred arc. For such study, alloy C276 coatings were produced on AISI 316L and API 5L X70 steels and characterized by tracks geometry, microstructure and properties.

2. MATERIALS AND METHODS

Nickel-based alloy was deposited by PTA using atomized powder form with grain size ranging from 90 to 150μm on AISI 316L stainless steel 12,5mm thick and API 5L X70 steel 10,0mm thick plates, with chemical composition shown in Tab. 1.

Tab. 1. Chemical composition of the materials used (wt.%)

Ni-Based Alloy									
Element	**Ni**	**Cr**	**W**	**Mo**	**C**	**Fe**	**V**	**Si**	**Mn**
NiCrMoW C276 alloy	Bal.	15,4	4,5	15,9	0,10	3,1	0,6	0,6	1,1
Steel Substrates									
Substrate 1	**C**	**Mn**	**Si**	**P**	**S**	**Cr**	**Ni**	**Mo**	**Al**
AISI 316L	0,02	1,35	0,43	0,03	0,008	16,78	10,1	2,1	0,002
Substrate 2	**%C**	**%Mn**	**%Si**	**%P**	**%S**	**%Cr**	**%Ti**	**%Nb**	**%V**
API 5L X70	0,17	1,40	0,21	0,02	0,003	0,005	0,015	0,041	0,034

PTA processing parameters used to produce coatings were: shielding gas: 2l/min; protection gas: 15 l/min; powder feeding gas: 2 l/min; main arc current: 120, 150 and 180A; constant powder feed rate in volume; travel speed: 100 mm/min; distance torch/substrate: 10 mm and electrode diameter: 3,125 mm.

Coatings were characterized in the as-deposited condition by microstructure analysis including laser Confocal and scanning electron microscopy on transverse cross section of coatings and X-ray diffraction (XRD) analysis on the top surface. XRD used $K_{\alpha}Cu$ from 20 to 120º with time of exposed channel of 3s. Vickers hardness profiles were taken on the transverse cross-section.

3. RESULTS AND DISCUSSION

Visual inspection of deposited coatings on both substrates, AISI 316L and API 5L X70, revealed smooth surfaces with no macroscopic processing defects like porosities, cracks, lack of fusion and undercut.

Processing the NiCrMoW C276 alloy resulted on coatings with thickness (t) ranging from 2,1 to 3,1 mm, width (W) ranging from 9,1 to 11,0 mm and wettability angle (Θ) varying from 43,3 to 64,9°. Single track NiCrMoW deposits processed on AISI 316L resulted better wettability, confirmed by the lower Θ, lower overlay thickness and higher width compared to coatings processed on API 5L X70, Table 2. Therefore, to protect large areas considering overlapping of tracks the AISI 316L steel would be a better choice, considering weldability.

Tab. 2. Geometry and dilution of welding tracks for NiCrMoW coatings.

Substrate	**Evaluation**	**Deposition Current (A)**		
		120	**150**	**180**
AISI 316L	Dilution	22,3	35,9	41,5
	Thickness (t)	2,9	2,4	2,1
	Width (W)	9,1	11,9	11,9
	Wettability Angle (Θ)	63,0	46,6	43,3
API 5L X70	Dilution	4,9	13,2	25,4
	Thickness (t)	2,8	3,1	2,8
	Width (W)	8,4	9,7	11,0
	Wettability Angle (Θ)	64,9	51,0	48,0

As expected, dilution increased with the deposition current, varying from 4,9 to 41,5%, Table 2. The higher dilution observed for coatings deposited on AISI 316L was a consequence of the lower thermal conductivity of this austenitic stainless steel (4, 11, 12, 13).

Coatings hardness depended on deposition current intensity throughout dilution level and refinement degree of microstructure. The lower thermal conductivity of AISI316L induced higher dilution and, as a consequence, lower coatings hardness, Figure 1.

As the dilution increased, iron contamination induced decreasing on main alloying elements molybdenum and tungsten, reducing solid solution hardening and then coatings hardness. Besides, increasing the deposition current, higher heat imput on welding is generated and, consequently, coarsened dendrites are formed, reducing the coatings hardness (13).

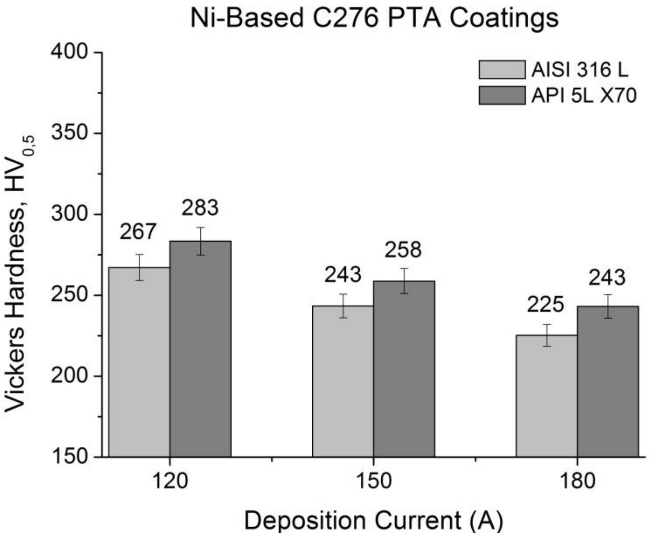


Fig. 1. Average hardness of Ni-based C276 alloy coatings.

Coatings microstructure on the transverse cross section assessed by laser Confocal and scanning electron microscopy revealed a hypoeutectic structure of nickel dendrites and an interdendrictic region showing carbides for all coatings, independent of current levels and utilized substrate, Figure 2. As expected, the most refined microstructures were obtained with the lower deposition current, 120A, and for API 5L X70 steel, due to the its higher thermal conductivity. Higher carbon contents of API5LX70 (0,17 wt%) steel influenced the formation of higher amount of carbides when compared to AISI316L (0,02 wt%) steel (4, 5).

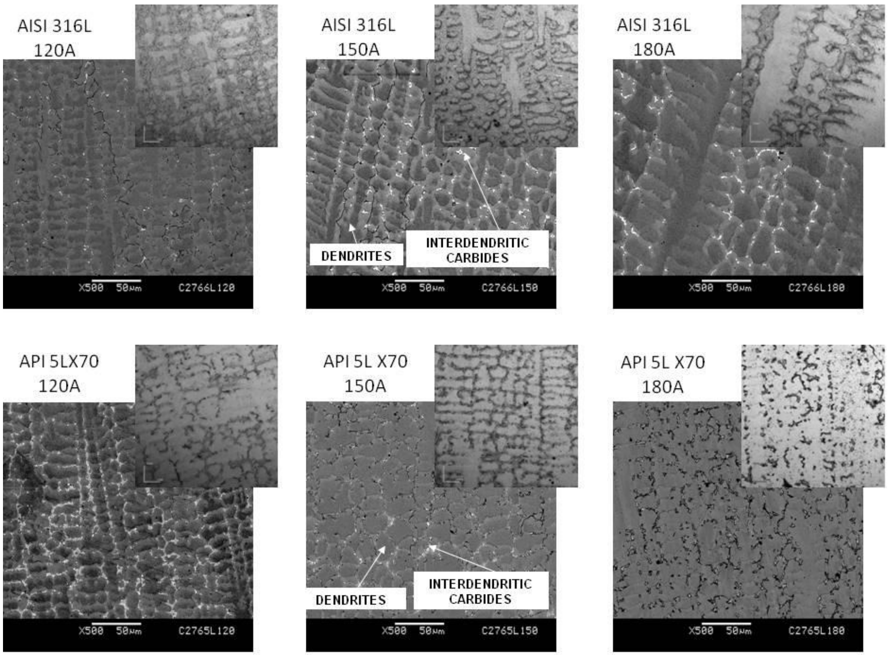
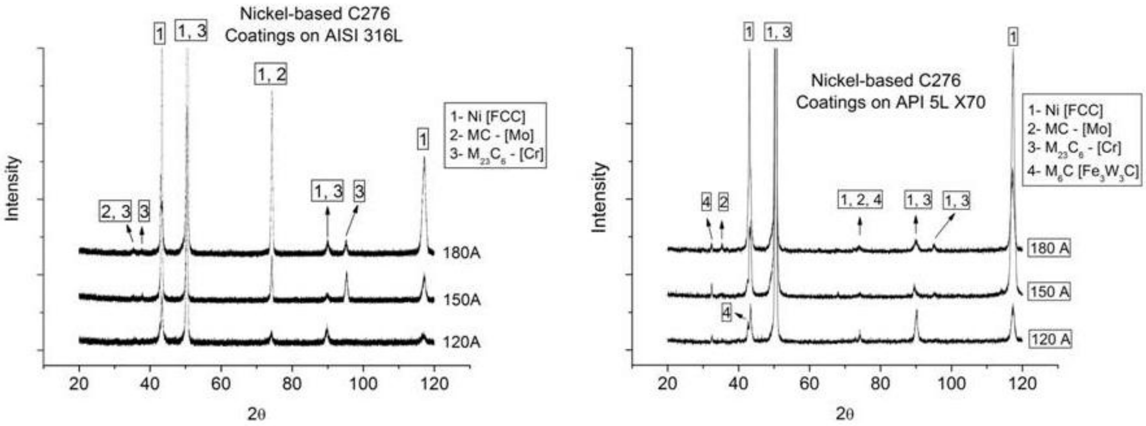


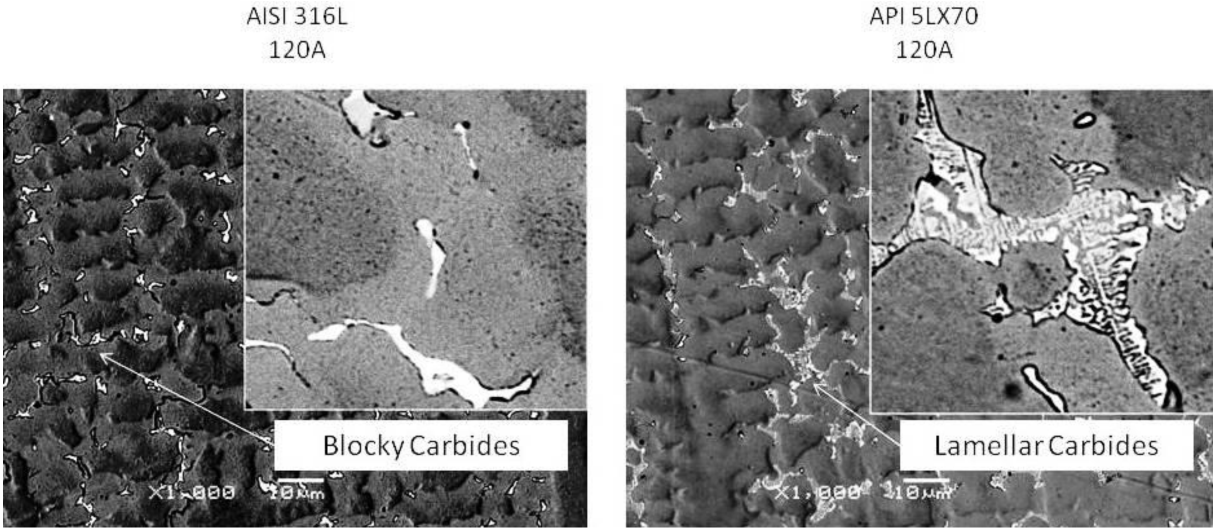
Fig. 2. Microstructure of Ni-based alloy coatings.

X-ray diffraction analysis revealed different carbides on interdendrictic region, indicating dependence between the phases formed and substrate, Figure 3. Coatings deposited on AISI 316L developed MC (M: molybdenum) and $M_{23}C_6$ (M: chromium) blocky carbides, as a consequence of higher dilution and lower cooling rate on solidification. Deposits on API 5L X70 showed MC (M: Molibdenum) and $M_{23}C_6$ (M: Chromium) blocky carbides and M_6C (M: Iron and Tungsten) with lamellar morphology carbides were formed on deposition, following literature predictions (3). Lamellar morphology of M_6C resulted from the lower dilution and higher cooling rates on solidification, Figure 4.



(a) (b)

Fig. 3. X-ray diffraction analysis of Nickel-based C276 coatings.



(a) (b)

Fig. 4. Carbides morphology for coatings on: (a) AISI 316L and (b) API 5L X70.

4. CONCLUSIONS

- Processing of Ni-based alloy C276 by PTA presented sound coatings with good weldability. Dilution increased with deposition current and the higher values were observed for coatings on AISI 316L as a consequence of its low thermal conductivity.
- Coatings hardness was dictated by the dilution and refinement degree, both influenced by steel substrate and deposition current. So, hardness decrease was measured for higher deposition current and the lower values associated to deposits on AISI 316L.
- The substrate influenced the phases formed, as the dilution and solidification cooling rate was dictated by thermal conductivity of steel substrate, inducing different kind of carbides and morphology on interdendrictic region.

5. ACKNOWLEDGEMENTS

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