

PTA hardfacing of Nb/Al coatings

(Revestimentos Nb/Al depositados por PTA)

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Abstract

Hardfacing is widely applied to components yet the majority of the welding techniques available restrain the variety of hard alloys that can be deposited. Plasma Transferred Arc hardfacing offsets this drawback by using powdered feedstock offering the ability to tailor the chemical composition of the coating and as a consequence its properties. The high strength and chemical inertia of aluminide alloys makes them very suitable to protect components. However, the strong interaction with the substrate during hardfacing requires analysis of each alloy system to optimize its properties and weldability. This work analyzed coatings processed with a cast and ground Nb40wt%Al alloy and the effect of Fe and C on the coatings features. It confirmed that sound Nb aluminide coatings can be processed by plasma Transferred arc hardfacing and will have a strong interaction with the substrate, which determines the final microstructure and properties of coatings. Final remarks point out that during Nb-Al coating tailoring the interaction with the substrate has to be considered at the early stages of design process.

Keywords: Aluminides; hardfacing; coatings, PTA; Nb/Al.

Resumo: Revestimentos soldados são amplamente usados para proteger componentes mecânicos entretanto a maioria das técnicas de soldagem disponíveis restringe a variedade de ligas de alta resistência que podem ser depositadas. O processo de plasma por arco transferido permite ultrapassar esta limitação ao utilizar material de adição na forma de pó, oferecendo a possibilidade de se customizar a composição dos revestimentos e em consequência as suas propriedades. A elevada resistência mecânica e inércia química das ligas de aluminetos tornam estas ligas atrativas para a proteção de componentes diversos. Entretanto a grande interação com o substrato que ocorre quando do processamento exige que para a otimização das propriedades e soldabilidade seja realizada uma análise de cada sistema liga e substrato. Neste trabalho foram processados e caracterizados revestimentos utilizando uma liga fundida e triturada de Nb40wt%Al e analisado o efeito do Fe e do C nas características dos revestimentos. O trabalho confirmou que é possível processar revestimentos íntegros de Nb40wt%Al por PTA e que ocorre uma forte interação com o substrato, que vai determinar a microestrutura final e as propriedades do revestimento. Destaca-se que na customização de revestimentos de Nb-Al a diluição tem de ser considerada logo nos estágios iniciais do projeto do revestimento.

Palavras-Chave: Aluminetos, revestimento soldados, plasma por Arco transferido, Nb/Al.

1. Introduction

The need for more efficient processes imposes a permanent search for materials that can better withstand the aggressive operating conditions of processing equipment [1, 2]. Protecting components includes enhancing surface properties to attend chemical and/or mechanical operating requirements. Therefore the selection of the processing technique and the surface alloy are of fundamental importance as failure most frequently initiates at the component surface. Hardfaced coatings act as a protection and a sacrificial material, wearing out without compromise the structure of the component. Hardfacing is widely applied to components yet the majority of the welding techniques available

restrain the variety of alloys that can be deposited. Plasma Transferred Arc (PTA) hardfacing offsets this drawback using powdered feedstock. The high quality coatings with low dilution, low distortion and fine microstructure, have been reported before [3,4] but little has been mentioned regarding the ability to tailor the chemical composition of the coating and as a consequence its properties. The potential of PTA to develop surfaces that meet specific requirements dictated by each application (tailoring) is an important innovation on hardfacing procedures particularly for the deposition of hard alloys that are difficult to fabricate as wire or rods.

There is an escalating interest on aluminide alloys due to their high strength and chemical inertia [5]. The former derives from the ordered structure of compounds and the latter from the alumina film that forms on the surface of these compounds. Similar to the Ni and Fe aluminides, Nb aluminides also form stable and high strength compounds and several studies have been focus on the processing of these alloys as coatings [6-

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Table 1. Materials and PTA processing parameters

Materials		Processing parameters	
Feedstock	Substrate	Current (A)	Other
Nb40wt%Al	AISI 1020	170A	Plasma gas flux: Ar 2,0 l/min; Shielding gas flux: Ar 15 l/min; Feeding gas flux: Ar 2,0 l/min; Stand off distance 10 mm; Scanning speed: 10 cm/min Feeding rate: constant vol/min
(Nb40wt%Al)+ 40wt%Fe	AISI 1045	100A and 120A	
	AISI1020		

9]. Studies evaluated carbides precipitation, Laves phase and other intermetallic as strengthening particles in ordered Fe/Al/Nb alloys [10,11] but the more attractive compounds of these systems are Nb₃Al [12] and NbAl₃ [13].

Previous work [14, 15] has suggested that the processing of aluminide PTA coatings does not respond to processing parameters in the same manner as superalloy coatings. In particular, a very high dilution has been reported and associated with the exothermal synthesis of the aluminides, the interaction of the plasma arc with the feedstock and with the melt pool. Therefore, to optimize processing parameters it is a key factor to anticipate the effects of the interaction between the feedstock and the substrate. This work analyzed Nb/Al coatings processed with a cast and ground alloy and the changes that may arise from the presence of elements from the substrate steel. In particular, the effect of Fe and C on the coatings features is discussed.

2. Experimental procedure

Coatings were processed by plasma-transferred arc (PTA) on (100 x 50 x 12mm) steel plates, using the processing parameters and feedstock shown on table 1. The feedstock was dried at 110°C in an air furnace for 1 hour before deposition.

These materials and processing parameters were combined to carry out two sets of tests to analyze the effect of two elements known to have a strong affinity with at least one of the elements in the Nb-Al deposited alloy:

- Fe: mixing Fe powders with the cast and ground Nb40wt%Al alloy and
- C: deposition of the (Nb40wt%Al)+ 40wt%Fe powder mixture on two carbon steel plates AISI 1020 and AISI 1045.

Deposits were analyzed regarding their soundness by visual inspection. Rockwell hardness on the face of coatings and Vickers microhardness (HV0,5) on the transverse section were carried out. The later considered the average of five profiles, going from the external surface and crossing the fusion line into the substrate until measurements exhibited similar values to that of the as-received steel plates.

X-ray diffraction analysis with Cu K α was performed on the top surface of coatings for phase identification. Specimens were prepared following standard metallographic procedures of grinding on silicon carbide papers and polishing with alumina suspension. Microstructure on the transverse section was revealed by immersion samples in a solution of 2,5 ml HNO₃; 2,5 ml HCl and 0,5 g picric acid solution, in 100ml alcohol, for 22 sec. Subsequently, specimens were evaluated by optical and scanning electron microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) semi-quantitative chemical composition analysis. Dilution, as a measure of the fraction of the substrate that melted and mixed with the deposited material, was calculated according to Eq.1.

$$\%Dilution = \frac{B}{A} \times 100 \quad (1)$$

Figure 1 shows a schematic representation of the procedure used to determine the dilution on the transverse section of sample.

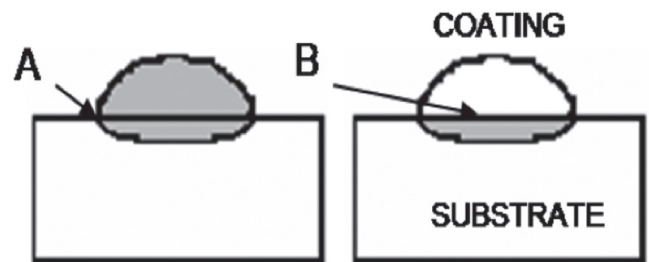


Figure 1. Schematic representation of areas used to calculate dilution of coatings where A is the total melted area and B the melted area of the substrate steel

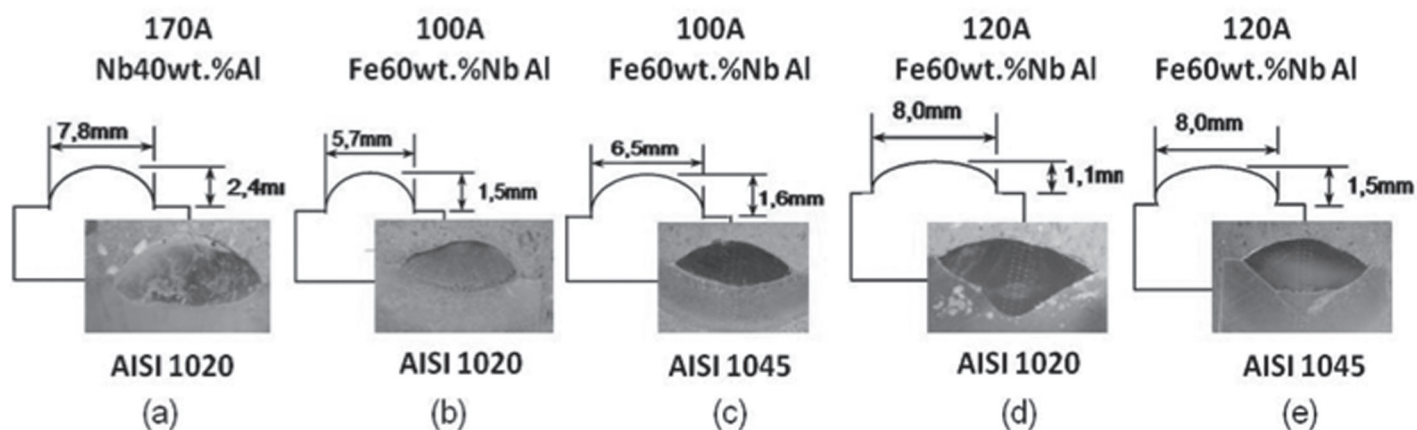


Figure 2. Cross section and geometric features of deposits (a) processed with the Nb/Al cast and ground alloy on AISI 1020 with 170A, (b) Fe/Nb/Al powder processed on AISI 1020 with 100A, (c) Fe/Nb/Al powder processed on AISI 1045 with 100A, (d) Fe/Nb/Al powder processed on AISI 1020 with 120A, (e) Fe/Nb/Al powder processed on AISI 1045 with 120A.

3. Results and Discussion

3.1. Processing Nb40wt%Al alloy

The Nb40wt%Al alloy deposited on the AISI 1020 plates resulted on high hardness homogeneous coatings measured by the uniform layer hardness $61\text{HRC}\pm 1$. The first evidence of the development of Nb aluminide compounds in the coatings also accounts for the low toughness of coatings and transverse cracks evenly spaced along the deposited layer were observed.

In spite of the high hardness, coatings exhibit a high dilution level, 39%. Although this value agrees with results reported for aluminide coatings [14,15] it contrasts with the low dilution reported for Co and Ni based superalloys coatings processed by PTA on low carbon steels [16,17]. The high dilution of aluminide coatings has been associated with the exothermal synthesis of the aluminides compounds, and the interaction of the plasma arc both with the substrate and with the feedstock [15].

Although in agreement with previous dilution results it is important to investigate the influence of the interaction with the substrate on the coating characteristics.

Deposition of the mixture of the Nb40wt%Al cast and ground alloy with Fe powders was carried out with a low deposition current (100A and 120A) aiming to reduce dilution. Sound coatings without cracks or porosity, were processed with 100A current intensity on the two substrates steels. The observed increase on coatings toughness can be associated with a larger fraction of the solid solution Nb-Fe-Al phase, expected to form [18]. Coatings homogeneity assessed by the hardness measured along the face of the deposits ($64\text{HRC}\pm 2$ and $59\text{HRC}\pm 3$, for deposits processed respectively on AISI 1020 and AISI 1045 plates) was not compromised. However, the predicted reduction on dilution with the decrease of deposition current [17, 19] did not occur and measurements on coatings processed with 100A revealed dilution levels of 38% and 44% for the coatings processed on AISI 1020

and AISI 1045, respectively.

Although sound coatings were also produced with the 120A, the increase on the deposition current caused a decrease on the coatings hardness and on the uniformity of coatings assessed by the dispersion on the hardness values, $55\text{HRC}\pm 5$ and $58\text{HRC}\pm 4$, for deposits on the AISI 1020 and AISI 1045 plates. A change of behavior was also identified on coatings dilution and significantly higher values were measured: 63% and 65% on coatings processed on AISI 1020 AISI 1045, respectively. These results suggest that the increment on the deposition current increased the interaction of the plasma arc with the feedstock allowing for some species to ionize increasing the energy of the arc [15]

Assessment of the geometry of deposited layers confirms the higher wettability of coatings processed with the powder mixture containing Fe in spite of the lower deposition current used, figure 2. The higher penetration depth observed on the transverse cross section of coatings corroborates with the assumption that an increase on the plasma arc energy occurred.

Microhardness profiles were analyzed to further assess the influence of Fe and C on the coating characteristics. Figure 3 compares the profiles for the coatings processed with the Nb40wt.%Al cast and ground alloy, with and without Fe, on steel plates with different carbon content.

Microhardness near the surface confirmed the previous ranking gained from the macrohardness measurements: the higher hardness ($725\text{HV}\pm 22$) of coatings processed with the Nb40wt.%Al alloy, show a small reduction when Fe is added to the alloy and the deposition was carried out at 100A ($701\text{HV}\pm 4$ on AISI 1020 and $678\text{HV}\pm 24$ on AISI 1045). Further hardness reductions were measured when processing with 120A ($586\text{HV}\pm 20$ on AISI 1020 and $474\text{HV}\pm 22$ on AISI 1045). Deposits processed with the same feedstock material follow a similar trend to that predicted for the effect deposition current on superalloys, which has been associated with the

faster solidification rates and lower dilution levels observed on coatings processed with a lower current.

It is interesting to notice that coatings processed on AISI 1045 plates exhibited a lower hardness, despite the larger fraction of Nb carbides expected to form. Differences on the heat-affected zone of AISI 1045 steel were also identified, where a hardness peak occurred associated with the martensitic transformation.

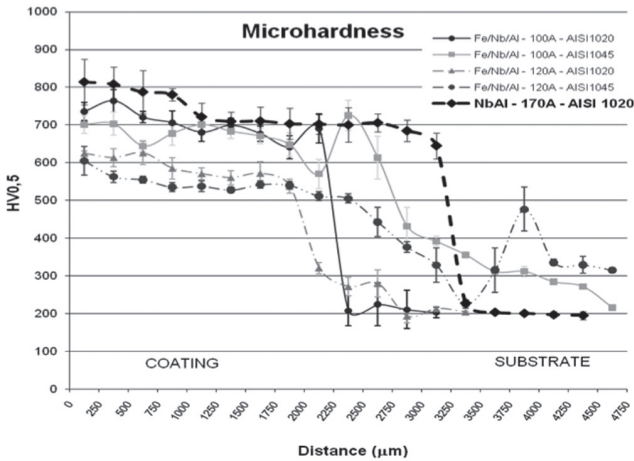


Figure 3. Microhardness profiles for coating processed with the cast and ground alloy Nb40wt.%Al on AISI 1020 and for Fe-Nb-Al coatings processed on AISI 1020 and AISI 1045 with 100A and 120A.

3.2. Microstructural features

The presence of low toughness aluminide compounds and carbides, identified by X-Ray diffraction analysis on the coatings processed with the cast and ground Nb40wt.%Al alloy, figure 4, explains the observed transverse cracks.

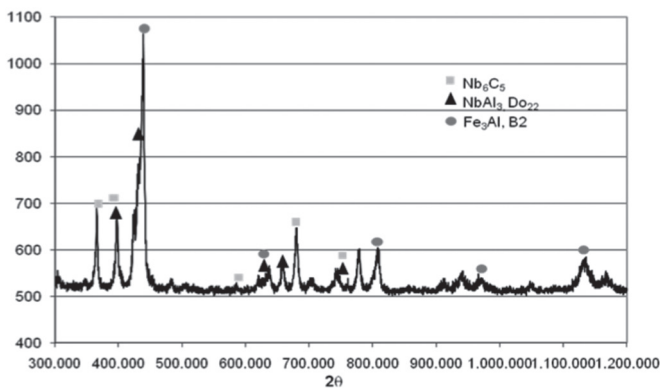


Figure 4. X-ray diffraction tests for the coating processed with the cast and ground Nb40wt.%Al alloy.

The analysis also confirmed the strong interaction with the

substrate steel revealed by the presence of the iron aluminide compound, Fe_3Al , and the Nb_6C_5 carbides. Moreover, the high dilution levels measured suggest that the aluminide compounds are probably Nb rich $(\text{Nb,Fe})\text{Al}_3$, and Fe rich $(\text{Fe,Nb})_3\text{Al}$ complex intermetallics.

The measured coating microhardness ($725\text{HV}\pm 22$) is in accordance with the reported hardness of the pure intermetallic NbAl_3 , 600HV, produced by Self-propagating High-temperature Synthesis (SHS) from Nb and Al plates [20]. And although it has been reported that the compound Fe_3Al deposited by TIG exhibits a significantly lower hardness, ranging from 320 to 360HV depending on Al levels [21], it did not affect significantly the coating hardness supporting the hypothesis that these are complex Fe rich aluminides, $(\text{Fe,Nb})_3\text{Al}$.

The effect of Fe on coatings is also perceived from the X-ray diffraction analysis, figure 5, as Nb rich aluminide is no longer identified and the $\text{Fe}_{0.2}\text{Nb}_{0.8}$ solid solution forms. It is interesting to notice that similar phases were identified when depositing Fe/Nb/Al powder mixture: $(\text{Fe,Nb})_3\text{Al}$, Fe/Nb rich solid solution and Nb_6C_5 carbides, regardless of the deposition current and the chemical composition of the substrate.

Further understanding of the effect of carbon and Fe on coatings was gained from the analysis of their microstructure. Figure 6 shows the cross section of the coating processed with the cast and ground alloy on AISI 1020 steel and EDS carried out on the different phases. A solidification structure with rich Nb, $(\text{Nb,Fe})\text{Al}_3$, dendrites, a rich on Fe, $(\text{Fe,Nb})_3\text{Al}$ interdendritic region and rich Nb precipitates of Nb_6C_5 (bright spots) can be observed.

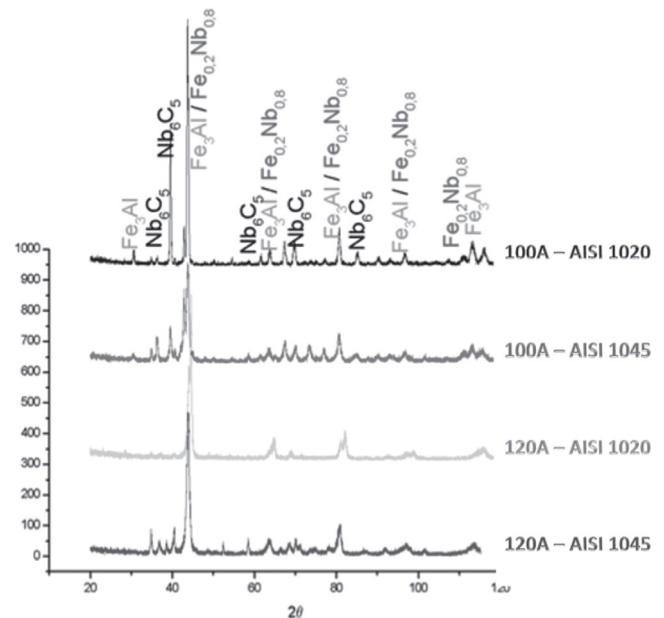


Figure 5. X-Ray diffraction analysis of coatings processed with the 100A and 120A on the two substrate steels

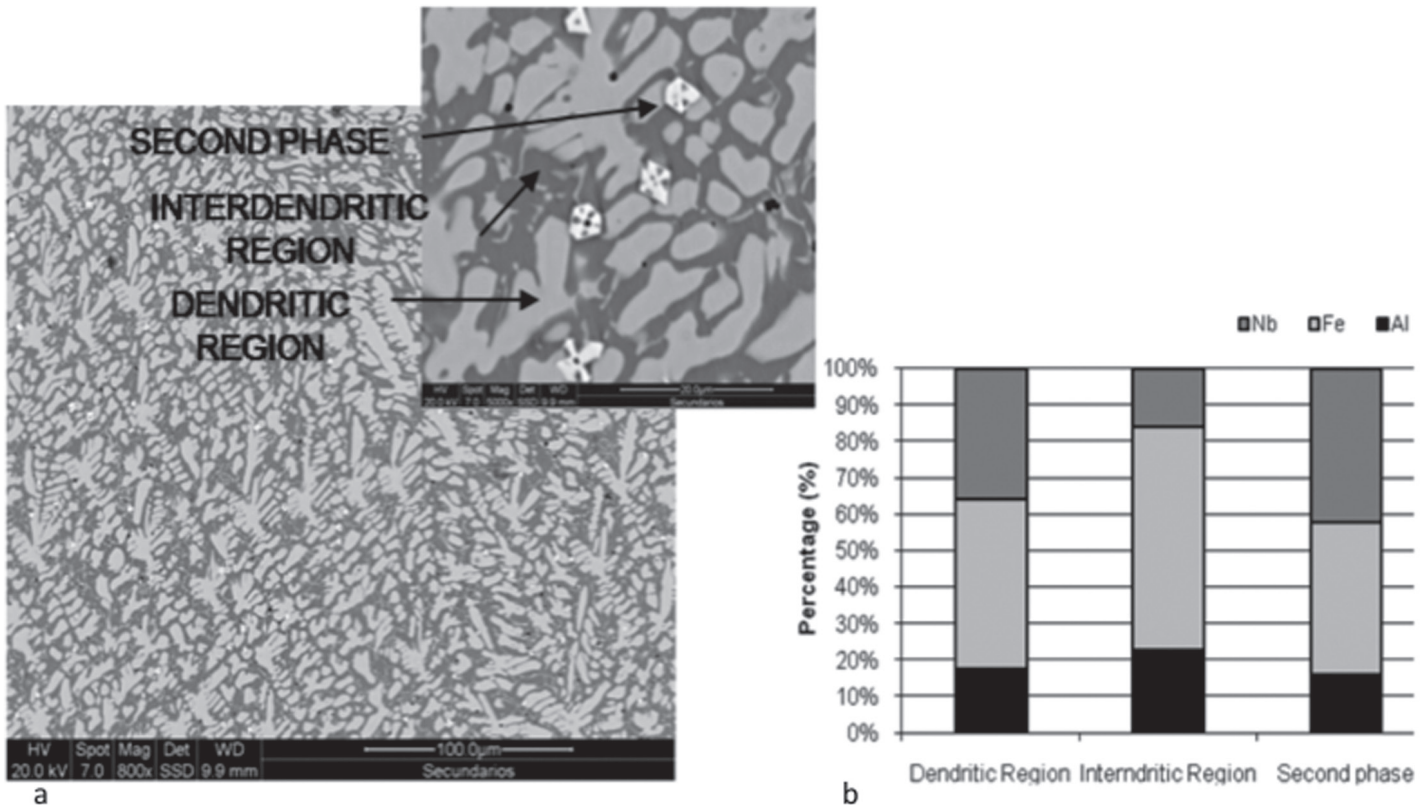


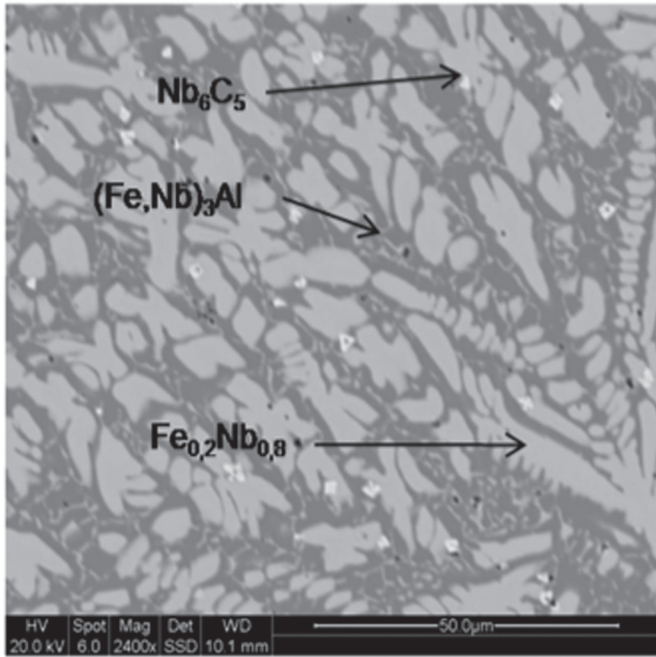
Figure 6. Transverse cross section microstructures of the coating processed with the cast and ground Nb40wt.%Al alloy (a) and corresponding EDS phase analysis (b).

The influence of Fe and C on the microstructures of coatings can be observed on figure 7 and 8. Coatings processed with the 100A current exhibited richer Nb dendrites (the Fe-Nb solid solution) and a rich iron interdendritic $(\text{Fe,Nb})_3\text{Al}$ figure 7. As before, Nb rich precipitates, identified as Niobium carbides, were also observed. The observed changes due to the presence of a higher Fe content agree with literature results on ternary Fe-Nb-Al alloys [22]. The strong affinity of Nb with C is confirmed by the larger apparent volume fraction of carbides and the decrease on the Nb content of the dendritic region. Further changes were observed following the increase on the deposition current to 120A that caused a significantly increase on dilution (63% and 65% for AISI 1020 and 1045, respectively), displacing the system towards Fe richer compositions. This composition shift impacted on the coatings microstructure as shown in figure 8. A columnar eutectic solidification structure is identified. The high

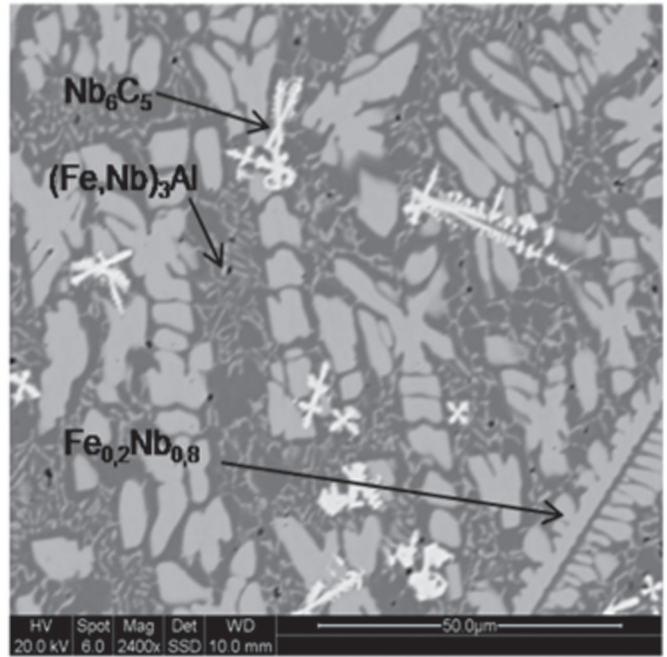
Fe content measured by EDS analysis on the columnar grains suggest the development of the eutectic. On coatings processed on the richer carbon substrate the high dilution accounts for the larger fraction of carbides and dendritic and interdendritic regions with very high and similar Fe contents. The higher Al content of the dendrites suggest that $(\text{Fe,Nb})_3\text{Al}$ forms whereas the higher Nb content of interdendritic eutectic agrees with the development of the $\text{Fe}_{0,2}\text{Nb}_{0,8}/(\text{Fe,Nb})_3\text{Al}$

Results suggest that when processing Nb-Al coatings from the deposition of the Nb40wt.%Al alloy there is a threshold dilution of a relatively high value the reasons for which have been discussed elsewhere [15]. This study shows that processing Nb-Al aluminide coatings requires the knowledge of the interaction between the elements from the substrate steel with the deposited alloy, particularly those which have a strong affinity with each other, in order to assess the properties of coatings.

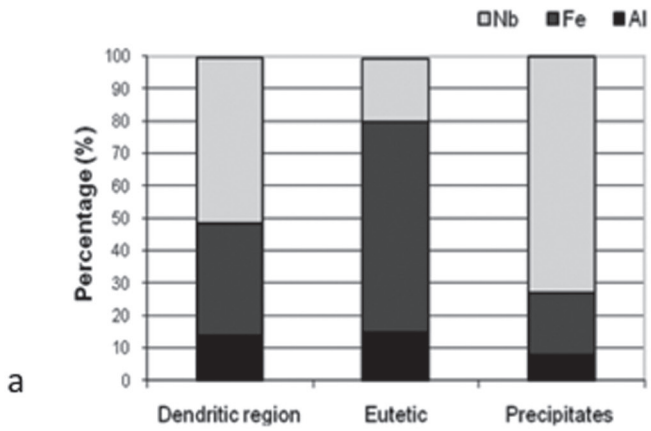
ABNT 1020



ABNT 1045



EDS 100A / AISI1020



EDS 100A / AISI 1045

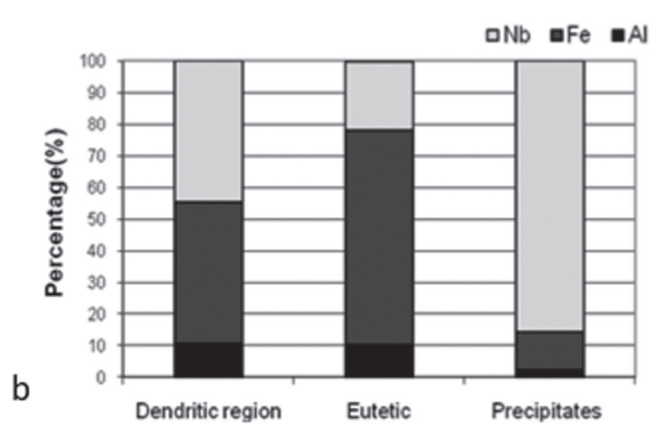


Figure 7. Solidification structure observed on the transverse cross section of coatings processed with 100A on: a) AISI 1020 steel and b) AISI 1045 steel.

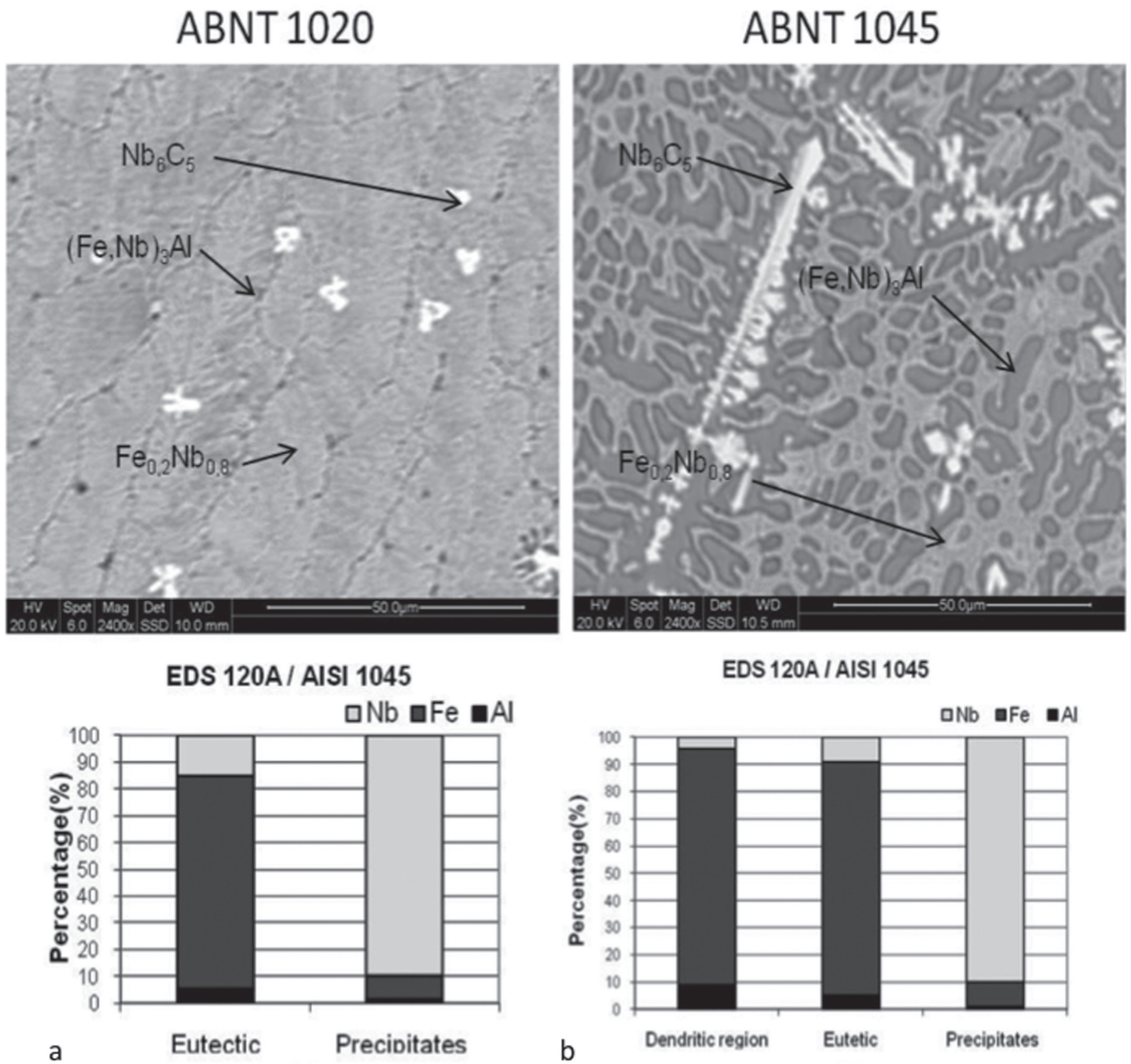


Figure 8. Typical solidification structure grown for specimen obtained by the higher current intensity (120A) deposited on steel AISI 1020 (a) and AISI 1045 (b).

4. Conclusions

The final remarks for this study on the evaluation of Nb/Al PTA coatings are:

- Nb aluminide coatings were processed by plasma Transferred arc hardfacing and the strong interaction with the substrate plate confirmed.
- The interaction with the substrate has to be considered at the early stages of the coating design as it has a determining role on the general features of coatings.
- The affinity between the depositing elements and those in the substrate material will determine the final microstructure and as a consequence the properties of coatings.

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